# Identification of Potential Ground Motion Using the HVSR Ground Shear Approach in Wirogomo Area, banyubiru Subdistrict, Semarang Regency

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# Identification of Potential Ground Motion Using the HVSR Ground Shear Strain Approach in Wirogomo Area, Banyubiru Subdistrict, Semarang Regency

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**Abstract**

Wirogomo area in Semarang regency is made up of steep mountain morphology that is prone to ground motion. This motion includes rock sliding and rock fall. In 2009, there were two events of landslides. In 2010, there were four similar events, and this was also repeated in 2015 with also four events. On 6 January 2016, there were death casualties due to a landslide there, despite the installation of an Early Warning System (EWS) by Semarang regency Regional Disaster Mitigation Board (BPBD). Landslide data reveal that all parts of Wirogomo area are prone to potential ground motion, and that the spots, types, and number of installed EWS are not adequate. This is because no proper zoning and characterization of ground motion is available yet. Therefore, there needs to be an investigation as to which locations are really prone to landslide. This means determining points of potential ground motion, types of ground motion, and implementing mitigation efforts in terms of both policy and technicalities. The approach used for those purposes is Ground Shear Strain with HVSR (Horizontal to Vertical Spectrum Ratio) analysis.Ground Shear Strain calculation that identifies potential land motion in Banyubiru sub district using HVSR measurement shows that the mechanism of ground motion in Wirogomo area is caused by landslide that stems from rock fall. The highest GSS value was obtained in a zone behind SMPN 3 Banyubiru, at 0.018608.In general, it can be concluded that the most prone zone is located south of Wirogomo (7.33839ºS, 110.3819ºE). This zone is visually marked with remnants of earlier landslides. The controlling factors of ground motion in Wirogomo area include slope (geomorphology), soil condition (rocks making up the slope), and the slopes' hydrology. Mitigation efforts to reduce the risk of probable landslide effects include installation of ground motion detectors, rainfall detectors, and proper communication with the local communities.

**Keywords:** ground motion, HVSR, ground shear strain, mitigation

## INTRODUCTION

Wirogomo area in Semarang regency is part of the quarter volcano morphology in Central Java. This morphology consists of steep mountains with volcanic sediment making up its lithology. This makes this area prone to ground motion, whether it is rock sliding or rock fall. Tectonic processes taking place in Central Java are deemed to directly or indirectly responsible for this ground motion. Structures of faults in the area cause secondary structures in the form of strikes. These strikes spilt rocks and weaken inter-fraction bond. They also let rain water sips into the rocks and hence put more burdens to them. The end results are landslides on steeper slopes.

Wirogomo is now a densely populated area. Therefore, potential landslides may cause detrimental effects to the community, in terms of both material and even life. Based on the database available in Banyubiru sub district, there were two events of landslides in Kenda Duwur and Jeruk Wangi villages respectively. In 2010 there were four events of landslide in Jeruk Wangi, Pule, Wirogomo Tengah, and Wirogomo Lor, respectively. In addition, based on data from many sources, there were four events of landslide in Wirogomo Tengah, Kendal Ngisor, Nlumpak, and Sebakung villages, respectively. Other than that, on 6 January 2016, there was a landslide that cost a few lives in Kendal Ngisor village, despite the available EWS (Early Warning System) instruments set by Semarang regency Regional Disaster Mitigation Board (BPBD). Landslide data reveal that all parts of Wirogomo area are prone to potential ground motion, and that the spots, types, and number of installed EWS are not adequate. This is because no proper zoning and characterization of ground motion is available yet. Therefore, there needs to be an investigation as to which locations are really prone to landslide. This means determining points of potential ground motion, types of ground motion, and implementing mitigation efforts in terms of both policy and technicalities Based on the elaboration above, this research aims to investigate ground motion in Wirogomo area using the Ground Shear Strain approach with HVSR analysis (Horizontal to Vertical Spectrum Ratio). This will in turn be base in determining mitigation approaches. Mitigation is aimed at dealing with technicalities prior to a disaster as to prevent any possible ground motion. Involvement of community members is imperative for the proper use of suitable technology that makes the most of locally available resources. Training for emergency readiness is also necessary for the community members. A policy is also needed concerning evacuation routes, and land use at the disaster scene. These must be integrated with the other mitigation efforts, and the local government must be involved. Lastly, these measures must be carried prior to any disaster from taking place.

## GEOLOGY, MORPHOLOGY, AND CLIMATE

Geological conditions in terms of rock formation affect the bed rock and the incoming sediments. Therefore, physical properties of upper soil cannot really be separated from their underlying bed rock. Geological condition will also affect slope stability and the landslide that may take place. Geological structure determines slope properties. Formation, thickness, and position of the bed rock greatly affect stability potential. Based on a geological map of Magelang and Semarang sheet (scaled 1:100.000)issued in 1996, the research area belongs to the rock formation of Gilipetung Volcano. This formation is made of porous lava that is greyish, solid, and ranges to soft granulation with small mafic phenocryst. It also contains volcanic alteration rocks, sandy sediments, and a mixture of gravel, sand, and clay that is not really solid. These rocks easily transform into soil under the process of decay and are prone to sliding when they are located on steep slope. The soil type in the research area is of sand with little clay in it. Its thickness in some survey points range from 0-200 cm. The soil in this zone rests on a layer of volcanic rock. At 60% inclination, this soil layer is very thin.

Field observations show that the area was formed from denudation. The soil type is andosol that is grey in color with rough texture. The slopes have >40% inclination, and some even have >60% inclination. There is no fountain in the area. The rainfall is at <3000 mm/year. No slope cut off found. There are also no signs of pond and no slope drainage either. No construction work is seen, and the land is predominantly covered with bushes, shrubs, and pines.

Landslide is a result of imbalances that cause soil and rock masses to move from higher to lower ground. These imbalances are due to the existing force in an uneven land or land with slope. This force that actually holds the soil on the slope is affected by ground water surface, physical properties of the soil, and the inner angle of the shear resistance that works along the slope plane (Sutikno,1997).According toCruden(1991),landslide is the movement of a mass of rocks, soils, and materials that make up a slope down to the valley. Karnawati(2004)explains that landslides are caused by factors that trigger and control ground motion. The controlling factors include geomorphology, soil, geology, hydrogeology, and land use, whereas the triggering factors include water infiltration into the slope, vibration, human activities or disruption to the land. The natural factors causing landslides include surface morphology, land use, lithology, geological structure, rainfall, and quakes. Other than those factors, human activities also affect the landscape. This includes farming, ground loading, slope cutting, and mining.

## HVSR METHOD

Horizontal to Vertical Spectral Ratio (HVSR) is a method that calculates comparisons of recorded horizontal seismic records against their vertical counterparts. It was introduced by Nakamura (1989) to estimate resonance frequency and amplification factor of local geological conditions from micro seismic data. HVSR was later used in estimating ground susceptibility index (Nakamura, 1997), estimating constructionsusceptibility index, (Sato et al., 2004; 2008), localizing areas prone to

damages due to local effects (Panou et al., 2005; 2007), and liquefaction(HuangandTseng,2002).Researches by Arai and Tokimatsu (1998; 2005), Asten et al. (2002), Sungkono and Santosa, B.J. (2011), Warnana, (2011), Carlos, et al (2004), Maksud and Midorikawa, (2006), and Nguyen et al. (2003) using the HVSR method were able to map sediment material thickness qualitatively.
HVSR is usually used for passive seismic (micro tremor) of three components. The most important parameters HVSR yield is natural frequency and amplification.Measured HVSR of the ground is aimed at characterizing the local geology, natural frequency and amplification, and related physical underground parameters (Herak, 2008). On the other hand, measuredHVSR of buildings is meant to figure out a building's strength and balance(Nakamura, 2000 and Nakamura et al.,2000). HVSR analysis results in values of maximum ground movement speed, susceptibility index, and ground shear strain. Soil layer characteristics greatly influence susceptibility index and ground acceleration at certain spots. Susceptibility index in an index that describes ground surface susceptibility rate against deformation. Knowing the maximum ground vibration acceleration and seismic susceptibility index can help analyze the ground shear strain or soil layer's ability to stretch and shift upon receiving elastic wave propagation. Micro zonation of ground shear strain helps map areas to look out for and figure spots of highest potential ground movement probability.

## MEASUREMENT POINTS

Based on visual observation, information from local people, and geological survey conducted, this research is focused on a cliff in the landslide zone located behind SMPN 3 Banyubiru to the North.HVSR measurement points are given in Table 1. Visual observation along this measurement line indicate landslide remnants at point Wiro I, at 7.33864º S and 110.3818º E with 1225 m elevation, next to point W7, as depicted in Figure 1. As the slope is very steep, measurements are made along the path people use to collect fire wood and feeding grass.

**Table1.** HVSR measurement points.

| Point | Latitude (º S) | Longitude (º E) | Elevation (m) |
|---|---|---|---|
| **W1** | -7.34079 | 110.3834 | 943 |
| **W2** | -7.34023 | 110.3834 | 1062 |
| **W3** | -7.33973 | 110.3833 | 1087 |
| **W4** | -7.33995 | 110.3831 | 1129 |
| **W5** | -7.33909 | 110.3824 | 1152 |
| **W6** | -7.3398 | 110.382 | 1220 |
| **W7** | -7.33839 | 110.3819 | 1231 |
| **W8** | -7.33705 | 110.3816 | 1296 |
| **W9** | -7.33688 | 110.381 | 1383 |
| **W10** | -7.33663 | 110.3804 | 1396 |

**Figure 1.** Observed signs of earlier landslides behind SMPN 3 Banyubiru, at 7.33864$^o$ S and 110.3818$^o$ E with 1,225 m elevation.

## HVSR MEASUREMENT RESULTS

Results of HVSR measurements are given in Table 2. Illustration of HVSR frequency values from measurement points along observation line are given in Figure 2. Meanwhile, Graph of frequency profiles against distance of measurement line is shown in Figure 3.

**Table 2.**Results of HVSR measurement.

| Point | Frequency (Hz) | Period (s) | Amplitude |
|---|---|---|---|
| **W1** | 1.1 | 0.91 | 2.16 |
| **W2** | 0.64 | 1.56 | 1.98 |
| **W3** | 13.35 | 0.07 | 2.45 |
| **W4** | 4.57 | 0.22 | 4.36 |
| **W5** | 9.03 | 0.11 | 3.91 |
| **W6** | 11 | 0.09 | 2.01 |
| **W7** | 13.05 | 0.08 | 1.28 |
| **W8** | 12.04 | 0.08 | 2.44 |
| **W9** | 3.04 | 0.33 | 0.96 |
| **W10** | 6.94 | 0.14 | 1.7 |

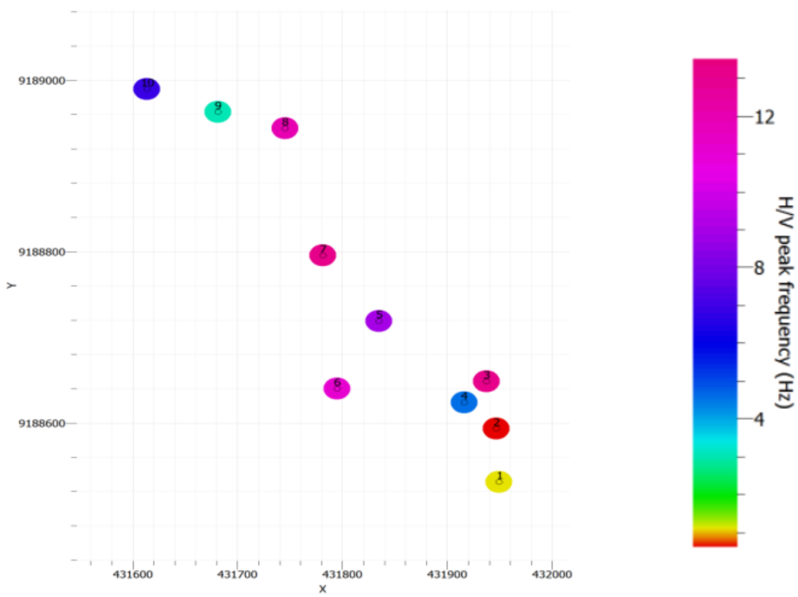


**Figure 2** Values of HVSR frequency at measurement points in UTM coordinate

It can be seen in Table 2 and Figure 2 that HVSR frequency distribution along measurement line, which is points from W1 through W4 to the South, and points W8 to W9 to the North, is lower compared to frequency value at the center of the measurement line. These frequency values show specific site frequency values that will resonate and have maximum superposition when there are sources of waves with the same frequency. The southern part of the measurement line is prone to landslide that may be triggered by a quake wave as the characteristic natural waves are low in frequency.

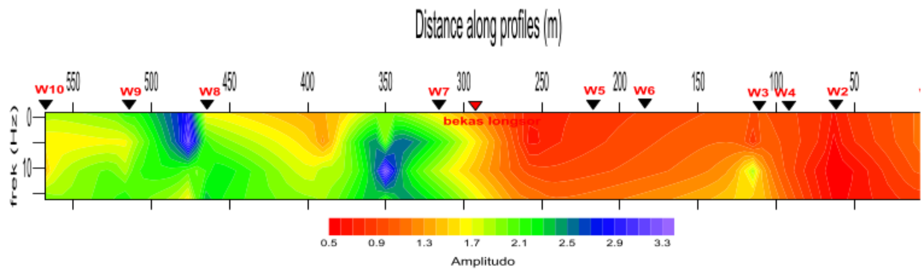


**Figure 3** Graph of frequency profile against measurement distance. Black triangles with W on top of them indicate measurement points

Values of HVSR amplitude describe ground amplification due to vibration sources with certain frequencies. The greater the amplitude, the higher the sediment on top of the bed rock is.In can be seen in Figure 3 that points from W1 through W7 have the highest potential for rock fall the ground amplification is lower than that of points from W7 to W9. Observations of previous landslides show that the landslides here are of rock fall type.

**Table 3** Results of ground shear strain calculation.

| Point | $Vs_{30}$ (m/s) | H (m) | $V_b$ (m/s) | Kg (cm/s) | α (gal) | *Ground shear strain* |
|---|---|---|---|---|---|---|
| **W1** | 754 | 171.4 | 1628.6 | 0.000264 | 58.62213 | 0.015484 |
| **W2** | 754 | 294.5 | 1492.9 | 0.000416 | 44.71365 | 0.018608 |
| **W3** | 754 | 14.1 | 1847.3 | 2.47E-05 | 204.2103 | 0.005041 |
| **W4** | 754 | 41.2 | 3287.4 | 0.000128 | 119.4817 | 0.015333 |
| **W5** | 753 | 20.8 | 2944.2 | 5.83E-05 | 167.9446 | 0.009795 |
| **W6** | 751 | 17.1 | 1509.5 | 2.47E-05 | 185.3696 | 0.004574 |
| **W7** | 752 | 14.4 | 962.6 | 1.32E-05 | 201.8878 | 0.002671 |
| **W8** | 751 | 15.6 | 1832.4 | 2.74E-05 | 193.9023 | 0.005307 |
| **W9** | 750 | 61.7 | 720.0 | 4.27E-05 | 97.43237 | 0.004161 |
| **W10** | 749 | 27.0 | 1273.3 | 3.32E-05 | 147.2113 | 0.004883 |

## GROUND SHEAR STRAIN

Calculation of ground shear strain of the research area was carried out with the help of data from Yogyakarta May 27, 2006 quake epicenter. It was located at 110.32° E and 8.03° S, at 11.3 km deep, with a magnitude of 5.9 Mb. The results are shown in Table 3. Ground shear strain distribution of research area and the corresponding value profile from points W10 to W1are given in Figure 4. The highest values are observed in points from W1 to W2 located behind SMPN 3 Banyubiru. Therefore, it can be inferred that the landslide danger zone is just South of W7 (7.33839°S and 110.3819°E). There are also remnants of previous landslides at this site.

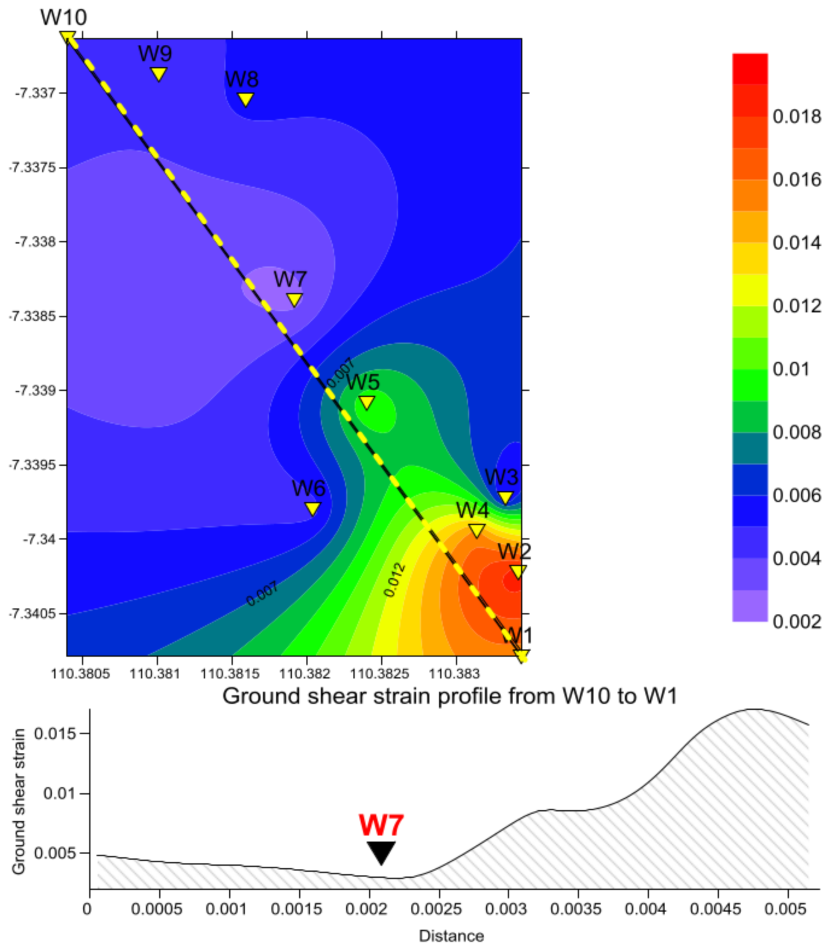


**Figure 4.**Ground shear strain distribution along a measurement line (above) andthe ground shear strain profile from points W10 to W1 (below). The zone South of W7 has high ground shear strain value.

## CONCLUSION

Ground shear strain calculation to identify potential landslide zones in Banyubiru sub district using HVSR measurementlead to the following conclusion:

1. The mechanism of ground motion that may lead to landslide in Wirogomo area is of rock fall type.
2. The highest value of ground shear strain was observed in a zone behind SMPN 3 Banyubiru, at0.018608.

3. It is inferred that the most susceptible zone for landslide is located south of point W7 (7.33839ºS and 110.3819ºE). This is elaborated with visually observed remnants of past landslides.
4. Controlling factors that affect ground motion in Wirogomo area include land inclination or slope (geomorphology), soil condition or rock make up, and hydrology of the slope.

Therefore, mitigation efforts to prevent damages should include installment of early detection systems, installment of rainfall measuring devices, and proper socialization for the local community.

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