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Identification of Ground Vulnerability Based on Kg, PGA, and GSS Assessment by Single Station Microtremor in Bendosari Hamlet, Kalasan Village, Yogyakarta

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ABSTRACT

Bendosari Hamlet, Kalasan, Yogyakarta is a research area that is one of the areas affected by the earthquake that occurred on May 27, 2006. The earthquake with a magnitude of 6.4 caused quite severe damage to buildings around the research area. Based on the phenomenon of earthquakes that have occurred, there needs to be further study related to vulnerable areas in the event of another earthquake. Research data is primary data taken using a single statiun microtremor tool with an overall acquisition point of 50 measurement points. This study aims to find out the value of seismic vulnerability index (Kg), Peak Ground Acceleration (PGA), and Ground Shear Strain (GSS). Using the Horizontal to Vertical Spectral Ratio (HVSR) method, the dominant frequency result (f0) and amplification factor value (A0) from data that has been recorded through the microtremor tool. Based on research that has been done, the results are obtained in the f0rm of seismic vulnerability index values that are in the range of 0.49 - 30.18, the value of the acceleration of ground movement is in the range of 0.21 - 0.61 Gal, and the ground shear strain value is in the range of 4 x 10^{-6} to 38 x 10^{-5}. Point K26 which is the original documentation of buildings affected by the earthquake, analyzed that the value of Vs of 858.112 m / s on the vs ground profile indicates that there is hard soil at a depth after 27.2 m. This shows that the thickness of subsurface sedimentary rocks at point K26 is quite thick.

Keywords: Bendosari Hamlet; Mikrotremor; GSS; HVSR; PGA; Seismic Vulnerability

INTRODUCTION

Earthquakes are a natural and devastating reality. The damage that it causes not only destroys property but often also takes thousands of human lives, for example, the Yogyakarta earthquake that occurred on May 27, 2006, with a magnitude of 6.4. The earthquake caused a lot of loss of life and property. Based on estimates, the earthquake damaged 500,000 residences, and 6,000 lives, not to mention damage to other infrastructure such as roads, electricity networks, water, and others (Elnashai, 2006).

On May 27, 2006, an earthquake struck Yogyakarta and its surroundings, including the regencies of Bantul, Sleman, Klaten, Gunung Kidul and Kulon Progo. The USGS recorded the earthquake at 05:53:58 WIB with an epicenter position of 7.97º South latitude and 110.44º East longitude, a depth of 10 km, and a magnitude of 6.4. History records that at least four destructive earthquakes occurred in the Yogyakarta area, namely in 1867, 1943, 1981, and 2006 (Elnashai, 2006).

Daryono (2013) analyzed the seismic vulnerability index based on microtremors in each landform unit in the Graben Zone of Bantul, an area with a seismic vulnerability index of 23.21 has a residential damage ratio of 77%. Research conducted by Nugroho (2016) resulted in the maximum ground acceleration (PGA) value in Bantul Regency based on the 1981-2014 earthquake varied from 57.7 - 412.7 gal. The maximum ground acceleration zonation in Bantul Regency is divided into 3 zones, namely the first zone with an acceleration value of 57.7 - 91 gal, the second zone with an acceleration value of 92 - 179 gal and the third zone with an acceleration value of > 180 gal.

The study area is an area that has experienced an earthquake that occurred in Yogyakarta in 2006, especially in the Bendosari Hamlet area, Kalasan, Yogyakarta. Based on local community reports, the dominant buildings in the area were flattened to the ground after the earthquake hit the area. Using a single station microtremor which is hereinafter referred to as the Horizontal to Vertical Spectral Ratio (HVSR) method is one of the methods found in Geophysics, this method aims to identify the response of soil layers and subsurface rocks. Therefore, research was conducted using single station microtremor to determine the vulnerability of the research area.

MATERIALS & METHODS

The primary data used in this research is from microtremor data collected in Bendosari Hamlet, Kalasan, Yogyakarta. This area suffered an earthquake on May 27, 2006 and the majority of buildings in this area experienced mass collapse as shown in figure 1.

Figure 1. Building Collapsed Condition at Point K26

Data were collected at 50 points in this area (figure 2) using the GL 240 tool with a measurement time of 10 minutes at each point. Observation data collection using the microtremor method was carried out in December 2021. The place for collecting research data in the Bendosari Hamlet area, Kalasan, Yogyakarta. Processing of data that has been obtained and analyzing the results was carried out in January - March 2021 and carried out at the Geophysical Laboratory of Diponegoro University Semarang.

The data obtained from the microtremor tool must be converted first in .txt form through notepad software then process all the data that has been converted in .txt form using Geopsy to get the HVSR curve and continue data processing using dinver, 2D and 3D modeling using Surfer12. There are four parameters obtained after performing the inversion process through dinver, namely, depth value, Vp value, Vs value, and density at each point.

Figure 2. Single Station Microtremor Data Acquisition Survey Design

The results were frequency and amplification factor values, soil susceptibility index (Kg) values, peak ground acceleration (PGA) values, ground shear (GSS) values, and Vs750 value analysis.

RESULT

The ground layer identification when considered from the dominant frequency is the greater the frequency obtained, it means that the thickness of the surface sediment layer is very thin and dominated by hard rock (Kanai, 1983). This also means that the thicker the sedimentary layer in an area, the higher the predicted ground motion. The frequency value is the vibration produced in a certain time span can be seen in Figure 3. The range of frequency values produced ranged from 0.75 - 9.23 Hz (vibrations per second).

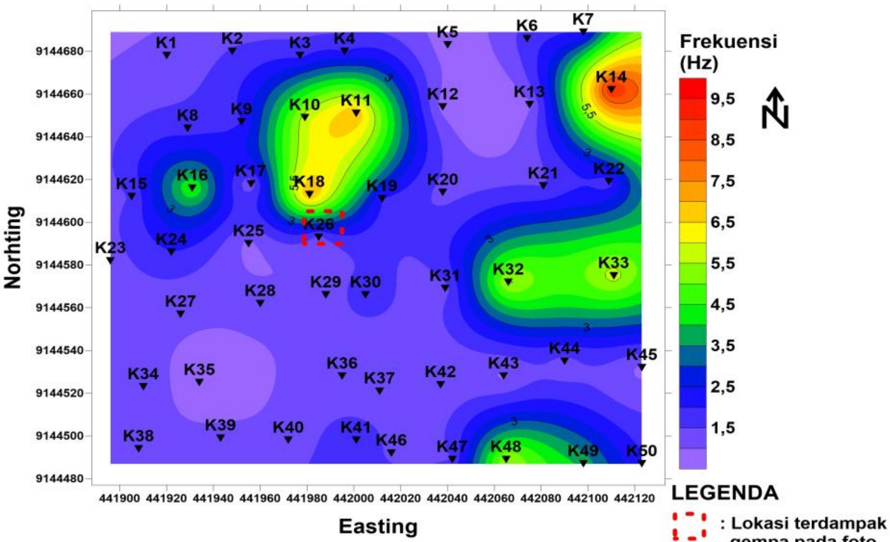

Figure 3. Contours of dominant frequency values in the study area

Based on Figure 3, the lowest dominant frequency value is 0.75 at point K5 and the highest dominant frequency value of 9.23 Hz (vibrations per second) is at point K14. In Figure 3 point K26 has a relatively low dominant frequency value of 1.33 Hz (vibrations per second) which means it shows the type IV soil classification and has a very thick sediment layer on its surface with a thickness of 10 - 30 meters.

The amplification value describes the magnitude of the strengthening of earthquake waves traveling through a particular medium. Amplification is influenced by wave velocity, so if the wave velocity is large, the amplification is also greater (Sitorus et al., 2017). The results of the subsurface amplification analysis in this study are shown in Figure 4. The amplification factor values obtained in this

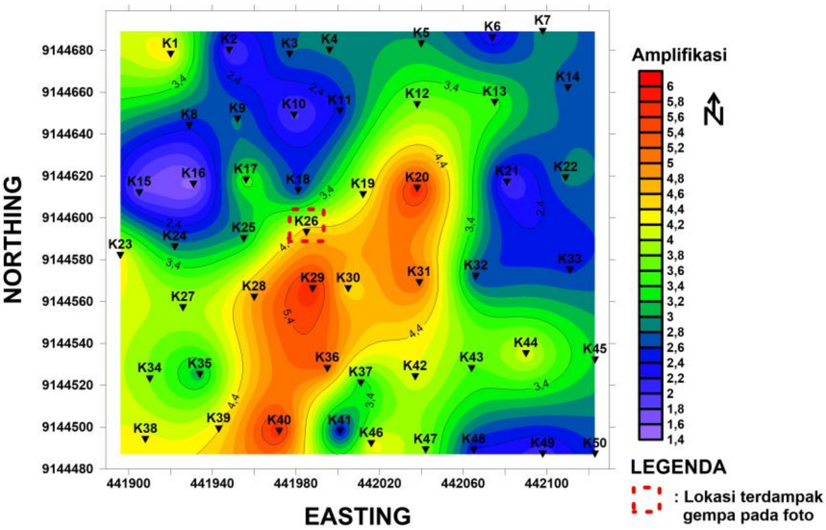

Figure 4. Contours of Amplification Factor Values in the Study Area

study were between 1.51 and 5.88. The lowest amplification value at point K16 means that it can be interpreted that the amplification factor value in the area is low, while the highest amplification factor value is at point K29, which means that the area has a medium amplification factor value. At point K26, which is clear evidence that the building is severely damaged, the amplification factor value is 4.61, which means that the amplification factor value in the area is moderate. A high amplification factor value means that it also has a thick sediment layer.

The soil susceptibility index value is obtained from the amplification factor value, frequency value, sediment layer thickness, and wave speed. It can be interpreted that the value of soil susceptibility in the research area can be a general description of the vulnerability of an area. The final results of primary data processing that has been taken from the research area; the results of the soil susceptibility index value range from 0.49 - 30.18. The classification of soil susceptibility index values according to Daryono (2009), there are three classifications: non-hazardous zones with low specifications for soil susceptibility values of Kg < 10, moderately hazardous zones with moderate categories for soil susceptibility values of 10 ≤ Kg ≤ 20, and hazardous zones with high categories for soil susceptibility index values of 20 > Kg.

The lowest soil susceptibility index value of 0.49 is at point K16. This means that referring to the classification of soil susceptibility index, it falls into the non-hazardous zone and is classified as low. Meanwhile, the highest soil susceptibility index value of 30.18 is at point K29. This means referring to the classification of soil susceptibility index into the dangerous zone and classified as high for soil susceptibility index value. Looking at Figure 5, the soil susceptibility index value at point K26 is 16.07. This implies that the soil susceptibility index value in the area is in into the medium classification and becomes a moderately hazardous zone. This is based on the presence of a fairly large river in the western part of the study area which is thought to affect the amplification and soil susceptibility index values. Seismic susceptibility values are also directly proportional to amplification. The greater the amplification value, then the value of seismic vulnerability is also the greater the strengthening of earthquake waves when passing through a certain medium so that the medium the more susceptible the medium is to shocks that can cause damage to the subsurface layer (Nakamura, 2000).

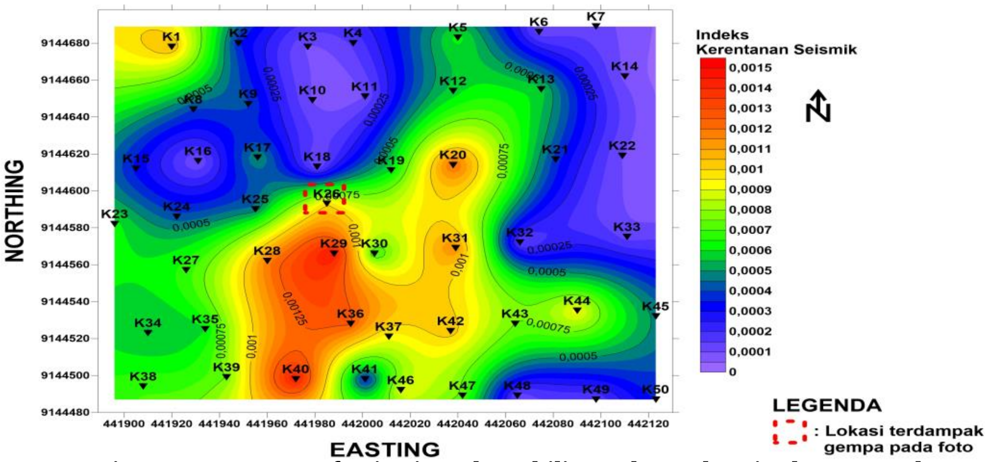

Figure 5. Contours of Seismic Vulnerability Index Values in the Research Area

The results of the calculation of peak ground acceleration (PGA) in bedrock calculated using the Nakamura formula (1997) show that during the Yogyakarta earthquake on May 27, 2006 with an earthquake magnitude of 6.4 SR with a depth of 10 kilometers in the research area, the PGA in bedrock ranged from 0.21 - 0.61 Gal. The PGA value obtained is influenced by the magnitude of the earthquake, the depth of the earthquake and the distance between the research point and the earthquake source point. The basis for obtaining the PGA value in this study is the Yogyakarta earthquake, May 27, 2006 with a magnitude of 6.4 SR and the depth of the earthquake was at 11.3 km at the coordinates 110.32 East, -8.03 LS (USGS). The results of peak ground acceleration in this study are shown in Figure 6 which can be interpreted that the lowest PGA value is at point K5 of 0.21 Gal. Classification according to USGS (2017) at point K5 is at intensity V and the highest PGA value is at point K14 of 0.61 Gal at intensity VII.

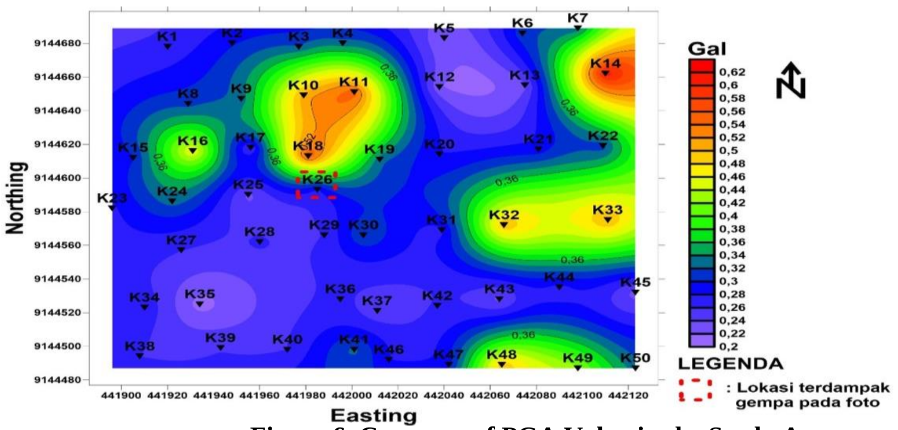

Figure 6. Contours of PGA Value in the Study Area

While the original documentation is at point K26 and has a PGA value of 0.28 Gal and is at intensity VI. It can be interpreted that the value of ground vibration acceleration is high if there is a source of vibration or an earthquake source that hits it. The result of the PGA value is directly proportional to the frequency value. The wave acceleration value is greater when the frequency value is large. This is because the frequency value easily passes through an area with a more tenuous layer compared to an area with a denser layer (Nugroho, 2016).

The magnitude of the GSS value is influenced by the value of the soil susceptibility index (Kg) and also the peak ground acceleration (PGA) value. The three factors are all directly proportional to each other, if the value of the soil susceptibility index and PGA is greater, the result of the GSS value is also greater. The identification caused by the GSS value is obtained after the calculated GSS value is correlated with the identification table and its dynamic properties. The GSS value that occurs is about 0.1 to 10^{-6}. The results of the calculations that have been carried out obtained GSS values can be seen that the value of the GSS magnitude is in the range of 4x10-6 to 38×10^{-5}. In Figure 7, it can be seen that the highest GSS value is at point K29 with a value of 38x10-5, while the lowest GSS value is at

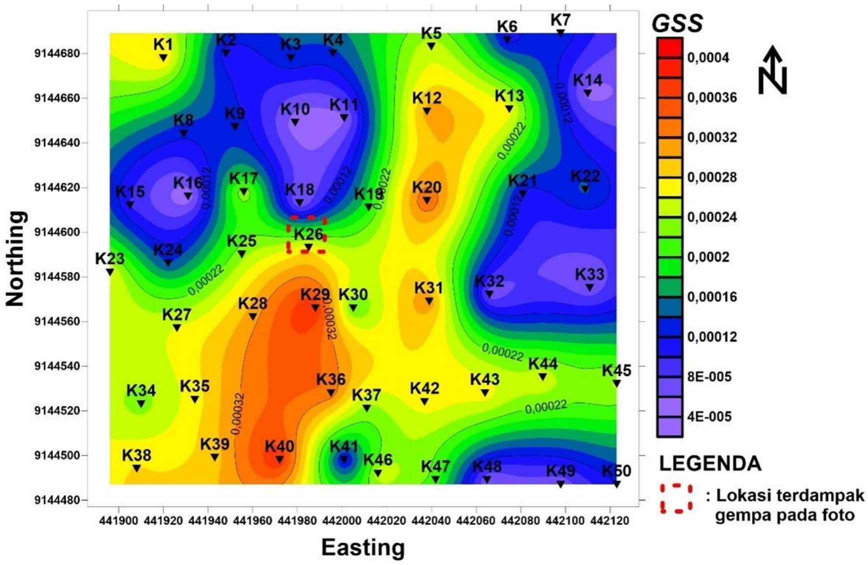

Figure 7. Contours of GSS Values in the Study Area

point K16 with a value of 4×10^{-6}. Considering that the location affected by the earthquake at point K26 has a GSS value of 28x10-5, this can be correlated with the rock lithology of the research area which can be explained that the research area is an area of volcanic deposits of young Mount Merapi. This result shows that the magnitude of GSS is strongly influenced by the level of compactness of the constituent material. Based on the geologic map of Yogyakarta, the location of this study is right to the north of the Opak fault that passes through, it can be explained that the possibility of soil fracture can also be influenced by the fault that passes through.

Ishihara (1996) states that the greater the GSS value, the more susceptible the soil layer is to landslides, fractures, and liquefaction. The smaller the GSS value, the more stable the soil condition. At strains of 10-6 and 10-5, the ground conditions experience vibrations. GSS research is effective for assessing earthquake hazards because it can determine the level of vulnerability of a land surface related to earthquakes.

The distribution of shear wave velocity (Vs) values found in each layer can be classified based on the BSNI 1726 (2019) classification and related to the analysis of the lithology of the subsurface layer can be identified with the classification according to Kaceli (2012) modeling is made from the west-east direction which is divided into 7 lines (as Figure 8a – 8g). In each layer there is a sediment layer found on the surface, this sediment layer can be identified by looking at the Vs value which is less than 750 m/s. The number of sedimentary layers found in the study area is in line with the depiction of the geological map of Yogyakarta, which can be explained that the area of the study area is in line with the geological map of Yogyakarta the study has a rock lithology code of Qmi which means there is there are volcanic deposits of young Mount Merapi. A Vs value of more than 750 m/s can be interpreted that a hard soil layer has been found in the layer.

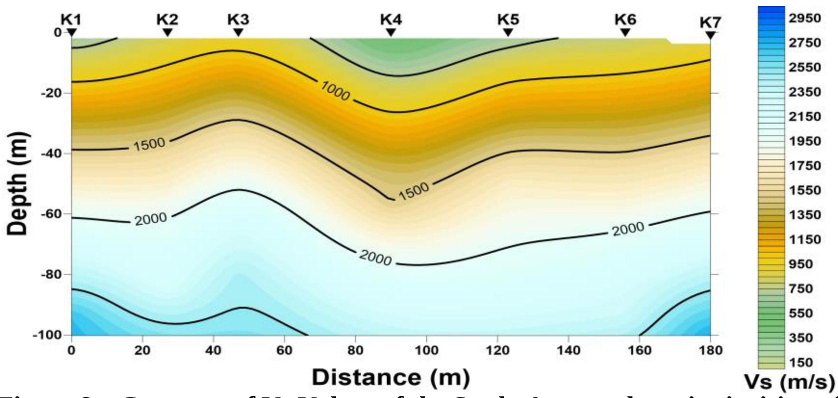

Figure 8a. Contours of Vs Values of the Study Area at the point incision of K1 - K7

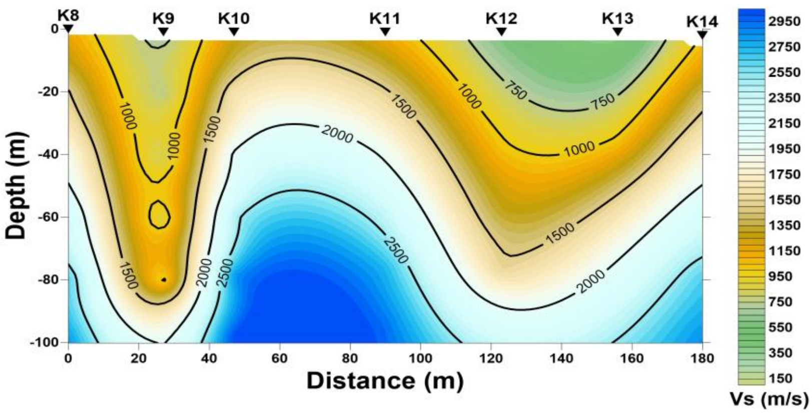

Figure 8b. Contours of Vs Values of the Study Area at the point incision of K8 – K14

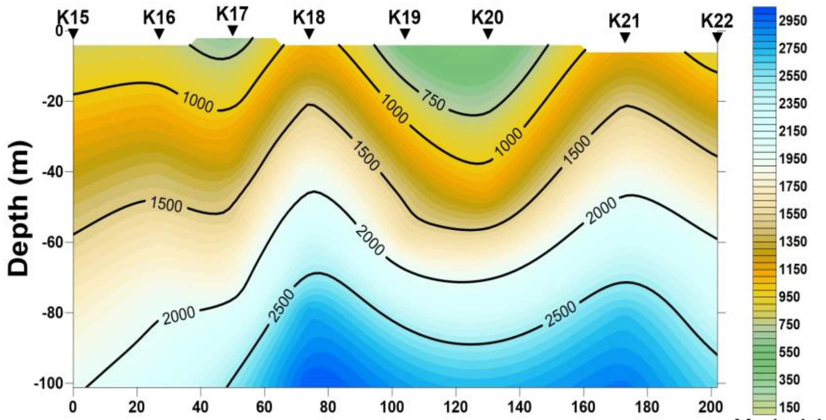

Figure 8c. Contours of Vs Values of the Study Area at the point incision of K15 – K22

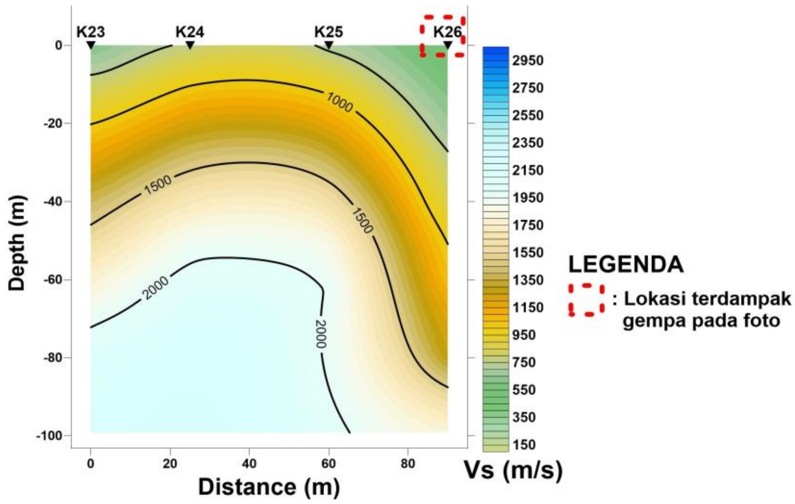

Figure 8d. Contours of Vs Values of the Study Area at the point incision of K23 – K26

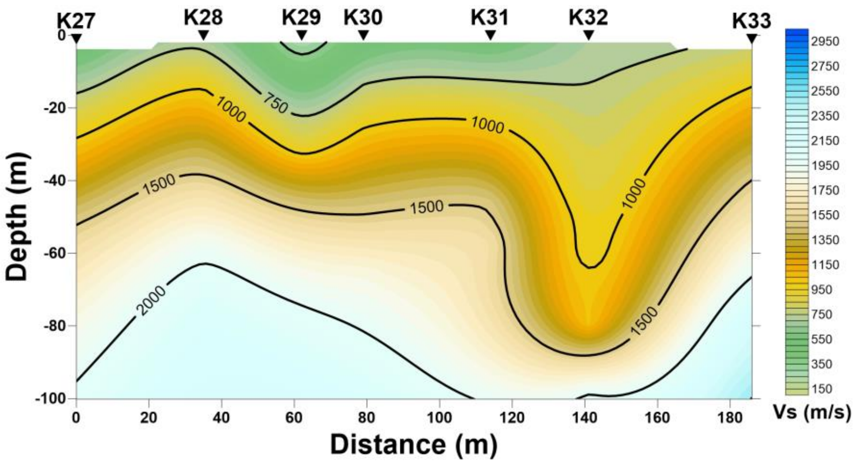

Figure 8e. Contours of Vs Values of the Study Area at the point incision of K27 – K33

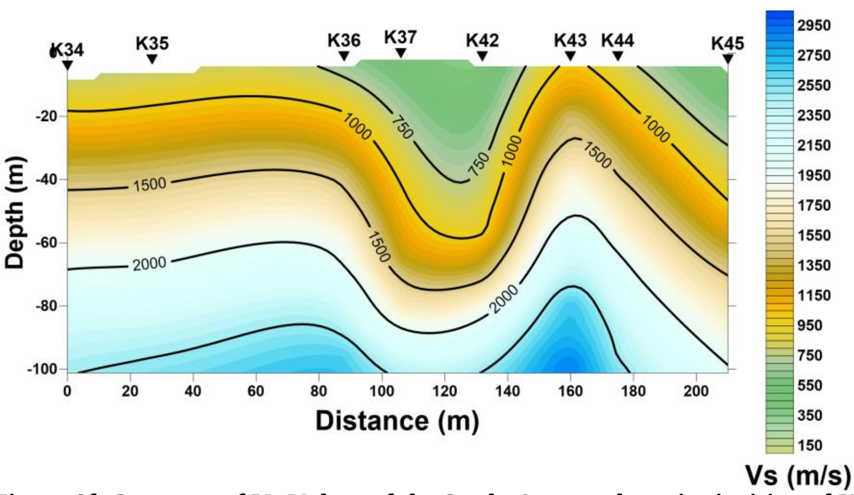

Figure 8f. Contours of Vs Values of the Study Area at the point incision of K34 – K45

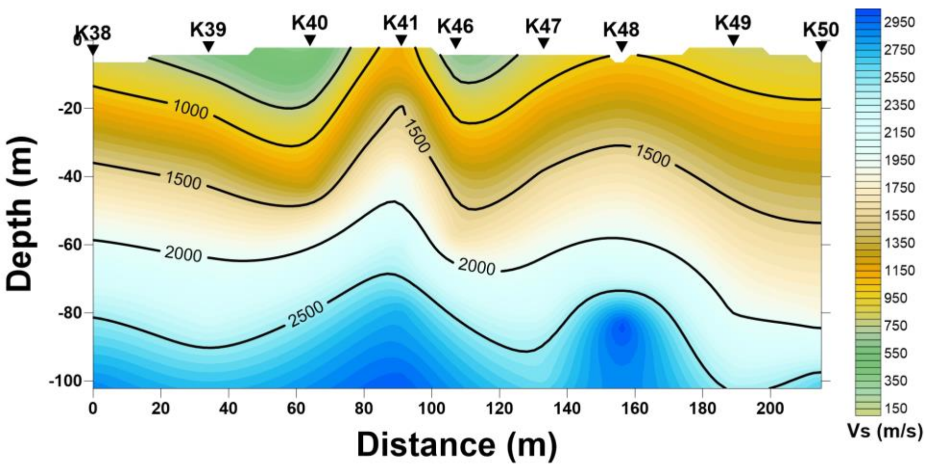

Figure 8g. Contours of Vs Values of the Study Area at the point incision of K38 – K50

The analysis of physical parameters for Vs750 is a value that can represent subsurface conditions and is also a barrier between soft rock and hard soil. According to BSNI 1726 (2019), the site classification of hard soil has a Vs > 750 value, while hard rock has a Vs > 1500 value. Subsurface conditions that have Vs < 750 have a site classification as medium soil and soft soil.

According to Kaceli (2012) the types of soil and rock in the subsurface have several classifications, for the Vs750 value is included in the stiff classification, which means that the Vs750 value is likely to have reached the bedrock below the ground surface. On Figure 9 it can be seen that the Vs750 value in the research area is at a depth between 0 - 36.53 meters below the ground surface.

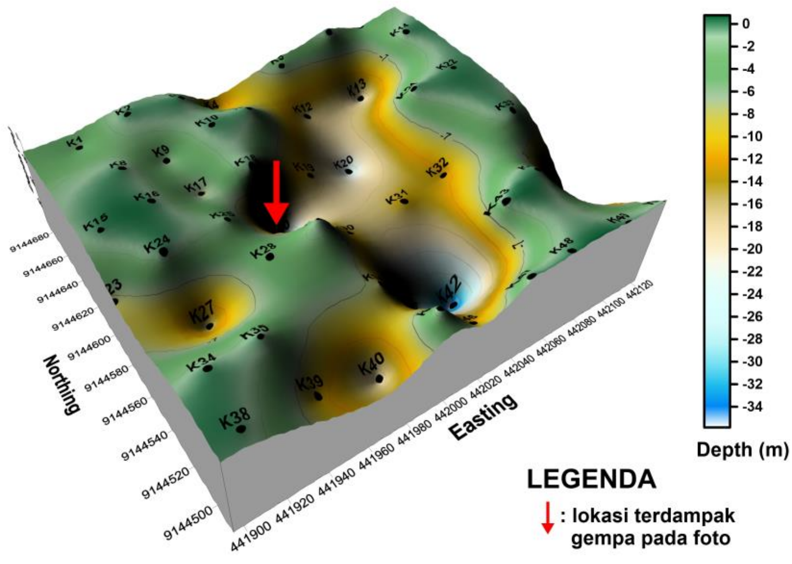

Figure 9. 3D contour of Vs750 value in the study area

Based on Figure 9, it can be interpreted that the Vs750 value is found in the deepest sediment at a depth of 36.53 meters at point K42, which means that the point has a fairly thick sediment layer. At point K26, which is evidence of the location affected by the earthquake at that time, the Vs750 value is around 27.2 meters deep, which means that point K26 also has a fairly thick sediment layer.

CONCLUSION

The value obtained from the calculation of the soil vulnerability index (Kg) in Bendosari Hamlet, Kalasan, Yogyakarta ranges from 0.49 - 30.18, which means that the research area is included in the classification of moderately dangerous zones on the ground surface. The value obtained from the calculations that have been carried out obtained the peak ground acceleration (PGA) value in Bendosari Hamlet, Kalasan, and Yogyakarta ranges from 0.21 - 0.61 Gal, which means that in the USGS classification the research area is on a scale of intensity value to VII which is explained that if there is an earthquake, it affects the maximum ground acceleration and has an impact such as damaged building construction parts, broken walls, plaster walls and stones in walls that are not firmly bound to fall.

The value obtained from the calculations that have been carried out the value of ground shear-strain (GSS) in Bendosari Hamlet, Kalasan, Yogyakarta ranges from 4x10-6 to 38x10-5, which means that in the classification of GSS values the research area experiences wave and vibration phenomena, which means this is caused by the elastic dynamic properties of the subsurface. The phenomenon of waves and vibrations is thought to be caused because on the Geological map of Yogyakarta, the research area is right to the north of the Opak fault which passes towards the Prambanan area.

Declaration by Authors

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Conflict of Interest: The authors declare no conflict of interest.

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