Vulnerability Analysis of Earthquake Hazards in Tasikmalaya City Using Horizontal to Vertical Spectral Ratio (HVSR) Method

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Abstract. Tasikmalaya City is one of the regions in West Java Province that is often hit by earthquakes due to its location near the Indo-Australian Plate subduction zone towards the Eurasian Plate. The surface deposits in this city are alluvium and weakly consolidated step deposits which can cause wave amplification during an earthquake. As a mitigation effort, seismic zoning needs to be carried out to map the areas that will experience heavy damage when an earthquake occurs. This study uses the Horizontal to Vertical Spectral Ratio (HVSR) method which is applied to the microtremor recording data to obtain spatial variations in the predominant frequency and amplification values that can explain the characteristics of the geological layer beneath the surface. Based on the obtained results, the predominant frequency ranging from 0.7 to 9.5 Hz with the lowest frequency distribution in the eastern and northwestern parts, which indicates a thicker sediment layer. Amplification ranging from 1.2 to 12.6 with the distribution of higher values in the eastern, southeastern, and northwestern parts. The inversion of the HVSR curves was carried out to determine the value of shear wave velocity ($V_s$) in order to obtain a more detailed subsurface geological structure that can be used to determine the level of vulnerability of earthquake hazards. The Neighborhood Algorithm is used to find an optimum model. Based on the results of the inversion process, the $V_s$ ranging from 150 - 3054 m/s with lower $V_s$ values in the eastern, southeastern, and northwestern parts at depth of about 25 meters. The average value of shear wave velocity at a depth of 30 meters ($V_{s30}$) can also be used to determine the type of soil for geotechnical study. From the obtained $V_{s30}$ data, the types of soil in the research area are classified into moderate soil, hard soil, and rocks.

1. Introduction
Tasikmalaya City is one of the regions in West Java Province that is often hit by earthquakes due to its location near the Indo-Australian Plate subduction zone towards the Eurasian Plate. The surface deposits in this city are alluvium and weakly consolidated step deposits which can cause wave amplification during an earthquake. Historically, this city was hit by quite destructive earthquakes, including the Pangandaran Earthquake on 2006, the Java Earthquake on 2007, and the West Java Earthquake on 2009. The impact of the earthquake was very massive, from infrastructure damage to fatalities. As an effort to mitigate the earthquake disaster, zoning needs to be carried out to map the areas that will experience heavy damage when an earthquake occurs.
2. Geological Setting
Geologically, Tasikmalaya City is included in the Central Depression Zone or the Bandung Zone [1], a volcanic area that has a relatively depressive shape compared to the zone that flanks it. This zone is mostly filled by alluvial and young volcanic deposits (Quaternary) from the surrounding volcanic products. The surface sediments are alluvium which is deposited in large river flood areas and weakly consolidated step deposits with a thickness of up to 150 m [2]. Lithology in the research area is shown in Figure 1.

3. Data and Methods

3.1. Data
We use microtremor recording data in the Tasikmalaya City collected by Indonesian Geological Survey Center between 15 to 28 May 2019 with recording time around 12.00 – 02.00 (GMT+7) with a measurement duration of ±30 minutes at each point. Measurements in relatively quiet areas are carried out during the day and in busy areas, such as markets, are carried out during midnight. There are 309 measurement locations with the distribution as shown in Figure 2.

3.2. Method
HVSR curves were created using Geopsy developed by Wathelet et al. [3], this is a collaboration of various institutions in the SESAME European Project. In order to calculate HVSR curve, we use these parameters: bandpass filter 0.5 – 10 Hz, temporal window length 60 s, STA / LTA 0.1 – 2.5, and smoothing constant 40. These parameters are determined based on literature studies and trial and error to obtain stable and representative HVSR curves. The amplitude spectra of the NS and EW components were averaged by the quadratic mean method. Predominant frequency ($f_0$) and amplification ($A_0$) values obtained for each curve then interpolated using Inverse Distance Weighted method (IDW) to produce the predominant frequency and amplification maps.

Inversion was carried out using Dinver package [3] to obtain the values of shear wave velocity ($V_s$) and layer thickness ($h$) underneath the stations. This software use Neighborhood Algorithm (NA), a direct search method for non-linear inversion that utilizes Voronoi cells to identify a multidimensional model space and obtain a new model iteratively in the best cells. Searching interval of the model parameters are determined by considering the geological conditions in the study area based on the previous study or using trial and error until a fairly small misfit is obtained in most of the data. In our
case, the lack of stratigraphic data in the study area makes it hard to determine precise parameters searching range, so that the parameter range is made as wide as possible to represent the variability of sediment and rock types below the surface [4]. In spite of that, the selected $V_p$ and $V_s$ range values are in the limit recommended in [5]. The interval model parameters are set as follows: 5 layers with 100 m depth on the top 3 layers and 2000 m depth on 4th and 5th layer, $V_p$ 200 – 5000 m/s, $V_s$ 150 – 3500 m/s, Poisson’s Ratio 0.2 – 0.5, and constant density of 2000 kg/m$^3$. The $V_s$ model obtained at each station then interpolated to create horizontal section at a certain depth.

4. Results and Discussion

4.1. Predominant Frequency Maps
The obtained predominant frequency ranging from 0.71 to 9.42 Hz with the distribution of low frequency values in the eastern, southeastern, and northwestern part (Figure 3). Comparing with the elevation contour data, areas with low frequencies forming a basin-like geometry which allows thicker surface deposits in this area. These deposits are thought to be weathered Quaternary deposits.

4.2. Amplification Maps
The obtained amplification ranging from 1.15 to 12.59 with the distribution of medium to high amplification values in the eastern, southeastern, southern, and northwestern part (Figure 4). The increasing values to the eastern and southeastern are in accordance with [6]. This increasing amplification is thought to be caused by hard bedrock of volcanic products underlying the weathered Quaternary deposits.

4.3. Inversion Results
Figure 5 shows the example of NA result of M235 station. The observed HVSR curve (blue) is approximated by set of calculated curves where the red curve is the calculated data with the best model characterized by lowest misfit (Figure 5.a). The blue vertical line in the observed curve is the standard deviation. Figure 5.b shows the variation of $V_s$ to depth, red stair curve is the best 1-D model related to the red HVSR curve in Figure 5.a. Based on the inversion results the obtained $V_s$ models ranging from 150 - 3054 m/s.
4.4. Horizontal Section of $V_s$

In order to investigate the lateral variation of shear velocity we create the horizontal slices of several depth as shown in Figure 6. We first classified the shear velocity into two big part, less than and greater than 750 m/s. The greater one dominated begin at 40 m and deeper. The horizontal section at a depth of 25 m (Figure 6.b) most clearly visualizes the boundary areas below and above the engineering bedrock ($V_s$ value of 750 m/s). In the eastern, southeastern, and southwestern the $V_s$ value ranging from 0 – 750 m/s which indicates that at depth of 25 meters those area are still a sedimentary layer, while in the southern, western, and northern the $V_s$ value ranging from 750 – 1500 m/s which is an engineering bedrock.

![Horizontal Section of $V_s$](image)

**Figure 6.** Horizontal section of $V_s$ in depth of (a) 10 m, (b) 25 m, (c) 40 m, (d) 100 m, (e) 250 m, and (f) 1000 m.
4.5. Vertical Section of $V_s$
Vertical section of $V_s$ were also created and shown in Figure 7. It shows the variation of $V_s$ up to 50 m depth, with red color representing the velocity in the sediment layer (0 – 750 m/s) and the blue color is the velocity in the engineering bedrock (750 – 1750 m/s). In general, the cross section shows the undulating sediment layer structure and dominated by velocities of 250 – 750 m/s. The area with the thickest sediment is on the eastern of the AA’ section (Figure 7.b) and on the western of the XX’ section (Figure 7.d).

![Figure 7](image)

**Figure 7.** (a) Line to obtain vertical section of $V_s$, (b) E-W direction, (c) N-S direction, (d) E-W and N-S direction.

4.6. Average Shear Wave Velocity at Depth of 30 m ($V_s^{30}$)
$V_s^{30}$ at each station are calculated from 1-D $V_s$ model and then mapped according to the type of soil [7] as shown in Figure 8. $V_s^{30}$ in Tasikmalaya City ranging from 264 - 772 m/s with soil types dominated by hard soil and at several points there are moderate soil and rocks.

![Figure 8](image)

**Figure 8.** $V_s^{30}$ and soil types in Tasikmalaya City.
4.7. Earthquake Hazard Vulnerability

Large seismic vulnerability correlates with low predominant frequency values and high amplification values [8]. Based on predominant frequency and amplification map, the areas that are more prone to earthquake hazards are the western and northwestern Bungursari Subdistrict; northwestern Mangkubumi Subdistrict; eastern Kawalu Subdistrict; northeastern, eastern, southeastern, southern, and southwestern Cibeureum Subdistrict; and southeastern, northwestern and northern Tamansari Subdistrict. These areas have low predominant frequency values and medium to high amplification values. This is also supported by the horizontal section of $V_s$ at 25 m depth (Figure 6.b) which shows that in that area at 25 m depth the layers are still sediment with $V_s$ below 750 m/s. It can be concluded that the thickness of the sediment in these areas are relatively thinner than in other areas and are more susceptible to damage if an earthquake occurs. There were buildings damage at SMKN 3 Tasikmalaya and the Asy-Syuhada Mosque which is located in the northwestern Tamansari Subdistrict due to the 2015 earthquake [9].

5. Conclusion

Based the obtained results we summarize some finding. The areas that are more prone to earthquake hazards are the western and northwestern Bungursari Subdistrict; northwestern Mangkubumi Subdistrict; eastern Kawalu Subdistrict; northeastern, eastern, southeastern, southern, and southwestern Cibeureum Subdistrict; and southeastern, northwestern and northern Tamansari Subdistrict. These areas has low predominant frequency values, medium to high amplification values, and low $V_s$ values at 25 m depth which are indicates thicker sediment layer.

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