Site characterizations of BMKG seismic network, Indonesia, based on HVSR analysis

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Abstract. In the last few years BMKG (Agency for Meteorology Climatology and Geophysics) has increased the number of seismic stations significantly. Until mid-2020, when this study was conducted, the number of BMKG stations has reached 339 units. Development of the network is aimed to improve the data quality, speed of earthquake data processing and information dissemination to the public, accuracy of the hypocenter, as well as the magnitude. The objective of this study is to identify the site characteristics of the network. We analysed the noise recorded at BMKG stations throughout Indonesia using the HVSR (Horizontal to Vertical Spectral Ratio) method. The results of HVSR analysis were used to classify the site conditions of each station. We got the number of stations with the classification of hard rock, rock, hard soil, medium soil, and soft soil, 47, 57, 52, 30, and 84, respectively. This site condition represents the stations characteristics and affects the quality of seismic waveform data.

Keywords: BMKG, seismic network, earthquake, HVSR

1. Introduction

Since the Sumatra earthquake in 2004 [1,2] which caused enormous damage and casualties, the Indonesian government has paid great attention to disaster management caused by the earthquake and tsunami. Since then, the government through BMKG (Agency for Meteorology Climatology and Geophysics) has increased the number of seismic stations for earthquake monitoring throughout Indonesia. In the last few years BMKG has added a significant number of new stations. Until mid-2020, at the time of this study was conducted, the number of BMKG seismic stations has reached 339 units which are distributed throughout Indonesia (Figure 1).

With the addition of the number of seismic stations, it is expected that the determination of hypocenter location, magnitude and mechanism of the earthquake source can be done more quickly with better accuracy. Moreover, by increasing the density of the number of stations, earthquakes with relatively small magnitudes can be recorded well by the national seismic network. The completeness of earthquake data up to a small magnitude can help research related to earthquakes and the identification of active faults which until now have not been well mapped [e.g. 3].
Rapid and accurate earthquake data processing of the hypocenter location, magnitude, and source mechanism can help the community to reduce the impact of earthquake disasters. Rapid and accurate information received by the community becomes an early warning for evacuation or decision making for emergency response. This issue is the main objective of BMKG through the project of InaTEWS (Indonesian Tsunami Early Warning System).

The significant development of BMKG national seismic network increases the dissemination speed and accuracy of earthquake parameters. However, there are a number of rules that must be considered in the installation of seismic stations in order to obtain good data quality. Several factors that must be considered are the type of sensor used, the station density according to the tectonic structure or identified faults, azimuthal coverage of the station distribution, installation procedures or quality, orientation of sensor installation, quality of station location, security, availability of communication networks, and accessible [4].

The objective of this study is to investigate the quality of BMKG national seismic network based on the site characteristics of the station location. The quality of station location is usually associated with the level of noise and surface soil structure [4,5]. This study focuses on discussions related to surface soil structure, identifying and classifying surface soil types from all BMKG stations throughout Indonesia to obtain the characteristics of each station.

2. Data and Method
In general, it is well known that the soft surface soil structure causes amplification of the seismic waves [6,7]. The stations located on the soft soil causing relatively higher noise [8]. If an earthquake occurs, especially with a relatively small magnitude, the signal to noise ratio is small, making it difficult to identify earthquake signal, even though the wave arrival time is not affected. In addition, seismic wave amplification also affects the accuracy of determining the magnitude of the earthquake and also the source mechanism using the waveform inversion method.

One method of identifying surface soil structures can be done by using HVSR (Horizontal to Vertical Spectral Ratio) of the ambient noise at the station location [9,10]. The HVSR method is simple and effective. This method has been widely used and successful for the interpretation of surface soil structures [11]. The basis of this method is that in the case of soft soil the noise spectrum of horizontal component has relatively larger amplitude than the vertical component. Whereas in the case of hard rock, the spectrum of noise for both components, horizontal and vertical, have more or less the same amplitude [12].

The interpretation of the results of HVSR curve is that if the dominant frequency is in the low frequency range it indicates the soft surface soil structure, and vice versa if the dominant frequency is high it indicates a typical rock or hard surface soil structure [12]. The development of ambient noise
analysis using this method shows that the dominant frequency indicated from HVSR can be used to estimate sediment thickness [e.g. 11].

The weakness of this method is that the large amplitude at the dominant frequency is inconsistent for the interpretation [e.g. 13]. This is possible due to the heterogeneity of the surface soil structure based on the layer structure, there are systematic, multi layers with a horizontal arrangement and another case are not systematic. In the case of many horizontal layers that are systematic allows the emergence of the optimal amplitude, and vice versa. Another possible cause of the difference in the HVSR amplitude is the difference in the level of impedance or contrast between the hard rock layer and the sediment above it. However, interpretation of the dominant frequency alone can be used to indicate the classification of surface soil types at the measurement location [14].

The HVSR analysis in this study was conducted using Geopsy software (e.g. Figure 2). Ambient noise data was collected from 339 BMKG seismic network entire Indonesia. At the time of the data was collected, there was 69 stations have no data. The time span used for each station with duration of 30 minutes is 00:00-00:30 WIB (local time). Waveform was downloaded from BMKG Webdc application (accessed on 18 April 2020).

### Table 1. The reference of site classes based on natural period and the approximately corresponding NEHRP site classes [14]

| Site Class | Description     | Natural Period (sec) | V$_{30}$ Calculated from Site Period (m/s) | Site NEHRP Classes |
|------------|-----------------|----------------------|------------------------------------------|--------------------|
| Hard Rock  | Rock            | $T < 0.2$            | $V_{30} > 600$                           | A + B              |
| SC I       | Hard soil       | $0.2 < T < 0.4$      | $300 < V_{30} = 600$                     | C                  |
| SC II      | Medium soil     | $0.4 < T < 0.6$      | $200 < V_{30} = 300$                     | D                  |
| SC III     | Soft oil        | $T = 0.6$            | $V_{30} = 200$                           | E + F              |

The classification of surface soil types is based on the reference table [14] and NEHRP (National Earthquake Hazard Reduction Program). Each station is adjusted to the results of the dominant frequencies and reference table (see Table 1).

## 3. Results and Discussion

In general, the dominant frequency based on the results of HVSR analysis on the ambient noise at each station can be seen clearly. This value is indicated by a significant spike or peak on the HVSR curve. However, at some station locations, the HVSR curve pattern shows more than one spike. In that case, the spike determination is based on additional information such as elevation and environmental conditions around the station location.

![Figure 2.](image-url) The result of HVSR analysis for BESI station located at 4.72 N and 96.87 E with the lowest dominant frequency of 0.57Hz.
We limited the HVSR interpretation of dominant frequency between 0.2 to 20Hz based on the optimal reference value of the dominant frequency at Mount Batu Lembang [15] and the low dominant frequency value at the measurement location with sediment that is about 200m thick [11]. Figure 2 shows the lowest dominant frequency, 0.57 Hz, precisely measured at station BESI located at 4.72 N and 96.87 E. On the other hand, the highest dominant frequency 19.32 Hz was measured at station KMPI located at 3.66 S and 133.70 E (Figure 3). Interpretation of the classification of surface soil types based on the dominant frequency shows that the stations BESI and KMPI have soft soil and hard rock structures, respectively, with classifications of IV and hard rock based on the reference table [14] and NEHRP.

Figure 3. HVSR of KMPI station representing the typical hard rock station with the dominant frequency of 19.32Hz. The station located at 3.66 S and 133.70 E.

In some locations the result of HVSR analysis shows that there is no dominant frequency or the curve fluctuates at certain amplitude of HVSR value (e.g. Figure 4). Determination of the dominant frequency is then selected manually by observing the HVSR curve, elevation, and conditions around the measurement location. Moreover, some other measurement results exhibit the significant spike with high amplitudes at high frequencies greater than 20Hz, even greater than 30Hz. Based on the reference of the HVSR value on Mount Batu Lembang which shows the dominant frequency around 18Hz [15], the interpretation was considered within the dominant frequency range smaller than 20Hz. Likewise, the results of HVSR method, which show the dominant frequency is smaller than 0.2Hz, were not interpreted. The selection of the dominant frequency values was considered within 0.2-20Hz frequency range.

Figure 4. Typical HVSR result for the hard rock station. The HVSR amplitude fluctuates at approximately one.

Figure 5 shows that from a total of 339 BMKG seismic stations, the number of stations with the typical hard rock, rock, hard soil, medium soil, and soft soil is 47, 57, 52, 30, and 84 stations,
respectively. This classification of surface soil types represents the characteristics and quality of the data recorded at the station. A good station is placed on a foundation with hard rock and a quiet environment. The station will produce data with good quality. However, other factors in selecting a station location must also be considered, such as accessible and security of sensors.

![Site classification of BMKG national seismic network based on HVSR of the ambient noise.](image)

### 4. Conclusions

The characteristics of BMKG seismic station are indicated through the classification of surface soil types which are estimated based on the dominant frequency of the HVSR curve. The quality of the station location represented by the surface soil structure varies from the typical hard rock, rock, hard soil, medium soil, and soft soil. The highest number of typical structure was soft soil with 84 stations. The locations of these stations are distributed throughout Indonesia. Meanwhile, the stations with tolerable quality with the criteria of at least having a surface soil structure with medium soil classification are 186 stations. This number of stations is 69 percent of the total number of BMKG national seismic stations. The use of BMKG data for the purpose of arrival time data can be used well for all stations, regardless of amplification factors. However, the use of waveforms for inversion or amplitude, as well as the magnitude needs to be more careful, especially for the waveform data from soft soil stations.

### Acknowledgments

We would like to thank the Deputy of Geophysics BMKG for their support. Thanks to all colleagues in the Division of Geophysical Research and Development, RDC (Puslitbang) BMKG. Thanks also to the colleagues from the Deputy of Instrumentation, Engineering, and Calibration BMKG for sharing information.

### References

[1] Lay, T., Kanamori, H., Ammon, C. J., Nettles, M., Ward, S. N., Aster, R. C., ... & DeShon, H. R. (2005). The great Sumatra-Andaman earthquake of 26 December 2004. Science, 308(5725), 1127-1133.

[2] Stein, S., & Okal, E. A. (2005). Speed and size of the Sumatra earthquake. Nature, 434(7033), 581-582.

[3] Nasional, P. S. G. (2017). Peta sumber dan bahaya gempa Indonesia tahun 2017. Pusat Penelitian dan Pengembangan Perumahan dan Permukiman, Badan Penelitian dan Pengembangan, Kementerian Pekerjaan Umum.

[4] Bormann, P. (2012). New manual of seismological observatory practice (NMSOP-2), IASPEI, GFZ German Research Centre for Geosciences, Potsdam.
[5] Picozzi, M., Strollo, A., Parolai, S., Durukal, E., Özel, O., Karabulut, S., ... & Erdik, M. (2009). Site characterization by seismic noise in Istanbul, Turkey. Soil Dynamics and Earthquake Engineering, 29(3), 469-482.

[6] Seed, H. B., Romo, M. P., Sun, J. I., Jaime, A., & Lysmer, J. (1988). The Mexico earthquake of September 19, 1985—Relationships between soil conditions and earthquake ground motions. Earthquake spectra, 4(4), 687-729.

[7] Bard, P. Y., Campillo, M., Chavez-Garcia, F. J., & Sanchez-Sesma, F. (1988). The Mexico earthquake of September 19, 1985—A theoretical investigation of large-and small-scale amplification effects in the Mexico City Valley. Earthquake spectra, 4(3), 609-633.

[8] Smith, K., & Tape, C. (2019). Seismic noise in central Alaska and influences from rivers, wind, and sedimentary basins. Journal of Geophysical Research: Solid Earth, 124(11), 11678-11704.

[9] Nakamura, Y., & Saito, A. (1983). Estimations of amplification characteristics of surface ground and PGA using strong motion records. Proc. 17th JSCE.

[10] Nakamura, Y. (1989). A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Railway Technical Research Institute, Quarterly Reports, 30(1).

[11] Parolai, S., Bormann, P., & Milkereit, C. (2002). New relationships between Vs, thickness of sediments, and resonance frequency calculated by the H/V ratio of seismic noise for the Cologne area (Germany). Bulletin of the seismological society of America, 92(6), 2521-2527.

[12] Nakamura, Y. (2008). On The H/V Spectrum. The 14th World Conference on Earthquake Engineering, October 12-17, 2008, Beijing, China.

[13] Sylvette, B. C., Cécile, C., Pierre-Yves, B., Fabrice, C., Peter, M., Jozef, K., & Fäh, D. (2006). H/V ratio: a tool for site effects evaluation. Results from 1-D noise simulations. Geophysical Journal International, 167(2), 827-837.

[14] Zhao, J. X., Zhang, J., Asano, A., Ohno, Y., Oouchi, T., Takahashi, T., ... & Fukushima, Y. (2006). Attenuation relations of strong ground motion in Japan using site classification based on predominant period. Bulletin of the Seismological Society of America, 96(3), 898-913.

[15] Tim Survey BMKG (2014). Laporan survei lokasi stasiun bedrock di wilayah Jawa Barat, Badan Meteorologi Klimatologi dan Geofisika (BMKG). Jakarta.