Seismic Hazard Analysis based on Earthquake Vulnerability and Peak Ground Acceleration using Microseismic Method at Universitas Negeri Semarang

H Sulistiawan*, Supriyadi, and I Yulianti
Departemen Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam, Universitas Negeri Semarang, Jalan Taman Siswa, Sekaran, Gunung Pati, Sekaran, Gn. Pati, Kota Semarang, Jawa Tengah 50229, Indonesia

Email : hendrisulistiawan@students.unnes.ac.id

Abstract. Microseismic is a harmonic vibration of land that occurs continuously at a low frequency. The characteristics of microseismic represents the characteristics of the soil layer based on the value of its natural frequency. This paper presents the analysis of seismic hazard at Universitas Negeri Semarang using microseismic method. The data acquisition was done at 20 points with distance between points 300 m by using three component's seismometer. The data was processed using Horizontal to Vertical Spectral Ratio (HVSR) method to obtain the natural frequency and amplification value. The value of the natural frequency and amplification used to determine the value of the earthquake vulnerability and peak ground acceleration (PGA). The result shows then the earthquake vulnerability value range from 0.2 to 7.5, while the value of the average peak ground acceleration (PGA) is in the range 10-24 gal. Therefore, the average peak ground acceleration equal to earthquake intensity IV MMI scale.

1. Introduction
The Indonesian archipelago is an archipelago that has a high level of seismicity. Most of the earthquake source in Java, especially in Semarang city comes from active faults in Java. Active faults that affect Semarang city are Opak Fault (Yogyakarta), Lasem Fault, Pati Fault, and Kaligarang Fault. In 1856, Semarang has been shaken by an earthquake with earthquake intensity of VII - VIII MMI, or a magnitude above 5 SR. In 1821 and 1890, Jepara and Pati have also been shaken by an earthquake with earthquake intensity of VII MMI. The most recent earthquake occurred in Jepara on October 23, 2015 which was caused by Lasem Fault activity with magnitude of 5 SR.

Semarang city with an area of 373.7 km² has several high seismic regions, such as Gunungpati and Mijen districts. Based on the vulnerability of ground movement zone map published by Pusat Vulkanologi Mitigasi Bencana Geologi (PVMBG), Gunung Pati is also considered as an area that prone to soil movement. The impact caused by earthquake depends on the earthquake intensity, the distance from the source of the earthquake, the scale of the earthquake, the size of the fault zone, and the energy released rock, as well as the condition of the local geology[1].

To determine the seismic hazard zone at Unnes area, geophysical survey should be conducted to determine the vulnerability of the earthquake and the maximum ground acceleration. Earthquake Vulnerability value and maximum ground acceleration can be determined by the microseismic method [2]. Microseismic is a geophysical method that can describe the level of vulnerability of surface soil
layers towards deformation during an earthquake [3]. Earthquake Vulnerability useful for predicting a weak zone during earthquake [4], and cracks of the ground due to earthquake [5].

Based on these descriptions, studies and analysis of seismic hazard needs to be done to analyze the risk of earthquakes based on the value of Peak Ground Acceleration (PGA) and earthquake vulnerability with microseismic methods to be used as information for disaster mitigation earthquakes in the Universitas Negeri Semarang.

2. Theory

2.1. Horizontal to Vertical Spectral Ratio (HVSR)

HVSR analysis method was first developed by Nakamura in 1989[2]. HVSR method used to calculate the spectrum ratio of the signal microtremor horizontal component towards the vertical component. Nakamura [6] divided microseismic waves into two types which are Rayleigh wave and body wave. Rayleigh wave is surface wave that propagates in the ground surface, whereas body waves propagates through the bedrock. Under these conditions, the HVSR equation can be written as follows.

\[
H_f = A_h S_{HB} + S_{HS} \tag{1}
\]

\[
V_f = A_v S_{VB} + S_{VS} \tag{2}
\]

so that

\[
H/V = \frac{H_f}{V_f} = \frac{A_h S_{HB} + S_{HS}}{A_v S_{VB} + S_{VS}} \tag{3}
\]

where \(H_f\) and \(V_f\) are the horizontal and vertical component of microseismic wave, \(A_h\) and \(A_v\) are amplification factor of body wave, \(S_{HB}\) and \(S_{VB}\) are spectrum of horizontal and vertical motion in the bedrock, while \(S_{HS}\) and \(S_{VS}\) are spectrum of horizontal and vertical motion on the soil surface or sediment layers. HVSR curve is obtained by plotting \(H/V\) to frequency. The frequency of the highest amplitude in HVSR curve shows the natural frequency of ground layer. Meanwhile, the highest amplitude represents the amplification. The natural frequency and the amplification obtained from the HVSR curve are used to calculate the earthquake vulnerability and also peak ground acceleration.

2.2. Earthquake Vulnerability

Earthquake vulnerability is a value that describes the vulnerability of the surface soil layer due to deformation during the earthquake [3]. Earthquake vulnerability aims to measure the level of vulnerability of land or structures when earthquake occurred [7] which is defined by:

\[
k_g = \frac{A^2}{f_o} \tag{5}
\]

where \(f_o\) and \(A\) are the natural frequency and amplification, respectively. The earthquake vulnerability is essential to predict weak zones during an earthquake [4]. According to Nakamura [3], parameters that affect the vulnerability of the earthquake (\(K_g\)) are the value of ground shear-strain (\(\gamma\)) caused by the deformation of the surface layer (\(\delta\)) and the acceleration of seismic waves on the bedrock (\(\alpha\)) which increases when propagates in a low-density medium such as soil layer surface. Ground shear-strain value is written in the following equation:

\[
\gamma = \frac{A}{h} \cdot \frac{a}{4\pi^2 f_o} \tag{6}
\]

where \(A\) is the amplification, \(\delta\) is the deformation of the surface soil layer caused by the earthquake \(\left(\frac{a}{(2\pi f_o)^2} = \delta\right)\), and \(h\) is the thickness of the sediment layer.
2.3. Peak Ground Acceleration (PGA)

Peak Ground Acceleration (PGA) is the maximum acceleration of ground vibrations that happened at particular location that caused by earthquake wave. Peak ground acceleration value depends on the propagation of seismic waves and the characteristics of the soil layers [8]. Kanai [8] formulated an empirical equation of maximum ground acceleration as follows:

$$PGA = \frac{5}{\sqrt{T_0}} \cdot 10^{(0.61M - 1.66 \cdot \frac{1.6}{R} \log R - 0.0167 \cdot \frac{1.83}{R})}$$  

(7)

where $T_0$ is the natural period of ground, $M$ is the magnitude of earthquake and $R$ is the hypocentre of earthquake.

According Gutenberg and Richter [9] there is a relationship between the value of maximum ground acceleration with earthquake intensity scale ($I_{MM}$) which is then formulated with the following empirical equation:

$$I_{MM} = 3 \log PGA + 1.5.$$  

(8)

Earthquake intensity defines the strength of earthquake that were perceived at certain location (on the surface) and is determined from the direct effects of the shake of the earthquake. The value of the maximum ground acceleration and the earthquake intensity depend on the magnitude of the earthquake, the distance from the earthquake source and the geology factor of the region affected by the earthquake.

3. Research Methodology

The research was conducted at Universitas Negeri Semarang with a research area of 1200 $\times$ 750 m. Data collection was done at 20 points as shown in Figure 1 with a recording duration of 30 minutes at each point.

![Figure 1. The data collection points at the research location](image)

Data collection were performed by using M.A.E seismometer. The data were then analyzed by using Geopsy software to determine the natural frequencies and amplification.

4. Result and Discussion

4.1. Natural Frequency and Amplification at Unnes Region
Natural frequency is the dominant frequency that exists in the region, while the amplification is the magnitude of wave amplitude reinforcement when the wave propagates through a particular medium. Herak [10] explains that the value of natural frequency and amplification on the surface associated with physical parameters of the subsurface. The result of HVSR curve analysis using Geopsy are the values of natural frequency and the amplification as shown in Figure 2.

![Figure 2. Values of (a) natural frequency and (b) amplification](image)

It is shown that the natural frequencies at Unnes region is ranging from 2.5 to 12 Hz, with natural frequencies of less than 8 Hz dominating at the research area. It is also found that high natural frequency value (>8 Hz) are located at area around point 8, 9 and 10 which are shown in yellow to red contour. The high natural frequency indicates thin sediment layer, while low natural frequency values describe thick sediment layer.

In terms of amplification, the results show that the value at Unnes region is ranging from 0.5 to 7.5. In general, almost all research locations have amplification value below 4.5. Therefore, amplification of above 4.5 is considered as high amplification. It is shown in figure 2(b), high amplification value located at around point 11, 13, 14, and 20. The difference of amplification value occurred due to deformation (weathering, folding or shifting) of the rocks below ground surface.[11]

4.2. Earthquake Vulnerability at Unnes Region

Earthquake vulnerability shows physical quantities of the impact due to shocks or movement of rock layers. The greater the value of the earthquake vulnerability is, the more vulnerable the affected area by shocks is. The result of the calculation of earthquake vulnerability is shown in Figure 3.

![Figure 3. Map of earthquake vulnerability value at Unnes region](image)
vulnerability which are located at around point 11, 16, and 20. The high earthquake vulnerability value indicates high ground shear-strain value. From equation (6) it is found that the ground-shear strain at point 11, 16, and 20 are $42.7 \times 10^{-4}$, $28.9 \times 10^{-4}$, and $44.6 \times 10^{-4}$, respectively. Based on table of strain dependence of dynamic properties of soil [11], the phenomenon of ground deformation caused by earthquake with those ground shear-strain value are in the form of crack and settlement.

4.3. Peak Ground Acceleration

The parameters used to determine the value of maximum ground acceleration is dominant period of soils derived from the natural frequency value and magnitude and hypocentre of earthquakes that was occurred around Semarang as defined by equation (7). The earthquake source that were used are the earthquakes that happened in the last 10 years with a magnitude of 5 SR or above, which are the earthquake in Yogyakarta on May 27, 2006, earthquake in Jepara on October 23, 2015 and earthquake in Tegal on March 23, 2015. The maximum ground acceleration value are shown in Figure 4.

Figure 4. Map of peak ground acceleration value at Unnes region based on earthquake source in (a) Yogyakarta, (b) Jepara, and (c) Tegal.

Figure 4(a) shows that the peak ground acceleration value at Unnes based on Yogyakarta earthquake are in the range of 26-54 gal. The highest ground acceleration are around point 8, 9 and 10. Based on Jepara earthquake (Figure 4.b), the peak ground acceleration value are in the range of 6-12 gal. Meanwhile, the highest ground acceleration are around point 4, 8, 9 and 10. It is found that the peak ground acceleration based on Tegal earthquake (Figure 4.c) are lower compared to peak ground acceleration based on Yogyakarta and Jepara, which in the range of 2-5 gal. The highest ground acceleration based on Tegal earthquake was around point 1, 4, 8, 9 and 10.

The average peak ground acceleration at Unnes are calculated based on the value of the peak ground acceleration caused by the earthquake in Yogyakarta, Jepara and Tegal. The average peak ground acceleration value at Unnes is shown in Figure 5.

Figure 5. The average peak ground acceleration value at Unnes
Figure 5 shows that the average peak ground acceleration value are in the range of 10-24 gal. The highest ground acceleration value are located around point 8, 9, and 10. From equation (8), it was calculated that the average of earthquake intensity at Unnes region is in the range of IV MMI scale. The impact of earthquake intensity in IV MMI scale is a swinging of hanging objects and vibration that similar to vibration caused by moving heavy trucks.

4.4. Interpretation of Seismic Hazard
Seismic hazard is a description of a phenomenon caused by earthquakes that have potential to cause damage. Based on earthquake vulnerability and peak ground acceleration obtained in previous subsections, it can be concluded that seismic hazard at Unnes region is relatively low. However, there are several regions with high earthquake vulnerability that should be more alert since these regions can easily deform. The deformation may cause damage to buildings and infrastructure during an earthquake. Therefore, it is suggested to not build any constructions on these regions. In case it needs to build construction, then the construction should be built with deep foundation.

5. Conclusion
The values of earthquake vulnerability at Unnes area are in the range of 0 to 7.5. Meanwhile, the average value of the peak ground acceleration (PGA) at Unnes area are in the range of 10-24 gal. Seismic hazard at Unnes area is generally classified as low seismic hazard. However, in areas with high earthquake vulnerability, it is not advisable to make buildings.

6. References
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