ARPN Journal of Engineering and Applied Sciences

LANDSLIDE DELINEATION USING SHEAR WAVE VELOCITY, POISSON'S RATIO, AND GSS PARAMETER ANALYSIS FOR THE CASE STUDY OF THE NGASINAN LANDSLIDE, BANYUMANIK, SEMARANG INDONESIA

Nurwidyanto M. I.[1] and Yuliyanto G.[2]
[1]Geophysics Laboratory Department of Physics, Faculty of Science and Mathematics, Diponegoro University, Indonesia
[2]Research Cluster for Geothermal, Faculty of Science and Mathematics, Diponegoro University, Indonesia
E-Mail: gatoty@fisika.fsm.undip.ac.id

ABSTRACT

In this study, ground motion delineation was carried out using shear wave velocity (vs) analysis, Poisson's ratio, and Ground Shear Strain (GSS). This data was obtained from inversion of micro tremor data which produces compression wave velocity and shear wave velocity. The results of the inversion are then carried out in 2D modeling so that the values of the landslide area can be compared with the values of the surrounding area. The landslide area in the Ngasinan area has a shear wave velocity value of less than 750 m/s, a Poisson's ratio value of 0.3, and an iso value of shear wave velocity that reaches a length of 50 m to the west. Based on the analysis, it was found that there was a possibility of increasing landslide area from this point, namely towards the north, namely towards the river at the bottom of the basin, and towards the west as high as 120 m.

Keywords: Poisson ratio, Vs, GSS, landslide, HVSR, micro tremor.

Manuscript Received 23 January 2024; Revised 19 April 2024; Published 30 May 2024

INTRODUCTION

Common geophysical methods for landslide studies include geoelectric methods and refraction methods. Surveys using the geoelectric method are carried out by spreading current and voltage cables to get an idea of the resistivity or electrical conductivity values below the surface, while surveys using the seismic refraction method are carried out by spreading geophone cables to get an idea of the speed of seismic waves propagating in the subsurface layer (Reynolds, 2011). Because they use a stretch of cable, both of these methods have problems with the topography of the terrain, the presence of rivers or cliffs that cross the stretch, and the risk of stretching the cable when passing through roads which determine the length of the cable strain which then influences the depth of penetration of the observed physical parameters. These constraints will also affect the ability of geophysical methods to delineate the boundaries of affected areas, which will then influence the mitigation that will be carried out in areas affected by landslides.

One geophysical method that has developed rapidly in recent years is the micro tremor method (Nakamura, 2000). This method offers convenience in tool mobility and data acquisition because the tool dimensions are quite compact and light and do not require long cables, so terrain obstacles can be relatively overcome and data acquisition can be done more quickly. One of the micro tremor methods is the single station method which is better known as the HVSR (Horizontal to Vertical Spectral Ratio) method and from this micro tremor method, an HVSR curve is obtained at each measurement point (Nurwidyanto *et al*, 2021). From the inversion of the HVSR curve obtained, the values for compression wave velocity and shear wave layer velocity with a certain layer thickness below the surface will be obtained (Yuliyanto and Nurwidyanto, 2021). Comparison of the values of compression wave velocity and shear wave layer velocity at a certain layer depth will produce a Poisson's ratio value at a certain layer depth (Arintalova *et al*, 2020). By entering the amplification parameters and dominant frequency of the HVSR curve combined with earthquake parameters such as epicentral distance, depth, magnitude, and speed of shear waves in the bedrock, the Ground Shear Strain (GSS) value can be obtained, namely the parameter of the soil layer's ability to stretch or shift, when there is an elastic wave vibration that passes through it (Nurwidyanto *et al*, 2021; Yulianto *et al*, 2021) of the soil is included in the collapsed category. These three categories are given in Table-1.

ARPN Journal of Engineering and Applied Sciences

Table-1. Relationship of strain with the dynamic nature of soil (Nakamura 1997).

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

Sunday 28 June 2020 at around 22.00 WIB a landslide occurred in Ngasinan, Srondol Kulon Village, Banyumanik District due to moving ground conditions. This incident was related to a road collapse that occurred about a month earlier, namely a landslide on residential land located northeast of the landslide location due to ground movement in the area. The landslide caused 50 meters of roads connecting residents to be damaged. As mitigation, the City Government installed gabions at the base of the landslide with a length of around 45 meters and a height of 3 meters. This research aims to determine landslide delineation using shear wave velocity, Poisson's ratio, and GSS parameter analysis in the Ngasinan area.

Figure-1. A 50-meter long avalanche cut off the residents' roads. To prevent the spread of landslides, tarpaulin closures, and bamboo taluds are made at the bottom of the landslide.

Horizontal to Vertical Spectral Ratio (HVSR) method or what is known as the single-station microtremor or passive seismic method, is a method that calculates the comparison of horizontal component seismic recording data with its vertical components. This method was introduced by Nakamura (1989) to estimate the resonant frequency and local geological amplification factors from micro seismic data. The use of this method then developed a lot in geotechnical and the environment with early publications

VOL. 19, NO. 7, APRIL 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

on the estimation of soil vulnerability index (Nakamura, 1997), then developed for estimation of building vulnerability index (Sato et 2004, 2008), estimation of vulnerable areas building damage due to local effects (Panou *et al*, 2005; Panou *et al*, 2007), local geological characterization, natural frequency and amplification related to physical subsurface parameters (Herak, 2008), and until now there have been many applications of this method such as identification of landslide zones (Sasongko *et al*, 2020; Yuliyanto *et al*, 2016, 2017, 2018, 2020, Afriyanti *et al*, 2020), vibration vulnerability identification (Sasongko *et al*, 2019), and identification of ground layer structures of land subsidence sensitive areas (Widada *et al*, 2019).

From micro tremor data inversion, one of the elastic parameters of the rock can be extracted is the Poisson's Ratio (σ), which is the ratio of transversal strains or contractions to longitudinal strains or extensions resulting from changes in normal stress due to compression or dilation. In the form of the ratio of the velocity of the longitudinal wave v_p to the shear wave v_s, the Poisson's ratio can be written as (Lay and Wallace, 1995):

$$\sigma = \frac{v_p^2 - 2v_s^2}{2(v_p^2 - v_s^2)} \tag{1}$$

In general, the elastic parameters of rocks largely depend on their lithological properties, one of which is water saturation. In a fluid medium that has zero rigidity, there is no shear wave that propagates, and the magnitude σ in the fluid is 0.5 (Sharma *et al*, 1990; Davidovici, 1985). The porous sediment liquid saturation causes an increase in P-wave velocity which results in the value σ will increase. It is generally known that seismic wave propagation from unsaturated sediments to saturated sediments will increase the P-wave velocity and consequently, the Poisson ratio tends to increase in magnitude. At constant pressure, σ increases with increasing water saturation and with increasing porosity.

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 (Nakamura, 1997)

$$\gamma = (K_g \alpha_g) \tag{2}$$

where $K_g = \frac{A_g}{\pi^2 v_s f_0}$ 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:

$$\alpha_g = \frac{5}{\sqrt{T_0}} 10^{\left(0{,}61M - \left(1{,}66 + \frac{3{,}66}{R}\right) \log R + 0{,}167 - \frac{1{,}83}{R}\right)} \tag{3}$$

where T_g is the predominant period of soil observation point (s), M is the Moment Magnitude, R is the epicenter distance (km), and α_0 is the ground acceleration on base rock (gal). GSS parameters obtained from micro tremor 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 are divided into three categories. First, 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. Second, if the strain value ranges from 10^{-5} to 10^{-3} then the phenomenon that will occur is cracking and soil subsidence. The dynamic nature of the soil is included in the category of elastic plastic. Third, if the strain value ranges from 10^{-3} to 10^{-1} then the phenomenon that will occur is landslides, land subsidence, and liquefaction. The dynamic nature

METHODS

In this study, data acquisition was carried out at 29 measurement points with the duration of data acquisition at each measurement point being 20 minutes. Data acquisition was carried out using 2 portable seismometers using a VHL PS 2B triaxial geophone sensor and a GL 240 data logger with a sampling of 50 ms (Yulianto and Yuliyanto, 2023; Yuliyanto and Nurwidyanto, 2023). By using geopsy software, the data in the time domain is processed, and HVSR curves are generated with information on the magnitude of the amplification value and the dominant frequency (Harmoko *et al.*, 2021). Then using the Dinver software the data is inverted and the data of compression wave velocity and shear wave velocity are obtained. Using Excel software, the Poisson's ratio value for a certain thickness or depth is calculated (Arintalova *et al*, 2021), and also the GSS value on the surface. Then using the Surfer software, contours of the shear wave velocity on the surface, Poisson ratio on the surface, Ground Shear Strain on the surface, as well as profiles of shear wave velocity and Poisson ratio for certain measurement paths are made.

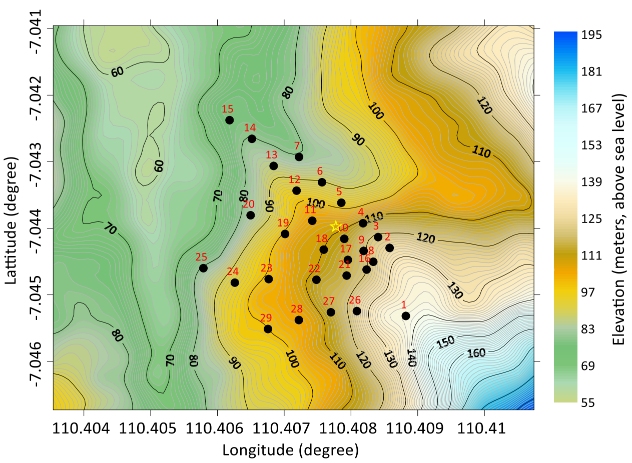

Figure-2. Locations and research points. The yellow asterisk indicates the location of the avalanche.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

RESULTS AND DISCUSSIONS

The vs or shear wave velocity contour of the study area is given in Figure-3, the Poisson ratio is given in Figure-4 and the Ground Shear Strain is given in Figure-5. The shear wave velocity in the soil layer in the landslide area is about 750 m/s, in the site classification in SNI 1726 including the lower limit of the rock layer value while the landslide extends downward from point 10 to point 11 along 50 meters moving towards point 5 has a value of vs which is smaller than 750 m/s which in SNI 1726 includes sites of hard soil, very dense and soft rock.

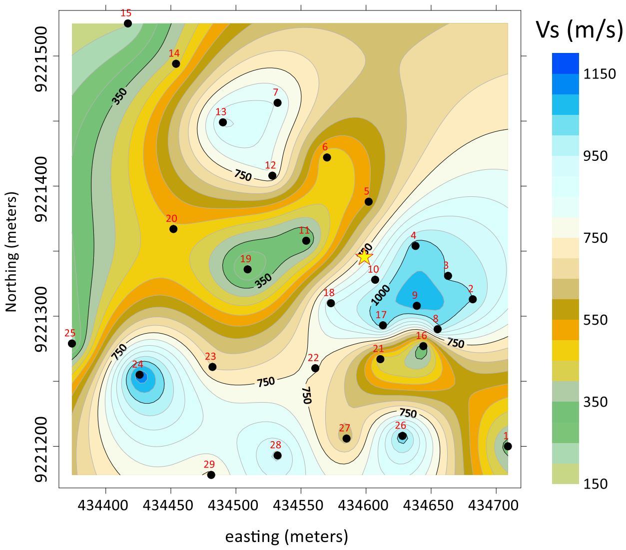

Figure-3. The shear wave velocity contour of the study area. The yellow asterisk indicates the location of the landslide.

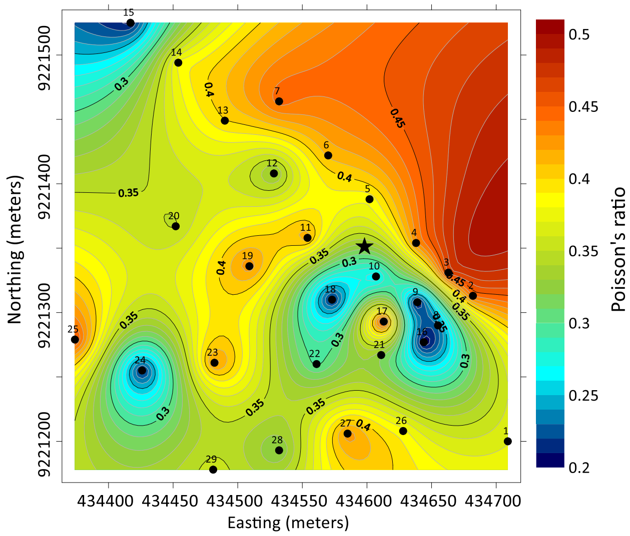

Figure-4. Poisson's ratio contour of the research area. The black asterisk indicates the location of the landslide.

Based on Figure-4, it can be seen that the Poisson ratio of the research area has a very high value in the north of the path from point 7 to point 2. Conditions in the field and based on Figure-2 show that the area is a small river in the basin.

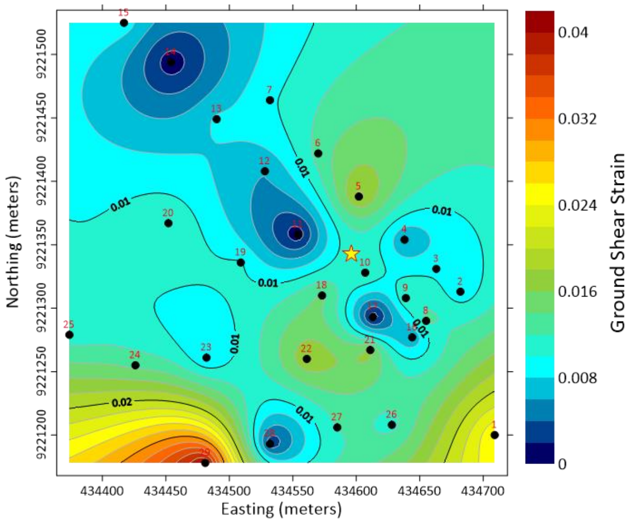

Figure-5. The contour of the Ground Shear Strain of the study area. The yellow asterisk indicates the location of the landslide.

The contour of the ground shear strain or GSS of the study area as shown The contour of the ground shear strain or GSS of the study area as shown in Figure-5, the avalanche point has a GSS value of 1.1×10^{-2} according to Table-1 The size of the strain has a landslide phenomenon and its dynamic nature is Repeat-Effect or Speed-Effect of Loading, so it needs to be watched out for.

To identify ground motion vertically, vs profiles are made for the path of point 7 to point 2 the path of point 15 to point 8 which is given in Figure-6, and the path of point 20 to point 4, and the path of point 5 to point 26 in

VOL. 19, NO. 7, APRIL 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

Figure-7. Based on Figure-6 shows the iso value of the shear wave velocity from the landslide point to the east of point 12 with a distance of about 50 m. The same things can be seen in the Poisson ratio profile. The possibility of landslides in other locations in the study area is east of point 14.

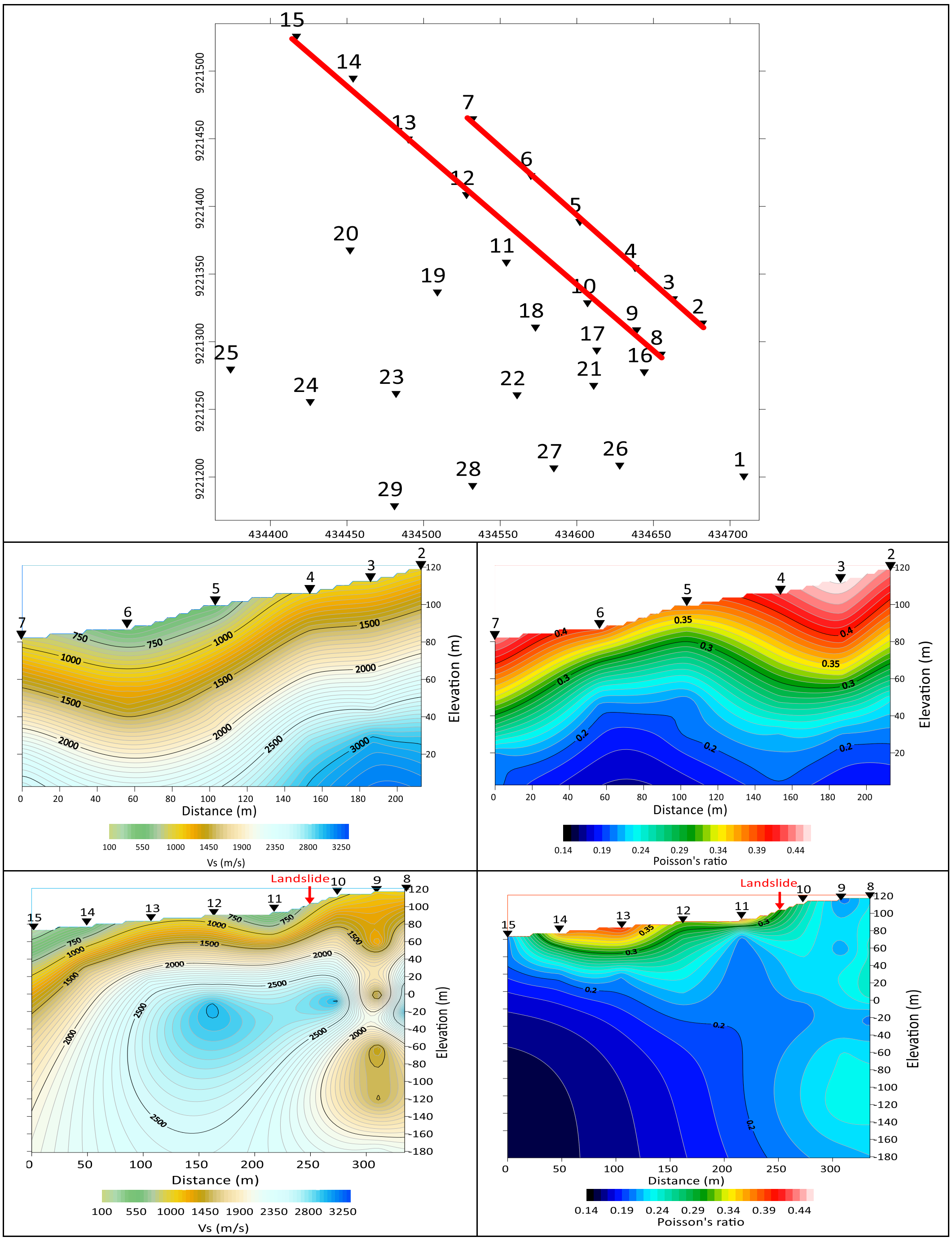

Figure-6. Measuring path of point 7 to point 2 and point 15 to point 8 (top), shear wave velocity profile (vs) and Poisson ratio profile for measurement path point 7 to point 2 (middle), and shear wave velocity profile (vs) and Poisson ratio profiles for the 15 to 8 point measurement path (bottom). The avalanche point is located between point 11 and point 10.

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

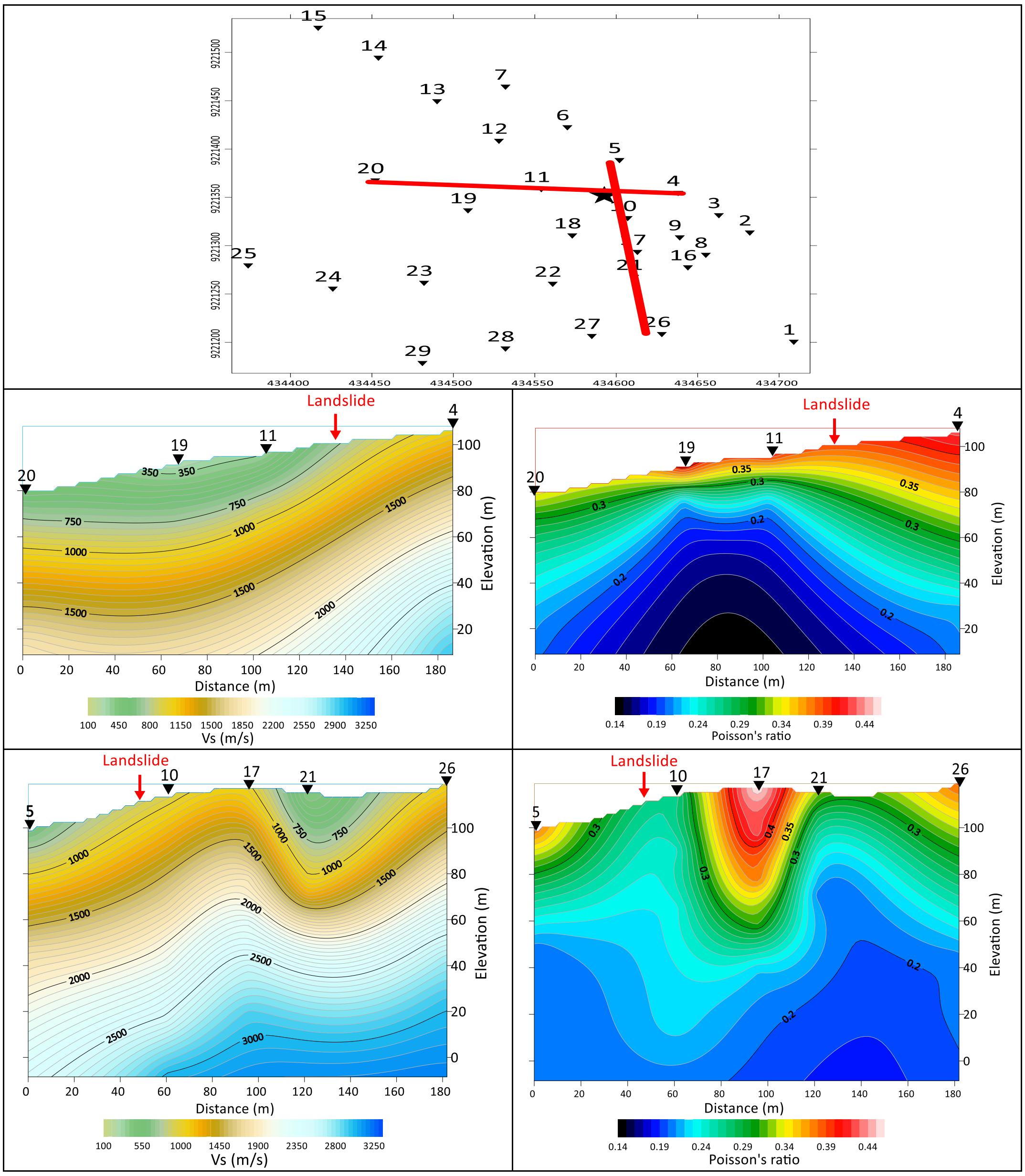

Figure-7. The measurement path of point 20 to point 4 and point 5 to point 26 (top), shear wave velocity profile (vs), and Poisson ratio profile for the measurement path of point 20 to point 4. The avalanche point is located between point 11 and point 4 (center), and the shear wave velocity profile (vs) and the Poisson ratio profile for the measurement path of point 5 to point 26. The avalanche point is located between point 5 and point 10 but closer to point 10 (bottom).

Based on the vs profile and the Poisson ratio profile shown in Figure-7, there is a possibility of landslides or landslides from the landslide location point to point 20 with a length of soil movement reaching 120 m while from point 10 to point 5 the possibility of landslides is relatively much smaller.

CONCLUSIONS

Based on the micro tremor survey using the single station method in the study area of the landslide area of Ngasinan, Srondol Kulon, Banyumanik, Semarang, it can be concluded that the landslide area in the Ngasinan area has a shear wave velocity value of less than 750 m/s, a Poisson's ratio value of 0.3, and an iso value of shear wave velocity that reaches a length of 50 m to the west. Based on the analysis, it was found that there was a possibility of increasing landslide area from this point, namely towards the north, namely towards the river at the bottom of the basin, and towards the west as high as 120 m.

REFERENCES

Afriyanti N., Yuliyanto G., and Irham M. N. 2020. Identification of landslides around Old Gombel in

Tinjomoyo Village Semarang using HVSR method. International Journal of Recent Trends in Engineering & Research (IJRTER). 06, 03, 38-46.

Arintalofa V., Yuliyanto G., Harmoko U. 2020. Subsurface characterization of Diwak Derekan geothermal field by HVSR analysis method based on microtremor data. AIP Conference Proceedings, 2296, 020057, https://doi.org/10.1063/5.0030356.

Davidovici V. 1985. Génie parasismique, École Nationale des Ponts et Chaussées, Paris, 1105.

Harmoko U., Gernowo R., Yuliyanto G. 2021. Determining the Hydrothermal Flow Media Using Seismicity Properties in Kaliulo Geothermal Field, Semarang, Central Java, Indonesia. Journal of Physics: Conference Series, 1943, 012031, doi:10.1088/1742-6596/1943/1/012031.

Herak M. 2008. Model HVSR: A Matlab tool to model the horizontal-to-vertical spectral ratio of ambient noise. Computers and Geosciences. 34, 1514-1526.

Lay T. and Wallace T. C. 1995. Modern Global Seismology. Academic Press, California, United States.

Nakamura Y. 1989. A Method for Dynamic Characteristics Estimations of Subsurface Using Microtremors on the Ground Surface. QR RTRI. 30, 25-33.

Nakamura Y. 1997. Seismic Vulnerability Indices for Ground and Structures Using Microtremor. World Congress on Railway Research, Florence, Nov.

Nakamura Y. 2000. Clear Identification of Fundamental Idea of Nakamura's Technique and Its Applications, System and Data Research Co. Ltd., 3-25-3.

Nurwidyanto M. I., Zainuri M., Yuliyanto G. and Wirasatriya A. 2021. Measurement of the ground response of Semarang coastal region risk of earthquakes by Horizontal to Vertical Spectral Ratio (HVSR) microtremor method. Journal of Physics: Conference Series, 1943, 012033, doi:10.1088/1742-6596/1943/1/012033.

Nurwidyanto M. I., Yulianto T., Yuliyanto G. and Widada S. 2021. Estimation of landslide prone zones around the Semarang Fault based on combining the slope stability analysis and HVSR microtremor methods. Journal of Physics: Conference Series, 1943, 012032, doi:10.1088/1742-6596/1943/1/012032.

Panou A. A., Theodulidis N., Hatzidimitriou P., Stylianidis K., Papazachos C. B. 2005. Ambient noise horizontal-to-vertical spectral ratio in site effects estimation and correlation with seismic damage distribution in an urban environment: the case of the city of Thessaloniki (Northern Greece). Soil Dynamics and Earthquake Engineering. 25, 261-274.

Panou A. A. 2007. Use of Ambient Noise for Microzonation Studies in Urban Environment: The City of Thessa Loniki (N. Greece). 4th International Conference on Earthquake Geotechnical Engineering. 25-28, 1580.

Reynolds J. M. 2011. An Introduction to Applied and Environmental Geophysics, edisi 2, Wiley-Blackwell, Oxford.

SNI 1726. 2019. Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung Dan Nongedung Sebagai Revisi Dari Standar Nasional Indonesia 1726: 2012 Tata Cara Perencanaan Ketahanan Gempa Untuk Struktur Bangunan Gedung Dan Nongedung, Badan Standarisasi Nasional, Jakarta.

Sasongko D. P., Yuliyanto G., and Arifin Z. 2019. Vibration Vulnerability Identification in Kota Lama Semarang using Microtremor Method. Indonesian Journal of Applied Physics. 9, 2, 105-111

Sasongko D. P., Yuliyanto G., and Arifin Z. 2020. Karakterisasi Daerah Rawan Gerakan Tanah di Lapangan Pandanmurti Desa Candigaron Kecamatan Sumowono .Kabupaten Semarang dengan Metode Mikrotremor. Jurnal Pembangunan Wilayah dan Kota. 16, 2.

Sato T., Nakamura Y., and Saita J. 2004. Evaluation of the Amplification Characteristics of Subsurface Using Microtremor and Strong Motion: The Studies at Mexico City. 13th World Conference on Earthquake Engineering, 862, Vancouver, B.C., Canada.

Sato T., Nakamura Y., and Saita J. 2008: The Change of the Dynamic Characteristics Using Microtremor. The 14th World Conference on Earthquake Engineering October 12-17, Beijing, China.

Sharma, H. D., Dukes M. T. and Olsen D. M. 1990. Field Measurement of Dynamic Moduli and Poisson's Ratios of Refuse and Underlying Soils at a Landfill Site. In: Landva, A. and Knowles, G. D., Eds., Geotechnics of Waste Landfills: Theory and Practice, American Society for Testing and Materials, Philadelphia, 57-70.

Widada S., Zainuri M., Yuliyanto G., Yulianto T. and Deny N. S. 2019. Identification Ground Layer Structure of Land Subsidence Sensitive Area in Semarang City with Horizontal to Vertical Spectral Ratio Method. IOP Conf. Series: Earth and Environmental Science. 246 - 012023.

Yulianto T., Sasongko D. P., Yuliyanto G., Indriana R. D., Setyawan A., Widada S. 2021: Correlation of Vp/Vs ratio against the resistivity value to determine the aquifers presence estimation in jetak subvillage, getasan sub-district, Semarang regency. Journal of Physics: Conference Series, 1943, 012028, doi:10.1088/1742-6596/1943/1/012028

Yulianto T., Yuliyanto G. 2023: Microtremor Data and HVSR Method in the Kaligarang Fault Zone Semarang, Indonesia. Data in Brief, 49, 109428, https://doi.org/10.1016/j.dib.2023.109428.

Yuliyanto G., Harmoko U., and Widada S. 2016: Identification of Potential Ground Motion Using the HVSR Ground Shear Strain Approach in Wirogomo Area, Banyubiru Subdistrict, Semarang Regency. International Journal of Applied Environmental Sciences. 11, 6, 1497-1507

Yuliyanto G., Harmoko U. and Widada S. 2017: Identify the Slip Surface of Land Slide in Wirogomo Banyubiru Semarang Regency Using HVSR Method. International Journal of Applied Environmental Sciences. 12, 12, 2069-2078

Yuliyanto G., Harmoko U. and Rina D. I. 2018: Identification of Landslide Area in Jabungan Village, Banyumanik, Semarang by Using Microtremor Method. International Journal of Recent Trends in Engineering & Research (IJRTER). 06, 03, 38-46.

Yuliyanto G., Nurwidyanto M. I. 2021: Analysis of landslide in Bungkah, Sepakung, Banyubiru using ground shear strain method and shear wave profile from HVSR method. Journal of Physics: Conference Series, 1943, 012027, doi:10.1088/1742-6596/1943/1/012027

Yuliyanto G. and Nurwidyanto M. I. 2023: Characteristics of Karst Caves Inferred from Microtremor Studies: A case study from Cerme Cave, Yogyakarta, Indonesia. Acta Carsologica, 52, 1, https://doi.org/10.3986/ac.v52i1.10987.