Analysis of landslide in Bungkah, Sepakung, Banyubiru using ground shear strain method and shear wave profile from HVSR method

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Abstract. In Bungkah, Sepakung, Banyubiru there was a landslide several times Monday to Thursday, 17 to 20 October 2017 which occurred due to the high intensity of rain in the region within 2 consecutive days. The landslide material was able to close the road that became access to local residents' settlements. Besides that, in Bungkah, there is a resident's house made of permanent walls that are curved on the wall due to ground movement while the house next to it does not occur. To analyze these phenomena, a single station microtremor method is used, namely the HVSR analysis with amplification values and dominant ground frequency of the curves obtained can be used to determine the peak ground acceleration and seismic vulnerability index which can then be used to analyze ground shear strain value or the ability of the soil layer to stretch and shift when receiving elastic wave propagation. Based on the ground shear strain value, Bungkah has values ranging from $10^{-3}$ to $10^{-1}$, the phenomenon that will occur is landslides with the dynamic nature of the soil included in the category of soil or rock collapse. Based on the results of frequency and amplitude inversion, the profile of $V_s$ is obtained to the depth that can accurately image the shape of the slip surface from landslide that occurred in October 2017. The sensitivity of $V_s$ to the presence of fluid imaged an accumulation of water below the landslide limit. The mechanism of land movement in the Bungkah hamlet is a rotational slide avalanche type. The movement of the soil which causes the curvature of the walls of one of the permanent houses in Bungkah due to the existence of a vertical soil layer with very low $V_s$ which is directly bordered by massive $V_s$. The boundary of this layer may be cavity or cavity. The existence of a massive layer in the east of the area makes no continuity of soil movement to the east.

1. Introduction
Bungkah area is the part of Sepakung Village, Banyubiru, Semarang Regency has morphology in the form of steep mountains with volcanic sediment lithology, making this area often occur ground movements, both in the form of sliding rock and rock fall. Tectonic processes that occur in Central Java, directly and indirectly, support the ground movement. Various fractures that occur cause secondary structure in the form of joint, a fracture (cracks in rocks) that relatively does not experience a shift in the fracture, caused by tectonic and non-tectonic symptoms. This joint presence makes the rock split and bonds between factions weaker. On the other hand, the joint presence causes rainwater to enter the rock and increase the load, making it easy for landslides due to its own burden on steep fields. In Bungkah, landslides occurred several times from Monday to Thursday, 17 to 20 October 2017, which occurred due to the high intensity of rain in the region which quite disturbed mobility and threatened the lives of the people. In addition, in Bungkah land movements also occur, which cause cracks and curvature of
the walls of houses (figure 1). In the geological map [1] the location of the ground movement is the Telomoyo colluvium unit that is set aside by the Telomoyo pyroclastic unit. In this regard, the investigation of locations that are prone to ground movement is very important. This investigation includes determining the points that have the potential for ground movement and determining the type of soil movement.

Geophysical methods commonly used for landslide analysis, such as the geoelectric method, cannot be carried out due to the constraints of topographic factors that are difficult to measure using geoelectricity and residential resistance factors that make it impossible to stretch the electrodes cables. Gravity and magnetic methods are also not possible because the coverage area of the study area is not too large, and the induction factor of the electric grid system affects the magnetic data. The Ground Penetrating Radar method also cannot be used in this area due to topographic constraints and the thickness of the landslide area, which exceeds the wave penetration capability of the GPR survey. So, based on the considerations above, then in this study, the investigation of ground motion was carried out through a method that can be done quickly, easily, at a relatively low cost [2] that is HVSR (Horizontal to Vertical Spectrum Ratio) method. Based on the data that can be extracted from the HVSR method, namely the predominant frequency, amplification of ground vibrations, and with the largest earthquake information data that has ever occurred near the research site, the shear wave velocity profiles and the ground shear strain can be used to map the potential landslide in the study area.

2. HVSR method
The horizontal to Vertical Spectral Ratio (HVSR) method is a method that calculates the comparison of horizontal component seismic recording data with its vertical components. The HVSR method was introduced by Nakamura [3] to estimate the resonant frequency and local geological amplification factors from microseismic data. The use of this method then developed a lot in geotechnics, and the environment with early publications on the estimation of soil vulnerability index conducted [4] then developing for estimation of building vulnerability index [5][6], estimation of vulnerable areas building damage due to local effects [7][8], and until now there have been many applications of this method such
as identification of ground layer structures of land subsidence sensitive areas [9], vibration vulnerability identification [10], and identification of landslide zones [2][11][12][13][14].

The HVSR method is usually used in passive seismic (microtremor) three components. Important parameters generated from the HVSR method are natural frequency and amplification. Measured HVSR on soil aimed at local geological characterization, natural frequency and amplification related to physical subsurface parameters [15]. Based on the HVSR analysis, the values of maximum ground vibration acceleration, vulnerability index, and ground shear strain can be obtained. Soil characteristics are very influential on the vulnerability index and soil acceleration in a certain place. A vulnerability index is an index that describes the level of vulnerability of surface soil layers to soil deformation. Knowing the value of the maximum ground vibration acceleration and seismic vulnerability index can be used to analyze the value of the ground shear strain or the ability of the soil layer to stretch and shift when receiving elastic wave propagation. Ground shear strain microzonation can be used to map the area of concern and to determine the highest potential ground movement.

Because the microtremor method has a compact survey tool, the acquisition with the HVSR method can be made for areas that have topographic contours that are difficult to do with other methods, for example, geoelectric or GPR. In addition, although GPR has the highest resolution at the top layer or on the surface of the ground, it has relatively small depth penetration limitations and mobility limitations. In the geoelectric survey, the resulting 2D profile also has a smaller depth with the same path distance as the HVSR method. This is because the ability of the electric current field to penetrate in depth has a value of only about one-third of the length of the electrode cable stretches (skin depth factor). Because microtremor consists of mostly surface waves and surface waves themselves are composed mostly of shear waves, so microtremor method is also sensitive to shear waves. Because shear waves cannot pass through the fluid, the presence of fluid in the form of water or air in rock fractures can be identified. The clay layer as a slip plane is a layer with low permeability that has a specific shear wave velocity value. The effectiveness of the HVSR method for landslide analysis can be compared with geoelectric methods, and it has a pretty good correlation [2].

3. Ground shear strain

Ground Shear Strain (GSS) is the ability of a soil layer material to stretch or shift during an earthquake. Areas that have high ground shear strain values have a high risk of ground motion due to earthquakes such as land subsidence and liquefaction. Ground shear strains can be written [4]:

\[ y = (K_g a_g) \]  \hspace{1cm} (1)

where \( K_g = \frac{A_g}{\pi V_s f_0} \) is the seismic vulnerability index, \( a_g = (2\pi f_0)^2 d \) is peak ground acceleration, \( f_0 \) is the predominant frequency, \( A_g \) is amplification factor, \( d \) is shifting seismic waves below ground level, and \( V_s \) are the velocity of wave shift below the surface of the ground and at the surface of the ground. Furthermore, peak ground acceleration \( a_g \) can be described as:

\[ a_g = \frac{5}{\sqrt{f_0}} 10^{(0.61M - (1.66 + \frac{3.66}{R}) \log R + 0.167 - \frac{5.83}{R})} \]  \hspace{1cm} (2)

where \( T_g \) is the predominant period of soil observation point (s), \( M \) is the Moment Magnitude, \( R \) is the epicenter distance (km), and \( a_0 \) is the ground acceleration on base rock (gal). GSS parameters obtained from microtremor measurements are the dominant frequency \( f_0 \) and the amplification factor \( A_g \). To identify the phenomenon of soil vulnerability conditions based on the GSS values obtained is divided into three categories, namely:

1. If the strain value ranges from \( 10^{-6} \) to \( 10^{-5} \) then the phenomenon that will occur is a wave or vibration. The dynamic nature of the soil is included in the elastic category.
2. If the strain value ranges from \( 10^{-5} \) to \( 10^{-3} \) then the phenomenon that will occur is cracking and soil subsidence. dynamic nature of the soil is included in the category of elastic plastic.
3. If the strain value ranges from $10^{-3}$ to $10^{-1}$ then the phenomenon that will occur is landslides, land subsidence, liquefaction. The dynamic nature of the soil is included in the collapse category. These three categories can be given in Table 1.

| Size of Strain ($\gamma$) | $10^{-6}$ | $10^{-5}$ | $10^{-4}$ | $10^{-3}$ | $10^{-2}$ | $10^{-1}$ |
|--------------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Phenomena                | Wave, Vibration | Crack, Settlement | Landslide, Soil Compaction, Liquefaction | Collaps |
| Dynamic Properties       | Elasticity | Elasto-Plasticity | Repeat-Effect, Speed-Effect of Loading |

4. Methods
The landslide area in Bungkah has dimensions of about 50 meters in length and about 10 meters in width. The main objective of this research is to obtain the ground shear strain and create a shear wave velocity profile, and then to analyze the phenomenon of landslides and building damage in Bungkah that crosses the landslide area and a house that is damaged. The measurement points are attempted to connect the two locations in a profile. Due to the constraints of the steep terrain topography, settlement factors, and awareness of the threat of landslides that may occur again, the overall effective length that can be done for data acquisition is about 400 meters, and the effective width is around 100 m with 14 measurement points as given in Table 2 and Figure 2.

| Bungkah | Easting | Northing | Elevation (m) | Bungkah | Easting | Northing | Elevation (m) |
|---------|---------|----------|---------------|---------|---------|----------|---------------|
| E       | 436138  | 9189252  | 738           | 15      | 436015  | 9189262  | 785           |
| F       | 436129  | 9189312  | 723           | 16      | 435989  | 9189242  | 790           |
| 10      | 436159  | 9189364  | 718           | 17      | 435797  | 9189284  | 821           |
| 11      | 436087  | 9189183  | 758           | 18      | 435817  | 9189281  | 819           |
| 12      | 435993  | 9189201  | 787           | 19      | 435816  | 9189304  | 815           |
| 13      | 435936  | 9189234  | 803           | 1A      | 435844  | 9189252  | 816           |
| 14      | 436021  | 9189239  | 777           | 1B      | 435676  | 9189258  | 831           |

Measurements were made with a measurement duration of 20 minutes and a sampling rate of 150 at each point measurement using a portable seismometer unit consisting of a Sunfull VHL-land triaxial geophone 2 Hz with a DI710 datalogger. Field data is then processed with geopsy and HVSR curves are obtained containing amplification parameters of ground vibration and dominant frequency. The values of these parameters together with the shear wave velocity values propagating in the basement and earthquake source parameters such as epicenter distance, hypocenter depth, earthquake magnitude are included in equations (2) and (1) to obtain the GSS value in each measurement point. The values of GSS values in each measurement point is analyzed using the values given in Table 1. Then to obtain the profile of the shear wave velocity at a certain depth in each point, the dominant frequency parameters $f_0$ and the amplification factor $A_g$ are converted in order to obtain the values of $V_s$ at a certain depth at each point and then by gridding for several points in one particular trajectory a profile $V_s$. 


5. Result and discussion
The results of the calculation of seismic vulnerability index, peak ground acceleration, and ground shear strain in the form of bar charts are given in Figure 3 to Figure 5. Measurement points near the landslide location are quite a high seismic vulnerability index compared to other points, while for peak values, the ground acceleration is relatively not high. For measurement points near damaged houses, the values are the opposite of those around the avalanche. This shows the different conditions for the two phenomena.

![Figure 2. Location of microtremor measurement points in Bungkah. A red ellipse dashed line indicates the location of a landslide, while a red dashed circle marks the location of a damaged house.](image)

![Figure 3. Seismic vulnerability index in the research area. Point 15, Point 12, and Point 11, which are located close to the landslide location, have the greatest value](image)

Although very far from the landslide, however, the vulnerability index at Point 19 is quite high. The vulnerability index is directly proportional to the magnitude of the vibration amplification in the soil layer and inversely proportional to its dominant frequency. At Point 19, from it ellipticity curve the soil layer has a large enough amplification value with a relatively not so high dominant frequency of the soil.
Figure 4. Peak ground acceleration values at Bungkah. The points close to the landslide location, namely Point 12 to Point 16, are relatively small compared to the values at point E or Point 1A while the measurement point near the damaged house shows a relatively high value.

The peak ground acceleration is quite high even far from the landslide, because at these locations it has a high enough ground vibration amplification which is correlated with the soil layer which has a large enough sediment. The sediment at this location is the result of the colluvial layer from a higher area with a large enough slope that allows a large enough gravitational force to exceed the ability of the shear strain so that it is transported to this location.

Compared with the peak ground acceleration value in Central Java [16], which shows that the Bungkah area is included in the zone with peak ground acceleration 0.16-0.2 g, then all measurement points in Bungkah have a greater value, which is greater than 2 g with 9 points exceed 3 g.

Figure 5. Ground shear strain values in Bungkah. The measurement points around the landslide have relatively high values.

Based on the Ground Shear Strain values obtained, the soil layer in Bungkah area has a value greater than 10^{-2} with the highest values at Point 15 located northwest and close to the landslide location, and Point 12 located in the southwest landslide location on the edge of a public road next to a relatively steep cliff. Phenomena that may occur are landslides and land subsidence, with the dynamic nature is the
collapse of soil or rock layers. Overall measurement locations to the east of residential areas show relatively higher Ground Shear Strain values.

![Profile V<sub>s</sub> to the depths of Bungkah from west (Point 1B) to east (Point 10), observed slip surface (slip surface) is located east of Point 14 and Point 15 to approach Point 11 which is actually a former landslide.](image)

**Figure 6.** Profile V<sub>s</sub> to the depths of Bungkah from west (Point 1B) to east (Point 10), observed slip surface (slip surface) is located east of Point 14 and Point 15 to approach Point 11 which is actually a former landslide.

To find out the mechanism that causes the phenomenon of soil avalanches and damage to the walls of people's homes, an analysis based on the shear wave velocity profile was obtained (Fig. 6). Based on the results of frequency and amplitude inversion, the profile of V<sub>s</sub> is obtained with respect to the depth that can accurately image the shape of the slip surface (slip surface) of the landslide former east of Point 14 and Point 15 to approach Point 11. The sensitivity of V<sub>s</sub> to the presence of fluid indicates the accumulation of water below boundary point 14 or landslide limit. The mechanism of soil movement in the Bungkah hamlet is a type of rotational slide erosion and liquefaction. Soil movement causes the curvature of the walls of permanent houses near Point 17 and Point 18 due to the presence of a vertical layer of soil with very low V<sub>s</sub> that is directly bordered by massive V<sub>s</sub>. The boundary of this layer may be cavity or cavity. The existence of a massive layer in the east of the area makes no continuity of soil movement to the east.

### 6. Conclusion

Based on the ground shear strain value, Bungkah has values ranging from $10^{-3}$ to $10^{-1}$, the phenomenon that will occur is landslides with the dynamic nature of the soil included in the category of soil or rock collapse. Based on the analysis of soil avalanche vulnerability based on ground shear strain values and V<sub>s</sub> profile to depth to identify potential landslide movements in the Bungkah area with HVSR measurements, it can be concluded that the mechanism of soil movement in this area is a type of rotational slide landslide. The movement of the soil which causes the walls of the house to crack and curl in residential areas in Bungkah is caused by the cavity in the vertical boundary plane of the low speed layer with the high speed layer controlled by gravity.

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