Landslide potency based on microseismic data-case study in Trangkil area Gunungpati, Semarang

Supriyadi¹,*, R H Hidayatullah¹, Mahardika¹, R Kusumawardani² and T C Upomo²

¹ Department of Physics, Universitas Negeri Semarang, Semarang, Indonesia
² Department of Civil Engineering, Universitas Negeri Semarang, Indonesia

*Corresponding author: supriyadi@mail.unnes.ac.id

Abstract. A research using microseismic method had been conducted in Trangkil Sejahtera area, Semarang. Microseismic is an effective method to determine the ground shear strain value of a region. This study aimed to determine a landslide prone area within Trangkil Sejahtera, Semarang. Microseismic measurements was performed in an area of 200 x 400 metres with 9 points of measurements. Acquired data from the measurements was then analysed using HVSR (Horizontal to Vertical Spectrum Ratio) method, obtained the natural frequency value between 1.38-7.07 Hz, amplification between 1.42-3.28, thickness of weathering layer between 17.02-95.53 metres and ground shear strain value between 0.00083–0.00203. Those values were then mapped using Surfer to depict the distribution. Furthermore, by integrating the natural frequency value, amplification, $K_g$, PGA and GSS, it could be known that the landslide prone area is in the northern area of Trangkil Sejahtera.

1. Introduction
Landslide disaster causes many losses, especially buildings and for some cases near the road around the hillside, landslide will damage the traffic. In addition, landslide can cause long-term negative impacts such as loss of fertile soil layer (top soil) that could decrease the soil productivity. Factors that cause ground motion (landslide) are topography of slope, soil conditions (texture, layer structure), rainfall, earthquake and the lack of vegetation [1,2].

Landslide occurred in the housing of Trangkil Sejahtera Semarang in 2014. Geological condition of Trangkil Sejahtera consists of alluvium and clay. Moreover, the rocks are composed of gravels and lumps which on the hillside are easily to move or roll over. Therefore, this area was chosen as the research location to know the depth of the weathering layer under the soil and the shear strain value in the study site [3].

The seismic waves during the propagation are trapped in soft soil layers, resulting in a multi-reflection phenomenon that produces the ground vibrations period equal to the soil predominant period. Microtremor measurements can be used to define this local ground vibration period [4]. Microtremor is a ground vibration with a shift amplitude for about 0.1-1 μm and a velocity amplitude for about 0.001-0.01 cm/s. Long period microtremor with a period longer than 1 second is associated with a deeper soil structure indicating the base of hard rock [5]. Mikrotremor studies have been used to analyze the characteristics of the soil, the natural frequency (fo), the amplification factor (Am), sediment thickness (h), ground susceptibility index (kg) ground shear strain (GSS) [6-8]. To determine the predominant frequency value on microseismic based on the HVSR method [9].

The HVSR analysis method was first developed by Nakamura in 1989. The HVSR method is used to calculate the spectrum ratio of microtremor’s horizontal component signal to its vertical component as shown in Figure 1. The HVSR analysis result shows a spectrum peak at predominant frequency [4]. Natural frequency and amplification from HVSR analysis illustrate the soil dynamic characteristics related to the subsurface physical parameter of the area [10,11].

![Image of H/V method](image)

**Figure 1.** Illustration of HVSR method

The HVSR equation for a measured vibration on the surface can be expressed as follows [12]:

\[
HVSR = \sqrt{\frac{(A(U-S)(f))^2 + (A(B-T)(f))^2}{(A(V)(f))^2}}
\]  

with HVSR = Horizontal to Vertical Spectrum Ratio, \(A(U-S)(f)\) = amplitude value of the north-south component frequency spectrum, \(A(B-T)(f)\) = amplitude value of the east-west component frequency spectrum, and \((A(V)(f))\) = amplitude value of the vertical component frequency spectrum. The result of HVSR processing is a HVSR curve as shown in Figure 2.

![HVSR curve](image)

**Figure 2.** The \(f_0\) value of HVSR processing results on the HVSR curve
The value of seismic vulnerability index can be calculated by the Nakamura equation [13]:

\[ Kg = \frac{A_0^2}{f_0} \]  

with: \( Kg \) = seismic vulnerability index, \( A_0 \) = soil amplification factor, and \( f_0 \) = predominant frequency (Hz). Ground shear strain (\( \gamma \)) value can be calculated by the Nakamura equation [13]:

\[ \gamma = Kg \times (1000 \times 10^{-6})amax \]  

where \( \gamma \) is ground shear strain, \( Kg \) is the seismic vulnerability index, and \( amax \) is peak ground acceleration. The value of \( amax \) is determined by Fukushima-Tanaka [10]

\[ Log\ amax = 1.3 + 0.41Mw - Log(R \times 0.3210.41Mw) - 0.0034R \]  

Shear strain \( \gamma \) of surface ground is noticed. Table 1 shows relationship of \( \gamma \) to ground disasters compiled. It indicates that from \( \gamma \approx 1000 \times 10^{-6} \) ground begins to show non-linear character and in \( \gamma > 10,000 \times 10^{-6} \) large deformation and collapse occur, shown in Table 1.

| Size of strain | \( 10^{-6} \) | \( 10^{-5} \) | \( 10^{-4} \) | \( 10^{-3} \) | \( 10^{-2} \) | \( 10^{-1} \) |
|----------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Phenomena      | Wave, Vibration | Crack, Settlement | Landslide, Soil compaction | Liquifaction | Collapse | Repeat-Effect, Speed-Effect of loading |
| Dynamic Properties | Elasticity | Elasto-Plasticity |                      |                      |                      |                      |

2. Methods
This research used a set of 3 component seismometer type of MAE with data logger. Microtremor measurements were carried out spreadly in 9 Trangkil Sejahtera area. The study begins with designing the concept of acquisition of the field, so that a detailed description of the acquisition will be obtained. The next step was microseismic acquisition at the previously designed point of acquisition. The tool’s standard operational measurement is based on the SESAME European research project [15]. Measurement duration was about 30 minutes for each point.

The data used in this research was the direct measurements of microtremor conducted in 9 points (primary data), and also earthquake magnitude and Vs-30 data obtained from USGS (secondary data). Processing data used software Seg2conv, Geopsy and Surfer. Microtremor data processing applied HVSR (Horizontal to Vertical Spectrum Ratio) method to generate the main variable i.e. predominant frequency data (\( f_0 \)) and amplification factor (\( A_0 \)) which used to determine PGA indicator for Kanai method, seismic vulnerability index (\( Kg \)), ground shear strain (GSS) and the thickness of the weathering layer (h). Meanwhile earthquake magnitude as the secondary data was used to determine the PGA (Peak Ground Acceleration) value for both Kanai and Fukushima-Tanaka method.

3. Results and Discussion
Microtremor is an ambient vibration with low amplitude generated by natural or man-made events, such as wind, ocean waves, or vibrations from a vehicle that could describe a geological condition near the surface [5]. Microtremor observations can provide useful information about landslide prone area using ground shear strain parameters (GSS).

This research focused on determining the GSS value distribution profile. Calculation results obtained from indicators PGA, \( Kg \), GSS and h in each measurements are shown in Table 2.
Based on the results in Table 2, it can be seen that the greatest value of each GSS indicator is generally located at points B2, C1 and C2. They are on the steeper slope with soft rock types so that considered to have a high risk level of landslide. The smallest value of each GSS indicator is generally located at points A2, A3 and C3. They are on the less steep slope with hard rock types so that considered to have a low risk level of landslides. Based on the results in Table 2 above, it can also be seen that the value of each indicator at each point shows an uneven distribution of values that may be caused by a site effect or local geological conditions.

The results of the previous study that have examined each indicator suggest that an area with high value of PGA, $K_g$, GSS and thickness of the weathering layer ($h$) will have a high risk of landslide disaster and will suffer severe damage if landslides does take place [8]. The contour map of ground shear strain value distribution from this research is shown in Figure 3.

**Table 2.** Results of microseismic data processing

| Point | $f_0$ (Hz) | $A_0$ | Vs30 (m/s) | $K_g$ | h (m) | $T_0$ (s) | $a_{max}$ (gal) | shear strain |
|-------|------------|-------|------------|-------|-------|-----------|----------------|--------------|
| A1    | 3.18266    | 1.689069 | 513.3455  | 0.896406 | 40.32362 | 0.314203 | 13.84474298  | 0.001257983 |
| A2    | 5.29916    | 1.42716 | 508.3886  | 0.38436 | 23.9844 | 0.188709 | 8.185821631  | 0.000832637 |
| A3    | 6.52448    | 1.61322 | 501.3754  | 0.398879 | 19.21132 | 0.153269 | 6.587821495  | 0.000861136 |
| B1    | 5.0869     | 2.024   | 502.8368  | 0.805319 | 24.71234 | 0.196583 | 8.571413893  | 0.001221285 |
| B2    | 2.1406     | 2.16528 | 498.0522  | 2.190245 | 58.16736 | 0.467159 | 20.27492097  | 0.002029771 |
| B3    | 1.3879     | 1.50584 | 484.6135  | 1.633802 | 87.29258 | 0.720513 | 25.882299188 | 0.001803615 |
| C1    | 1.24055    | 1.57967 | 474.0719  | 2.011493 | 95.53664 | 0.806094 | 32.78474126  | 0.002048099 |
| C2    | 5.91803    | 3.28717 | 470.3284  | 1.825859 | 19.86845 | 0.168975 | 7.287762234  | 0.001969097 |
| C3    | 7.07092    | 1.83667 | 483.0578  | 0.477075 | 17.07903 | 0.141424 | 5.899176094  | 0.000977581 |

**Figure 3.** The contour map of ground shear strain value distribution
It can be seen in Figure 3 that there is a congruity between the geological formation and the GSS value. Areas with soft soil have greater wave amplitudes than the areas with hard soil so the softer soil will be more easily damaged than the harder soil. The data points with the greatest GSS value are in the Alluvium (Qa) Formation composed by loose material, granular material, clay and gravel. However, at the location of the research, there was only found the loose material in sand grain size. This area is mostly functioned as residential areas and gardens. In general, liquefaction occurs in the layers formed by loose materials with sand grain size or silt. This is due to the ability of the layer with sand grain size which tends to absorb and store water. The condition of water-saturated layer can be one of the factors that causes an area to potentially experience liquefaction or landslide [16].

4. Conclusion
The greatest value of PGA, Kg, GSS and thickness of the weathering layer (h) are present at B2, C1, C2 located on the steeper slope which are considered to have a high risk level of landslide disaster. While the smallest value of PGA, Kg, GSS and thickness of the weathering layer (h) are present at A2, A3, C3 located on the less steep slope. Based on the results of each indicator, it can be concluded that the area around the housing of Trangkil Sejahtera which consists of soft rock (alluvial) has a high risk level of landslide disaster. It can also be concluded that the value of each indicator depends on the site effect factor or local geological conditions of the area. In addition, it can also be known that one single parameter or indicator is not enough to determine a landslide prone area.

References
[1] Wuryanto A 2004 Prosiding Ekspose BP2TPDAS-IBB. 6 2
[2] Seed H B and Idriss I M 1971 J Soil Mech Found Eng 9 1249
[3] Motamed R, Ghalandarzadeh A, Tawhata I and Tabatabei S H 2007 J Earthquake Eng 11 110
[4] Nakamura Y 1989 Q Rep Railw Technol Res Inst (RTRI) Japan 30 25
[5] Mirzaoglu M and Dýkmen Ü 2003 J Balkan Geophys 6 143
[6] Konno K and Ohmachi T 1998 Bull Seismol Soc Am 88 228
[7] Lermo J and Chavez-Garcia F 1993 Bull Seismol Soc Am 83 1574
[8] Woolery E R Street and Hart P 2009 Seismol Res Lett 80 525
[9] Wibowo N B and Gunawan A 2014 J Appl Phys 4 115
[10] Nakamura Y 2000 World Conf Earthquake Eng (Auckland, New Zealand)
[11] Herak M 2008 Comput Geosci 34 1514
[12] Nakamura Y 2008 14th World Conf Earthquake Eng (Beijing, China)
[13] Nakamura Y 1997 World Congr Railw Res (Florence, Italy)
[14] Farid M 2014 Microseismic Study To Detect Shoreline Changes With Seismic Vulnerability Index Peak Ground Acceleration And Ground Shear Strain Indicator In The Bengkulu Province Dissertation Universitas Gadjah Mada University
[15] Sesame 2004 Guidelines for the implementation of the h/v spectral ratio technique on ambient vibrationsmeasurements, processing and interpretation European Commission – Research General Directorate (Paris, France)
[16] Refrizon I 2015 J Gradien 11 1122