Sediment thickness mapping and soil classification using ellipticity inversion of Rayleigh wave in the eastern part of Mataram City, Indonesia

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Abstract. A soil's dynamic characteristics greatly influence earthquake potential damage inland. Subsurface investigations to determine the dynamic characteristics of the soil can minimize the risk of such damage. The sediment layer thickness is one of the parameters to assess the local geological character in response to an earthquake. Another parameter is $V_{S30}$ value, which is used to classify soil types as an indicator of soil response, which generally dominates ground motion amplification. In this study, the two parameters are analyzed to determine the potential for local damage in the event of an earthquake in the eastern area of Mataram City using the rayleigh wave inversion from microtremor data. The research area covers 3 districts, including Selaparang, Cakranegara, and Sandubaya Districts. The results showed that the value of the sediment thickness in the entire study area ranged from 12.78 m to 57.20 m. The value of $V_{S30}$ varies between 286 m/s to 866 m/s with the classification of rigid soils, very dense soils, and soft rocks and rocks. These results indicate that the study area in general experiences a large potential for damage if an earthquake occurs. This research is expected to be a reference for the spatial plan of Mataram City.

1. Introduction
Lombok Island is one of the islands in Indonesia which is prone to earthquakes. Based on the records from the United States Geological Survey (USGS) [13], the City of Mataram, on the island of Lombok, often experiences earthquakes with massive earthquakes and shallow hypocenter. According to the records of the Meteorology, Climatology, and Geophysics Agency (BMKG), for the last 40 years, there have been more than 2000 earthquakes that have occurred in Mataram City. For example, an earthquake with a magnitude of Mw 7.0 with a hypocenter depth of 15 km shock Lombok's island on August 5, 2018. The earthquake caused quite severe damage in the City of Mataram, both to houses and buildings. This also resulted in many victims being injured and died. The nature of repeated earthquakes for a certain period (earthquake cycle) shows that earthquakes' potential threat in the City in the future is still very high. Because prevention against this disaster cannot be done, the most important thing from an earthquake evaluation is mitigation, not just an earthquake cycle review. One of the mitigation efforts that can be taken is to know the local soil's characteristics and its response to earthquakes so that an earthquake risk map can be made. Spatial planning and building infrastructure should be considered to the soil's dynamic characteristics against earthquake vibrations are expected to minimize future casualties and losses.
Agustawijaya and Syamsuddin [2] have analyzed disaster risk in Mataram City by considering geological conditions and input parameters from earthquake disasters. The results obtained from this study indicate that Mataram’s city over all is at a medium-scale risk. This study has not considered the dynamic characteristics of the soil that affect the effect of vibrations when an earthquake occurs. Research on soil characteristics in the city of Mataram was conducted by Azmiyati [11] by analyzing 4 parameters, namely dominant frequency, dominant period, amplification, and seismic vulnerability index. To complement the research, this study analyzed different parameters, namely the thickness of the sediment layer and soil classification based on the inversion of the rayleigh wave ellipticity curve from the microtremor data. This rayleigh wave inversion is estimated to provide a more precise prediction of ground motion due to future earthquake shocks [7].

2. Methods

2.1. Target area

The target area in this study is the capital city of West Nusa Tenggara Province, which is located on Lombok Island, namely Mataram. The research target is precisely in the eastern part of the city Mataram. This research located in 3 districts, namely Selaparang sub-district, Cakranegara district, and Sandubaya district. With an area of ± 2500 km² research location. Based on the geological map in Figure 1, the study’s target area is entirely covered by a homogeneous type of lithology, namely alluvium. These alluvial rocks are quarterly old, consisting of clay, sand, gravel, peat, and coral fragments lose/compact with a thickness of up to 50 meters. The types of soil in Mataram City are mostly clay, sandy clay, and tuff. This is due to the quaternary sediment originating from the erosion of the slopes of mountains or rivers that are abundant in this area, then deposited in relatively lower areas [8].

Figure 1. Research area lithological map [8]

2.2. Rayleigh wave ellipticity curve

The use of the microtremor method to study the subsurface structure of the earth has long been thought of by scientists. The results of the investigation in this direction resulted in the accumulation of a lot of data showing the correlation between the spectral characteristics of microseismic objects and geological objects. In the mid-20th century, seismologists assumed that the Horizontal to Vertical Spectral Ratio (HVSR) as in equation 1 is the motion of particles functionally depending on the underlying layer parameters: including seismic wave strength, density, and speed [4]. To study this functional
dependence, then used - spectral analysis of seismic vibrations in different modifications for longitudinal (P), shear (S) and surface waves [3].

\[
HVS R = \frac{S_H}{S_V}
\]  

(1)

where \(S_H\) is the Spectrum of the horizontal component and \(S_V\) is the Spectrum of the vertical component.

The HVS R method was originally introduced by Nogoshi and Igarashi [10] and developed by Nakamura[9] in a journal publication so that this method is better known as the Nakamura method. Then Herak [6] introduced the inversion model or better known as the inversion model to estimate numerical model parameters based on data using a specific model. One of the modelling methods that can be used for HVS R curve inversion is the rayleigh wave ellipticity curve. Rayleigh wave ellipticity as a function of frequency represents the velocity profile of shear waves and the thickness of the sediment layer. The shear wave velocity \(V_s\) obtained from this method is not recommended for \(V_s\) values in deep soils. But for a fairly shallow upper profile of the soil structure, this method can be used to determine the velocity profile accurately (Fah et al., 2003). In this study, the value of \(V_{s30}\) is estimated using equation 2. \(V_{s30}\), in this case, is calculated as the time of the shear wave traveling from a depth of 30 m to the surface, not the average velocity of \(V_s\) to a depth of 30 m.

\[
V_{S30} = \frac{30}{\sum\left(\frac{1}{V_s}\right)}
\]  

(2)

Several input parameters in this study used \(V_p\) between 200-4000 m/s, Poisson's ratio between 0.4-0.5, \(V_s\) between 150-3500 m/s and density between 1000-2000 kg / m3. For the \(V_s\) speed mode the linear increase speed mode is selected because the deeper the soil layer speed will increase, and the sub-layer value is selected by seven layers to see in detail the velocity \(V_s\) to the layer depth. After all parameters are entered, a running program is carried out until the smallest misfit is obtained in order to obtain the velocity profile of the value of \(V_s\) and the thickness of the sediment layer from the surface to the bedrock.

Soil profile criteria classified based on the \(V_{s30}\) value have been established and agreed upon by the National Earthquake Hazard Reduction Program [BSSC 2003] and the American Society of Civil Engineers [1]. Soil profiles are divided into six categories from soil profiles A to F in Table 3.1 [12].

| No | Classification | \(V_{s30}\)         | Soil Type                  |
|----|----------------|---------------------|----------------------------|
| 1  | A              | >1.500 m/s          | Hard Rock                  |
| 2  | B              | 760-1.500 m/s       | Rock                       |
| 3  | C              | 360-760 m/s         | Very dense soil and soft rock |
| 4  | D              | 180-360 m/s         | Rigid Soil                 |
| 5  | E              | <180                | Soils with special specifications |
3. Results and discussion

3.1. The thickness of the sediment layer in Eastern Mataram City
The inversion of the rayleigh wave ellipticity curve in this study was carried out to obtain the smallest missfit as shown in Figure 2a which then provided a ground profile as in Figure 2b. The information obtained from the ground profile is the shear wave velocity and the thickness of the sediment layer. The black curve line is the initial model, then the inversion ellipticity curve model must be as close as possible to the initial model curve. Then the value of the thickness of the sediment layer spread over 60 target area points is made on a map which can be seen in Figure 3.

![Figure 2](image)

(a) Inverse ellipticity of a rayleigh wave. (a) Missfit target after iteration, (b) Ground profile.

The value of the sediment layer thickness in this study ranged from 12.78 m to 57.20 m. The thinnest sediment layer is at the research point M30 which is located in the north of Cakranegara sub-district and the thickest is at point M56 which is located in the western part of Selaparang sub-district. The map in Figure 3 shows the distribution of the variation in the thickness of the sediment layer in the study area, showing that the sediment layer in this city has low value of sediment thickness in the east and has higher value in the west. The results of this study follow the form of regional lithology. To the west of Mataram City is the sea, which means that the further west the area is relatively lower. The sediment layer deposition originated from Mount Rinjani which is located in the northeast of Mataram City towards the west of Mataram City which is lower, so that the thickness of the sediment layer in the west of the city is thicker than the eastern area.

3.2. Soil classification in Eastern Mataram City
In this study, 60 shear wave velocity profiles ($V_{s30}$) were obtained as shown in Figure 2b at single microtremor measurement points which are considered to represent the eastern part of Mataram City. The $V_{s30}$ profile generated at each measurement point shows the difference in rock types below the surface. In general, the value of $V_{s30}$ in the target area varies from 286 to 866 m/s, which means that the study area is classified as D (rigid soil) to B (rock). The softer the rock, the smaller the shear wave velocity value because the value of Vs is directly proportional to the density (density) of the rock.

The distribution of $V_{s30}$ values in Selaparang District ranges from 344 m/s to 734 m/s in the classification of rigid soil to soft rock, in Cakranegara district it ranges from 326 m/s to 828 m/s and in Sandubaya sub-district between 286 m/s to 865 m/s with the classification of rigid soil to rock. In
general, Sandubaya sub-district is dominated by harder rocks than the other two sub-districts, while Selaparang sub-district has an area dominated by rock types that tend to be soft based on the $v_{s30}$ value.

![Figure 3. The sediment layer thickness distribution map](image)

### 4. Conclusion
The value of the sediment thickness throughout the study area ranged from 12.78 m to 57.20 m, where the Selaparang District had a relatively large sediment thickness distribution value compared to Cakranegara District, and Sandubaya District had a relatively small sediment thickness distribution value. The value of $v_{s30}$ varies between 286 m/s to 866 m/s with the classification of rigid soils, very dense soils and soft rocks and rocks.

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### References:
[1] American Society of Civil Engineers 2010 *Minimum Design Loads for Buildings and Other Structures* ASCE/SEI 7-10 Reston VA
[2] Agustawijaya D S and Syamsuddin 2012 *Dinamika Teknik Sipil* 12 (2) 146-150
[3] Bath M 1979 *Intensity Relation for Swedish Earthquake* Seismological Institute
[4] Boore D M 2004 *Bull. Seismo. Soc. Am* 94 (2) 591–597
[5] Fah D, Kind F and Giardini D 2003 *Journal of Seismology* 7 449–67
[6] Herak M 2008 Computers and Geosciences 34 1514-1526
[7] Miura H, Matsuko A, Kanno T, Shigefuji M and Abiru T 2018 Estimation Of Shear-Wave Velocity Profiles By Joint Inversion Of Earthquake Ground Motion Data And Microtremor Array Dispersion Data 16th European conference on earthquake engineering
[8] Mangga A S, Atmawinata S, Hermanto B and Amin T C 1994 Peta Geologi Lembar Lombok, Nusa Tenggara Direktorat Jenderal Geologi dan Sumberdaya Mineral Departemen Pertambangan dan Energi
[9] Nakamura Y 1989 Railway Technical Research Institute, Quarterly Reports 30 25-33
[10] Nogoshi M and Igarashi T 1971 Jour. Seism. Soc. Japan 24 26-40
[11] Uzlifatul A, Kirbani S B and Suprapto D 2018 Jurnal Pendidikan Mandala 3 (3)
[12] Wair B R and Dejong J T 2012 Guidelines for estimation of shear wave velocity profiles (California: Pacific Earthquake Engineering Research Center)
[13] USGS 2012 Earthquake Map Server (1890-2012) download on Augustus 10th 2020 from http://earthquake.usgs.gov/hazards/apps/vs30/custom.php