Analysis of Soil and Rock Strength Using Vs30 Value and Ground Shear Strain Based on Microtremor Data in the Pindul Cave Area, Gunung Kidul, Yogyakarta

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Abstract. *The study of rock and soil strength is one of the roles of geophysics. This study uses the microtremor method to determine the shear velocity at a depth of 30 meters (Vs30) and ground shear strain (GSS) which will show the strength of soil and rock under a force. This study was investigated in the Pindul Cave Area. The samples consisted of karst rock types. This study uses the HVSR method which is analyzed to determine the strength of soil and rock in the study area. The results of the study found that the GSS map in general has a range of values of 3,1x10-1 – 3.0x10-2, with the phenomenon of land subsidence and elastic to plastic soil dynamics. Then, the velocity-S 30 has a general value of the range of 250 m/s - 530 m/s is obtained to have a hard soil type, soft rock classification. based on such values, several zones were created to describe the strength of soils and rocks based on classification. the zone is divided into 3; the weak zone is in the southeastern area, the medium zone is in the area extending from the northwest-southeast direction, and the strong zone is in the northwest area.*

Keywords: *Ground Shear Strain, Karst, Microtremor, Soil and Rock, Velocity-S 30.*

INTRODUCTION

Pindul Cave in Bejiharjo village, Gunung Kidul district, Yogyakatya is a tourist area which is dominated by karst geomorphology, the rocks are composed of non-clastic limestone so that it can be identified that there are empty cavities below the ground surface. Karst areas are very susceptible to weathering, this weathering can cause collapse, especially in zones that have cavities and weak soil and rock resistance (Fahmi,et al., 2017)

The development of tourism in Pindul Cave until 2022 is an active tourist spot and is often visited by domestic and foreign tourists, which can be seen on the Gunung Kidul Central Statistics Agency page (Badan Pusat Statistik Kabupaten Gunung Kidul, 2021). Thus, transportation activities and the development of tourism supporting infrastructure will continue to be carried out in order to increase people's income in the Pindul Cave tourist area.

Infrastructure development, transportation infrastructure and others, must be placed in areas that are safe from disasters, such as subsidence disasters, landslides, soil liquefaction, and others. To describe the strength of soil and rock dynamically, one way that can be done is to estimate the value of the shear wave velocity and soil shear during an earthquake (Sunardi, et al., 2017). The shear wave velocity at a depth of 30 meters (Vs30) is an important parameter in predicting ground motion from the effects of earthquake shaking (Sunardi, et al., 2018). Vs30 is an indicator of the ground response which generally dominates the amplification of ground motion due to earthquakes (Sunardi, et al., 2018).

One way to obtain shear wave velocity and shear strain values is to use the microtremor method with microtremor data. The use of microtremor in this study is to identify the presence of voids in karst areas in Gunung Kidul. This method has a high level of sensitivity, is cost-effective in detecting underground voids, and is eco-friendly. The microtremor method is a passive method where the sources used come from nature such as ocean waves, wind, atmosphere, and also human activities such as traffic, industry, and others (Sunardi, et al., 2018). Microtremor is defined as a small, continuous ground vibration that originates from various vibrations and resonates with each other (Sunardi, et al., 2018). The processing method to obtain the value of shear wave velocity and soil

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shear is using the HVSR (Horizontal to Vertical Spectral Ratio) method. The HVSR technique states that there is a relationship between the ratio of the H/V spectrum as a frequency function which is closely related to the site transfer function of the shear wave (Vs) (Edison, et al., 2022).

This study was conducted to analyze the strength of soil and rock in the Pindul cave area, Bejiharjo village, Gunung Kidul sub-district, Yogyakarta using Vs30 and GSS (Ground Shear Strain) values from the HVSR (Horizontal to Vertical Spectral Ratio) analysis method. so that there will be several strong and weak soil zones for disaster mitigation both in infrastructure and agricultural land processing in the Pindul cave tourist area

METHODS

The research was carried out through several stages of the process ranging from the acquisition, processing, and interpretation of data. This study begins with the acquisition of microtremor data at each point of measurement, based on the Microtremor Acquisition Map.

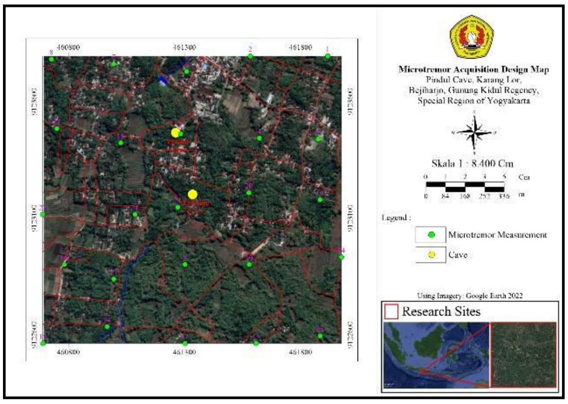

Figure 1. Map of Acquisition of Mikrotremor Method

The study was conducted in the Pindul Cave area, Gunung Kidul, Yogyakarta. Microtremor data acquisition activities have a research grid size of 1.5 x 1.5 km with a total area of 2.25 km^2. The study was conducted in Goa Pindul due to the potential risk of landslides that may endanger the safety of visitors who are exploring the cave. This landslide risk is related to the geological characteristics of the karst area in Gunung Kidul, which is vulnerable to the occurrence of landslides and erosion. Microtremor data acquisition instrumentation using a TSD type Portable Digital Short Period Seismograph tool. The microtremor data acquisition process was carried out as many as 25 measurement points with a distance between points of 300 m as in **Figure 1.** Data acquisition at each measurement point is carried out for ± 40 minutes, to obtain accurate data results so that a signal to noise ratio (S/N) is obtained.

The study activities are divided into 3 stages in **Figure 2.** namely the stages of data collection, data processing and data interpretation. At the data collection stage, a literature study was carried out on microtremor, HVSR method, Ground Shear Strain, and Vs30 and a literature review based on the Yogyakarta earthquake in 2006. Microtremor data acquisition activities were carried out in the Pindul Cave area, Gunung Kidul, Yogyakarta, so that the final results were obtained in the form of microtremor data and X,Y coordinates.

The data processing stage starts from the input of data from acquisitions in the research area. At each measurement point, data processing is carried out using Geopsy Software by applying the HVSR method so that the results of the H/V curve are obtained which include the values of F0 and A0. F0 and A0 data were carried out further processing by paying attention to the reference values based on a review of the 2006 Yogyakarta earthquake library in the form of hypocenter and epicenter values. Through the calculation of F0 and A0 data, they will get the PGA and Soil Vulnerability (Kg) values at each point, from both the PGA and Kg values as a reference calculation to produce the Ground Shear Strain (GSS) value. Other processing of the H/V curve results using Dinver Software is carried out data processing to produce Ground Profiles graphs based on wave velocity Vs and Vp. Ground Profiles are obtained based on the determination of subsurface depth by 30 m with a missfit value at each point of 0.3 - 0.7. Obtained vs30 value or wave velocity S at a depth of 30 m as the basis for making Vs30 maps.

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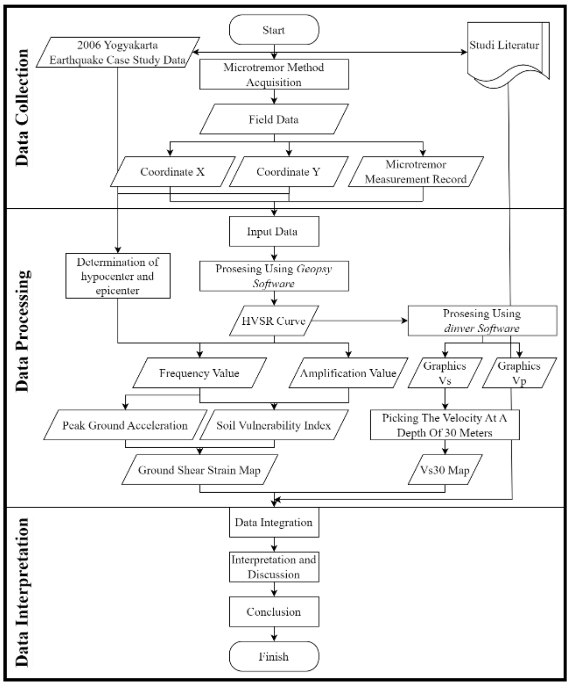

Figure 2. Research flow chart

The interpretation stage is carried out after the final results of data processing are obtained, then the final results are integrated between the Ground Shear Strain map and the Vs30 map. Integration between the two maps by conducting interpretations and discussions to produce discussions of the intended targets in the form of soil and rock vulnerability areas. Furthermore, make conclusions from the results of interpretation and discussion on this study.

In the research conducted to be able to analyze the strength of soils and rocks in the research area, through several methods of applying interpretation to microtremor data. The method used in this study can be discussed based on the concept, usefulness, and application as follows.

HVSR (Horizontal to Vertical Spectra Ratio)

HVSR is a method for calculating the spectrum ratio of the horizontal signal component to the vertical signal component of the recorded microtremor signal. The HVSR analysis shows a spectrum peak of the natural frequency (Amrullah, 2018) which is shown in Figure 3. HVSR analysis states that the H/V spectrum ratio as a frequency function is closely related to the site transfer function of the S wave (Amrullah, 2018). The H/V equation can be written as follows:

$$H_f = A_H S_{HB} + S_{Hs} \quad (1)$$

$$V_f = S_V S_{VB} + S_{Vs} \quad (2)$$

So the value of H/V:

$$\frac{H}{V} = \frac{H_f}{V_f} = \frac{A_H S_{HB} + S_{Hs}}{S_V S_{VB} + S_{Vs}} \quad (3)$$

Variables:

H_f/V_f : Horizontal and Vertical Components

A_H/A_V : Horizontal and Vertical Body Wave Amplification

S_{HB}/S_{VB}: Horizontal and Vertical Motion Spectrum in Bedrock

S_{HS}/S_{VS}: Horizontal and Vertical Motion Spectrum at Sediment Layer

Site effects on sediment layers on the surface are usually described by comparing the spectrum between the horizontal component of the seismogram recording on the sedimentary or alluvial soil layer with the horizontal component of the seismogram recording on hard rock (Amrullah, 2018). site effect or local effect is strongly influenced by the propagation of microseismic waves which are influenced by local geological conditions (Amrullah, 2018). site effect (T_{site}) is determined based on the ratio of the amplification factor of horizontal (T_H) and vertical (T_V) movements of the soil surface exposed to bedrock as illustrated in **Figure 4** (Amrullah, 2018). So the equation:

$$T_H = \frac{S_{HS}}{S_{HB}} \quad (4)$$

$$T_V = \frac{S_{VS}}{S_{VB}} \quad (5)$$

So the value of T_{site}:

$$T_{Site} = \frac{T_H}{T_V} = \frac{H_f S_{VB}}{S_{HB} V_f} \quad (6)$$

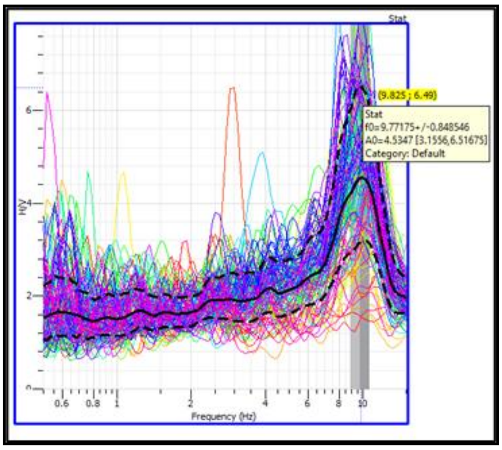

Figure 3. Horizontal to Vertical Spectra Ratio Curve

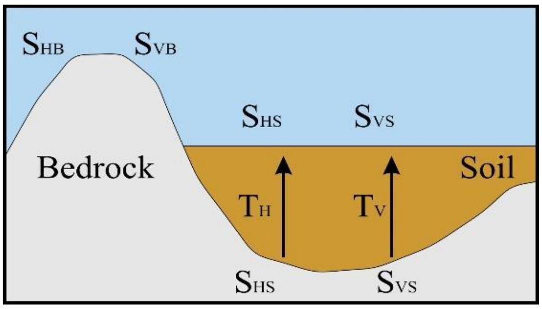

Figure 4. Illustration of The Source of The Microtremor (Amrullah, 2018)

Ground Shear Strain

A rock or soil that is in a state of equilibrium when given a force such as a pull, shear, or pressure then the object will be deformed. Ground Shear Strain (GSS) is a method that estimates the potential of the soil layer to shift or deform due to the influence of an earthquake (Iswara, et al., 2020). The GSS value will show the disaster caused by the land listed in **Table 1**. The GSS value equation is calculated based on the equation:

$$\gamma = K_g \times \propto (10^{-6}) \qquad (7)$$

Variables:

γ : The Value of GSS (GSS)
$\propto$: Peak Ground Acceleration (gal)
K_g : Soil Vulnarability Index

Table 1. Connection Between Dynamic Character of Soil and GSS (Iswara, et al., 2020)

Strength Value (γ)	10^{-6} 10^{-5}	10^{-4} 10^{-3}	10^{-2} 10^{-1}
Phenomenon	Waves, Vibrations	Crack, Land subsidence	Landslids, Land subsidence, liquifaction
Character	Elastic	Plastic elastic	Collapse
Dynamic		Repeat effect, speed effect of charge

Velocity-S 30 meters

The value of Vs30 is the average value of the shear wave at a depth of 30 meters (Prasisila, et al., 2020). This value is commonly used to predict soil and rock classification and predict subsurface lithology which has been divided by the Badan Standarisasi Nasional Indonesia in **Table 2** (Badan Standarisasi Nasional, 2019). Vs30 is an indicator of the ground response which generally dominates the amplification of ground motion due to earthquakes (Sunardi, et al., 2018). Vs30 data can be obtained by active seismic measurements such as the MASW (Multichannel Analysis Surface Wave) method and passive seismic measurements such as microseismic or microtremor measurements (Wibowo & Huda, 2020). The value of Vs30 can be found using the HVSR analysis method based on the inversion of the HVSR curve obtained from the measurement then inversion is carried out to get the value of Vs and Vp at the measurement location then take or choose the shear wave velocity (Vs) at a depth of 30 meters (Annas, et al., 2020). The calculation of Vs30 can be obtained by the equation:

$$Vs30 = \frac{30}{\sum_{i=1}^{n} \frac{h_i}{Vs_i}} \qquad (8)$$

Variables:

h_i : The thickness of the layer i
Vs_i : Velocity Vs on Layer i
n : Number of Layers

Table 2. Vs30 value classification based on SNI 1726 -2019 (Badan Standarisasi Nasional, 2019).

General Description	Vs30 (m/s)
Hard Rock (SA)	Vs30 ≥ 1500
Medium Rock (SB)	750 ≤ Vs30 ≤ 1500
Hard Soil, Soft Rock (SC)	350 ≤ Vs30 ≤ 750
Medium Soil (SD)	175 ≤ Vs30 ≤ 350
Soft Soil (SE)	Vs30 ≤ 175

Result and Discussion

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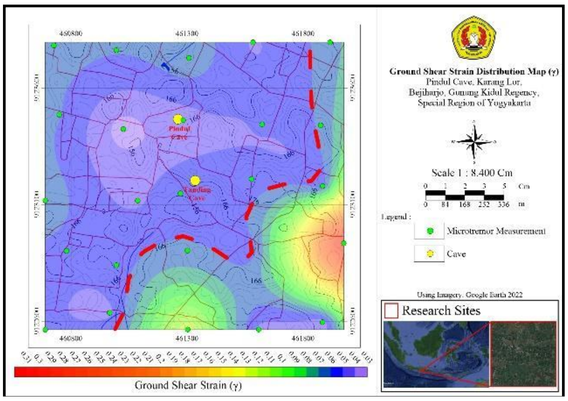

Figure 5. Ground Shear Strain Distribution Map

Figure 5 is a Ground Shear Strain distribution map, GSS map that depicts the value of the surface soil's ability to stretch maximum in the event of an earthquake. Ground Shear Strain value parameter is related to the constituent value components in the form of Soil Vulnerability (Kg), Peak Ground Acceleration (PGA) values and strain value estimation settings. So that the distribution of the Ground Shear Strain value will be used as a reference for the level of soil deformation on the surface due to tension when an earthquake occurs. The map marked with a dashed red line, which is the cutoff value of soil shear strain, shows areas with changes in soil shear strain values between low and high based on **Table 1.** This value indicates that the area is experiencing dynamic changes in soil elasticity, ranging from moderate to high plasticity, which also indicates that the area has moderate to high deformation rates.

The interpretation results are classified based on high, medium, and low values that characterize each interpretation of the target in this study, which is based on the classification of Ground Shear Strain values against the appearance of phenomena and dynamic characteristics according to Edison, et al (2022) in **Table 1**. (Iswara, et al., 2020). High value in the eastern part of the map symbolized in red to orange has a range of values of 0.31 - 0.17, indicated as an area with the phenomenon of Land Subsidence and elastic to high plastic soil dynamics. Moderate values in the eastern and southern parts of the map symbolized green have a range of values of 0.12 - 0.09, as areas with the phenomenon of Land Subsidence and elastic to medium plastic soil dynamics. Low values on the northwestern part of the map symbolized in dark blue to purple have a range of values of 0.08 - 0.03, with the phenomenon of Land Subsidence and elastic to low plastic soil dynamics.

The distribution of Ground Shear Strain values in the study area to be able to identify soil and rock strength. It can be reviewed on the east of the map with a high GSS value as an area with a high deformation rate, a medium GSS value as on the east and south parts of the map with a moderate deformation level, and a low GSS value on the northwest part of the map as a low deformation level area. The level of deformation is based on the strength of the soil and rocks in the study area to stretch during an earthquake. This relates to the soil susceptibility value (Kg) and Peak Ground Acceleration (PGA) to produce a small distribution of ground shear strain values.

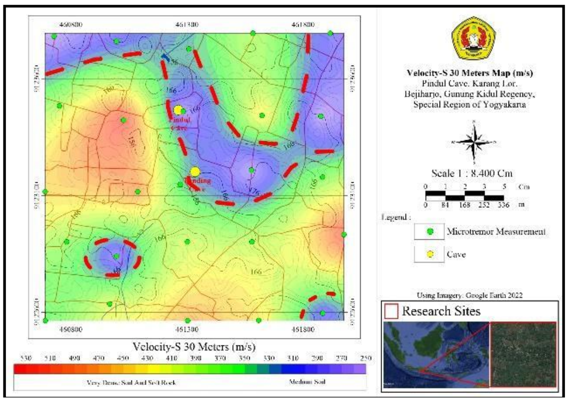

Figure 6. Velocity S 30 Meters Map

Figure 6 is a map of the distribution of the velocity-S 30 (Vs30) values in the study area. The Vs30 map is used to be able to determine the characteristics of soil and rock in the study area based on subsurface features, counted 30 m from the surface. The appearance of a depth of 30 m is based on the propagation of seismic waves that will experience wave amplification (Amplification/A0) in layers at a depth of 30 m. The map marked by the dashed red line, which is the 30 m shear wave velocity cutoff value (Vs30), shows areas with low to high changes in shear wave velocity values based on **Table 2**. This value indicates that the area has experienced rock changes, ranging from medium soil and hard soil with soft rock, the study area is dominated by strong with soft rock.

The distribution of Vs30 values can be classified as types or characteristics of soils and rocks with reference to the provisions listed in SNI 1726:2012 as shown in **Table 2** (Badan Standarisasi Nasional, 2019). Based on SNI 1726:2012 (**Table 2**)

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(Badan Standarisasi Nasional, 2019), the type or characteristics of soils and rocks are classified into soft soils (SE) with Vs values ≤ of 175 m/s, medium soils (SD) with Vs values of 175-350 m/s, hard soils (SC) with Vs values of 350-750 m/s, medium rocks (SB) with Vs values of 750-1500 m/s and hard rocks (SA) with vs values ≥ 1500 m/s.

In general, the value of Vs30 in the Pindul Cave Area varies from 250 m/s to 530 m/s. The low distribution of Vs30 values in the range of values of 250-350 m/s, mostly found on the north side of the study area is symbolized in purple to blue. Some parts have relatively higher shear wave velocity values in the range of values of 350 - 530 m/s symbolized in green to red. This zone is spread over the southern regions of the study area. Based on the vs30 value, the Goa Pindul Research Area is divided into two parts, namely medium soil and hard soil, soft rock. Most of the northern to northeastern areas of the study including pindul caves and sparring caves have a medium soil type. Then most of the area located in the south of the research plot has a type of hard soil, soft rock.

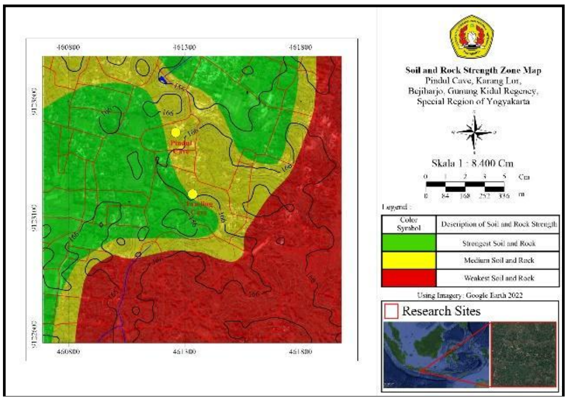

Figure 7. Soil and Rock Strength Zone Map

Figure 6 is the result of analysis of the GSS and Vs30 maps so that a map of the land strength distribution zone is produced. Judging from the GSS value in the southeastern part of the map, it is an area that has a high level of deformation due to the stretching of the soil on the surface in the event of an earthquake, it can be seen that it has a value of around 10^{-1} so that it has a low soil and rock strength and is easily deformed due to a force. Based on the Vs30 value in the southeastern part of the map has a high shear wave value ranging from 350 - 530 m/s, based on the SNI standard in Table 2. The study area is an area that has a strong soil type with weak rock (SC) so that weak rocks can be analyzed in the area as an internal subsurface factor that causes deformation.

In the zone that extends from the northwest to the southeast is an area that has medium strength which indicates that the soil and rocks have a soft characteristic. Based on the GSS value in the northwest-southeast zone, it has a GSS value at a value ranging from 10^{-1} which indicates that the section has resistance to deformation, but the Vs30 value has a value of 250 m/s - 350 m/s, based on the SNI standard the value is a medium soil (SC) so that the area is a soft area and will have an impact if a force occurs. so that it can be interpreted in the longitudinal part northwest-southeast the influence of soft soil can aggravate the value of the soil buffer that occurs on the surface.

In the northwestern part of the map is an area that has a strong land force. Based on the GSS value, it has a value ranging from 10^{-2} so that it has a lower deformation rate than the southeastern part. Based on the vs30 value of the area located in the northwestern part varies greatly from low to high anomalies, namely 250 - 530 m/s, based on SNI standards the area has medium soil (SD) and Hard Soil, Soft Rock (SC) soil types, so there is a rock difference between the northwest and southeast zones that makes the soil strength lower. The difference is interpreted to mean that rocks in the southeastern zone have many subsurface cavities compared to the northwest zone, and are easily deformed because rocks have the characteristics of soft rocks.

So that the results of the analysis on each part of the GSS and Vs30 maps of the value anomalies formed resulted in a map of soil and rock strength zones (**Figure 6**). To represent the intended target, the study area is divided into several zones of potential soil and rock strength in the study area. It is divided into 3 parts of the area, each of which is symbolized by red, orange, and green colors. On the map the soil and rock strength zones are symbolized by the color red as areas with low or weak soil and rock strength. In the map section, it is symbolized by yellow as an area with moderate soil and rock strength. In the map section, it is symbolized by the green color as an area with high soil and rock strength.

Based on the classification on the map of soil and rock strength zones in the Pindul Cave area which is one of the tourist areas in Yogyakarta that

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is crowded with tourists, it can be known some potential mitigation in tourist activities and daily activities in the research area. Through the distribution of soil and rock strength in the research area, to be able to avoid areas with weak soil and rock strength dominance in the southeast to the south of the map, be it the daily activities of local residents such as agriculture and the construction of tourism supporting infrastructure in the research area. This will later have an impact for a long period of time, because the research area is a karst area that is easily dissolved by water over time and also when there is an earthquake, the potential for surface soil to be deformed will be high, so it is very dangerous and has a major influence later on the social, environmental, and economic aspects of the Pindul Cave area.

Conclusion

Based on the studies that have been carried out, it was found that the measurement of soil and rock strength can be determined using the HVSR analysis method to produce GSS and Vs30 values, the comparison of GSS and Vs30 values is to compare the shear velocity values that describe rock characteristics and the value of soil and rock deformation when given a force. so that the results obtained are in the form of a map of the soil and rock strength zones where the strong soil strength is at a value of Vs30 ranging from 350 m/s - 530 m/s with a GSS value of 10-2 being in the northwest, the medium strength zone is at a value of Vs30 ranges from 250 m/s - 350 m/s with a GSS value of 10-2 which extends from northwest to southeast, and the weak strength zone is at a value of Vs30 ranging from 350 m/s - 530 m/s with a GSS value of 10-1 which is in the southeast. Through the distribution of soil and rock strength from this research, it is necessary for the continuation of infrastructure development and agricultural managers to be aware and avoid the area as an active activity area, especially the southeastern part of the research area, because this will have an impact both in the short and long term.

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