Determination of Ground Profile and Peak Surface Acceleration (PSA) using single station microtremor Inversion method for earthquake hazard zonation of Lombok Island

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Abstract. There were two fairly destructive earthquake phenomena in 2018 of M 6.4 and M 7 at East Lombok District. However, severe damage occurred in the West Lombok District, Mataram City, and North Lombok District where the three locations were far from the earthquake epicenter. This proves that the potential for infrastructure damage does not only depend on the magnitude and the earthquake source distance, but rather the presence of local site effects. This study aims to determine the dynamic characteristics of the soil and the distribution of Peak Surface Acceleration (PSA). The method used are HVSR analysis (Horizontal to Vertical Spectral Ratio) and inversion of Rayleigh wave ellipticity curve from single station microtremor measurements. The results showed that West Lombok Regency, Mataram City, and the western part of North Lombok Regency were dominated by sedimentary layers which were softly included in the SD (stiff soil / soft soil) site category. These regions are soil deformation vulnerable due to the earthquake. Based on PSA distribution, the southern part of Lombok Island and Mataram City have a relatively high PSA value. The high value of PSA has the potential to cause ground shaking hazard that are strong enough when an earthquake occurs. This research is expected to be a reference for the design of spectra response to minimize damage of building infrastructure at various levels due to earthquake events.

1. Introduction
Lombok Island has quite active seismic activity. This is because the area’s flanked by two earthquake generators from the north and south. In the north there is a geological structure of the fault rising Flores (Flores Back Arc Thrusting), while from the south there is a subduction zone of the Indo-Australian Plate which dips below the island of Lombok. Some results obtained from updating the national earthquake map where the earthquake map of the Nusa Tenggara - Banda Sea earthquake map are known to have 49 earthquake sources [1]. One of the investigative efforts to find out the dynamic characteristics of soil is by estimating the value of shear wave velocity [2]. To define site classification in geotechnical requirements, generally the parameter was used is the average shear wave velocity below the surface 30 meters deep or called VS30 [3]-[4]. The need for dynamic parameters of this soil is because the damage caused by earthquakes is not only caused by the proximity of the location to the epicenter, but is caused
by several other factors such as local conditions (geological formation, subsurface lithology conditions or the structure of geological formations).

There are several methods for obtaining shear wave velocity profiles (Vs). An alternative method that can be used is by measuring single station microtremor which is then inversed by using the Rayleigh wave ellipticity curve approach. The method assumes that surface waves dominate microtremor data and the shape of the H / V curve is largely dominated by the elliptical Rayleigh waves [5]. The main reason for using the single station microtremor inversion method is because the cost required is not much, does not damage the environment, and tends to be more dynamic and not constrained by the measurement land compared to the seismic borehole, seismic refraction, and MASW (Multichannel Analysis Surface Wave).

2. Methodology

2.1. Data and Study Area
The research was conducted on February 25 to May 23, 2019 at the Indonesia Agency of Meteorology Climatology and Geophysics (BMKG), the sub-field of Engineering Seismology. The data used is secondary data from 32 single station microtremor measurements distributed on Lombok Island, West Nusa Tenggara. Data from vibration recording (seismogram) in the form of a waveform in the time domain. The data consists of three main components, such as; vertical components, North-South horizontal components, and East-West horizontal components with a measurement duration of approximately 30 minutes to one hour.

![Map of single station microtremor data acquisition in Lombok Island, West Nusa Tenggara.](image)

**Figure 1.** Map of single station microtremor data acquisition in Lombok Island, West Nusa Tenggara.

2.2. Research methodology
These are following stages of data processing in this study:
2.2.1 Research flow
Generally, the workflows used in this study are as follows:

![Research Flow Chart](image)

Figure 2. Research Flow Chart.

2.2.2 HVSR (Horizontal to Vertical Spectral Ratio) analysis.
In general, the concept in HVSR analysis begins with the process of windowing or sorting the stationary wave. This process aims to separate the microtremor data with noise in the form of transient data (specific sources). This transient noise or signal is generally caused by disturbances during data acquisition, both in the form of factory and vehicle activity. Determining several parameters in this stage follows the international standards of SESAME (Ambient Excitations Site Analysis Assessment) in 2004. After that, an FFT (Fast Fourier Transform) process was carried out to convert the waveform in each component from the time domain to the frequency domain. Furthermore, the fourier spectrum obtained was carried out with the type of Konno-Ohmachi smoothing in bandwidth 40. The combination of North-South horizontal and East-West curves using the Pythagoras equation based on the square of...
the two components. Then the estimated ratio of the average fourier spectrum between horizontal components and vertical components in the frequency domain is to get the H / V value at that point.

2.2.3 Rayleigh Wave Ellipticity Inversion

The method assumes that surface waves dominate microtremor data and the shape of the H / V curve is largely dominated by the elliptical Rayleigh waves [5]. Rayleigh waves are a type of surface wave formed by interference with reflected waves P and SV whose angle of incidence exceeds a critical angle. The particle motion of the medium when passed by this wave is elliptical which is a combination of the motion of the P wave particles and SV. This ratio of horizontal and vertical particle motion is called Rayleigh wave ellipticity [6]. The result of HVSR analysis in the form of H / V curve is used as an initiation model in the ellipticity curve method which will be influenced by several parameter initiations.

Input parameters (Vp, Vs, Density, and Poisson’s Ratio) are influential in the iteration process of the matching curve or model approach with the actual conditions. The closer the initialization value is to the field conditions in the study area, the better the resulting model will be. Due to the limited geological data, several approaches are used to obtain the initial parameters. For example, in searching for density values, then using the equation approach that connect compressed waves with density [7]-[8]. The two equations are written as follows:

\[ \rho \text{ Christensen} \left( \frac{g}{cm^3} \right) = 0.541 + 0.36 \text{ Vp} \]  

\[ \rho \text{ Godfrey} \left( \frac{g}{cm^3} \right) = 2.4372 + 0.076 \text{ Vp} \]  

where \( \rho \) is the density of rocks, while Vp is compressional velocity. This inversion based on Neighborhood algorithm to look for the minimum misfit [9]. The equation is:

\[ \text{misfit} = \frac{1}{N} \sum_{i=1}^{N} \left( \frac{D_i - M_i}{\sigma_i} \right)^2 \]  

where N is number of data, Di is inversion data, Mi is observation data, and \( \sigma_i \) is standard deviation. The smaller misfit value will produce the best inversion model, where the graph in the inversion model (calculation) will coincide with the observation model.

Figure 3. Waveform windowing step.
3. Result and Discussion

3.3.1 Distribution and mapping of dominant periods (Tdom)

The value of the dominant period obtained from HVSR analysis is the opposite of the natural frequency parameter. This parameter is the time required by the surface waves (Rayleigh) in the measurement of microtremor to propagate in a particular medium and experience one reflection of the reflected field to the surface. The value of the dominant period (Tdom) can indicate the character of the rock layer and the thickness of the sediment layer in the study area. The use of the parameters of the dominant period itself is relatively more often used in the field of earthquake microzonation than natural frequencies (F0).

From the data in each measurement as the table above, then a 2.5 D mapping is carried out to find out the distribution / distribution of the dominant period (Tdom) parameters on Lombok Island. From figure 4.3, it can be observed that the distribution of the value of the dominant period in the study area ranged from 0.04 seconds to 2.16 seconds. According to the soil type classification table based on Tdom parameters [10]. The map above can be classified into four different classes. Where the area of Mataram City and most of West Lombok Regency has the value of the dominant period between 0.88 seconds to 2.16 seconds. So that it can be grouped in the class IV SC (Soft Soil) or soft soil. The high value of this dominant period indicates a thick layer of sediment. This correlates with the geological formation on the western part of Lombok Island which is dominated by Alluvium, where the constituent rocks consist of clusters, gravel, sand and clay. While the relatively low value of Tdom is found in most of East Lombok Regency, Central Lombok Regency, and a small part of North Lombok Regency. The range of
Tdom values obtained is between 0.04 - 0.67 seconds. So that it can be classified into three different classes, including; Rock I stiff soil, SC II (Hard soil), and SC III (Medium Soil). The relatively low distribution of the value of the dominant period in the region is due to the influence of the geological formation and its dominant rock constituents. Especially in the area around the area of Mount Rinjani which is composed of volcanic rocks such as lava, breccia, and tuff. These rocks are spread in the majority of the Lombok geological formations including; Inseparable Volcanic Rock in the area of Mount Rinjani, Lekopiko Formation (Qvl), and Kalibabak Formation (Tq).

3.3.2 Ellipticity curve and shear wave 1D ground profile

The ellipticity curve is used as a reference or data validation whether or not the inversion results obtained are representative. In one graph consisting of H / V elliptical (Y axis) plots of frequency values (X axis), there are several kinds of curves with certain colors. Black curves are observation data (Dobs) or initial / reference models for inversion processes, where the curve is the result of HVSR analysis for each
measurement point in the field. While the color spectrum of the curve other than black is the result of the estimation model (Mest) of the inversion process for each value of misfit. The pink curve is inversion modeling with the largest misfit, while the white spectrum has the smallest misfit value. So, the curve with white will later be used as the "best model" or the final model for further analysis. The estimation model will increasingly coincide with the initial model (Dobs) if the value of the misfit obtained is getting smaller. The results obtained from the microtremor inversion process in addition to the ellipticity curve are one-dimensional shear wave velocity (Vs) model profiles. The profile consists of a range of values of Vs (X axis) for the thickness of each layer (Y axis). As with the concept in the previous explanation of the ellipticity curve, this inversion process works by iterating the initial model (Dobs) to be adjusted to the HVSR curve of the measurement until the best model is obtained with a slight misfit with the HVSR curve measured.

![Figure 8. Rayleigh wave ellipticity curve as the result from inversion process](image1)

![Figure 9. Shear wave velocity 1D ground profile to layer depth from inversion process](image2)

### 3.3.3 Vs30 distribution mapping and site classification determination

To define site classification in geotechnical requirements and earthquake hazard zoning, generally the average shear wave velocity parameters below the surface are 30 meters deep or commonly called Vs30. The use of the Vs30 parameter is because when an earthquake occurs, the thing that causes damage to building infrastructure is not only the strength of the earthquake magnitude, but the local conditions such as soil characteristics and constituent rocks in the geological formation at that point. In this study, equation (4) was used to obtain the Vs30 parameter at each profile ground point as a result of the inversion ellipticity curve;

\[
Vs30 = \frac{30}{\sum h \cdot v}
\]

where Vs30 is average shear wave velocity at 30 meters depth (m/s), \( h \) is thickness of soil/rock (m), and \( v \) is shear wave velocity (m/s).

Result for the distribution of Vs30 2D map indicate quite varied values. There is a range of Vs30 values from 185.07 m/s to 873.87 m/s. Vs30 values that are relatively low accumulate in most areas of West Lombok Regency and the whole city of Mataram, which ranges from 185.07 m/s to 529.47 m/s, where the area is dominated by alluvium (Qa), which consists of clusters, gravel, sandstones and claystone. The value of Vs30 which is relatively high is found in North Lombok Regency and East Lombok Regency which is equal to 529.47 m/s to 873.87 m/s. The high value of Vs30 in the region
is due to the dominance of volcanic rocks from the Rinjani mountains which consist of breccia, lava and tuff. After obtaining a distribution of distribution of Vs30 values, then site classification can be determined in the study area. Determination of this site class is based on the reference of SNI 1726: 2012 concerning procedures for planning earthquake resistance for structures of buildings and non-buildings. The use of this SNI is a renewal of the next version, namely SNI 1726: 2002. The following is a site classification map on Lombok Island based on the value of Vs30. The Lombok Island region has three different types of site classes. Rock class (SB) with a range of values of Vs30 of 750 m / s - 873.87 m / s is found in a small part of North Lombok Regency. Whereas the classes of hard soil and soft rock (SC) which have a value of Vs30 ranging from 350 m / s to 750 m / s are located in most of Central Lombok District and East Lombok Regency. This SC class is the dominant site class in the Lombok Island region. The soft soil class (SD) with a value of Vs30 ranges from 185.07 m / s - 350 m / s scattered in most of West Lombok Regency and the whole of Mataram City.

Figure 10. Vs30 distribution map of Lombok Island.
3.3.4 Distribution analysis of PSA value with probabilistic approach.

In this study, PGA (Peak Ground Acceleration) data was used through the PSHA (Probabilistic Seismic Hazard Analysis) method, which used three types of earthquake sources; Flores Back Thrust / shallow background, Sumba Megathrust, and Benioff Zone (deep background). An increase in the estimated PGA value against Peak Surface Acceleration (PSA). This was because the distribution of the PSA value is influenced by the local site effect so that the acceleration in the bedrock is amplified. Here are variations in the value of Peak Surface Acceleration (PSA) ranging from 0.35g - 0.60g. This value was previously obtained by equation;

$$ \text{PSA} = F_{\text{PGA}} \cdot \text{PGA} $$  \hspace{1cm} (5)

This amplification factor ($F_{\text{PGA}}$) is obtained by considering the site class at the measurement point that is correlated with the value of Peak Ground Acceleration (PGA) based on SNI 1726:2012. The distribution of PSA values is relatively greater in the southern part of Lombok Island. This is due to the results of processing PGA values using the Probabilistic Seismic Hazard Analysis (PSHA) method that tends to be influenced by the subduction (Megathrust) source in the south compared to other earthquake sources. So that this region is quite vulnerable to ground shocks due to high PSA values.

![Figure 11. Site classification map of Lombok Island](image)
4. Conclusions

From this study it can be concluded that:

- Mataram City Region, West Lombok Regency, and Tanjung District (North Lombok Regency) are dominated by soft soil types. It is proven by the existence of a high Dominance (Tdom) Period (0.60 seconds - 2.16 seconds) and relatively low Vs30 (185.18 m/s - 460.54 m/s) and
included in the SD (stiff soil) site category. So that potentially more severe damage due to soil deformation

- The distribution of PSA values on Lombok Island ranges from 0.35-0.60g. The southern part of Lombok Island and Mataram City have a relatively high distribution of PSA values. So that these areas have the potential to experience strong ground shocks during earthquakes.

- The zoning of earthquake hazards on Lombok Island is reviewed from two sides; (1) the potential zone of damage is quite severe based on the dynamic parameters of the soil characteristic (Mataram City, West Lombok District, and Tanjung District in North Lombok Regency). (2) Potential zones of ground shocks that are quite strong based on the value of PSA (southern Lombok and Mataram City).

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