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**Research Paper**

# Identification of Soil Layers using the SPAC Method in the Ngasinan Landslide Area, Srondol Kulon Village, Semarang City, Central Java, Indonesia

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***ABSTRACT***: *Spatial Autocorrelation (SPAC) measurements have been carried out in the Ngasinan landslide area, Srondol Kulon Village, Semarang City. This study aims to determine the soil layer in the research area based on the speed of the S wave (Vs). This SPAC measurement with a linear configuration of 10 passes. Data retrieval using eight vertical seismometers with a recording duration of 10 minutes for each track. The results showed that the research area has a Vs value of 170.89 – 1315.69 m/s and a velocity ratio (Vp/Vs) of 2.34 – 5.97. The soil layer structure in the Ngasinan area, Srondol Kulon Village, Semarang City, is dominated by thick sedimentary rocks. On the surface, up to a depth of 31 meters, there is a layer of fine and loose soil in the form of sand, gravel, and clay. At a depth of 14 – 82 meters, there is a slightly hard layer of soil in the form of clay and limestone. At a depth of more than 54 meters, there is a hard layer (bedrock) in limestone, conglomerate, and sandstone. The soil layer is indicated by the slip field at a depth of 5 – 18 meters with the direction of the landslide from south to north. The results of this study indicate that the potential for soil movement in the Ngasinan area is relatively high, with a thick layer of loose and soft soil. This layer has a Vp/Vs value of 4 – 6 from the surface to a depth of 30 meters so that the soil is easily eroded and vulnerable in case of aftershocks of ground motion.*

***KEYWORDS***: *Landslide, SPAC, S-wave Velocity (Vs), Ratio Vp/Vs, Slip Field.*

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## I. INTRODUCTION

Natural disasters are natural events that occur naturally or artificially. This natural disaster is hazardous for human life because it occurs anywhere and anytime, resulting in material loss and human death. One of these disasters is landslides that often threaten many cities in Indonesia. Landslides caused by triggering factors that affect soil stability are the soil layer acting as a slip field below the surface [1].

One city with a history of landslides is the city of Semarang. In 2018 there were 88 landslides, in 2019 there were 89 landslides, and in 2020 there were 175 landslides.One of the landslide disasters in the Semarang City area occurred in Srondol Kulon Village. The land is on a steep slope, especially in the western part, which the Gunung Pati Regency directly erodes. There were three land disasters in Srondol Kulon Village, with two incidents on Jalan Ngasinan RT 03 RW 10 [2]. The steep slopes and rainfall caused landslides in the area. The landslide began on June 28, 2020, when the road collapsed as deep as 7 meters with a length of approximately 50 meters due to ground movement. On October 27, 2020, the erosion continued to expand, resulting in several cracked houses and yards being eroded by erosion. The landslide occurred because the Srondol Kulon river eroded the slope beside the Ngasinan road, which flows from west to east and empties into Kaligarang.

The subsurface geological conditions of an area can be determined by determining the value of the S wave velocity (Vs). A *Microtremor array* is a measurement that can estimate the velocity profile of S waves. Microtremor measurements use the Spatial Autocorrelation (SPAC) method in this array. The SPAC method is an array processing technique used to estimate dispersion curves and analyze correlations between noise recorders at nearby places. Aki introduced the SPAC method by calculating the SPAC coefficient, which determines the subsurface structure [3]. Many studies use the SPAC method by estimating the coherence spectrum and reversing the dispersion curve [4]. These results are obtained from the velocity profile of the S wave (Vs) to the depth used to search for the subsurface layer.

A previous study used the SPAC method to obtain an S wave velocity profile (Vs) and know the potential for liquefaction in the Palu area, Central Sulawesi. Data acquisition in this study uses four sensors and five measurement points. In this study, the velocity profile of the S wave (Vs) was obtained from the inversion of the dispersion curve. The value of Vs is used to identify the subsurface layer in the Palu area. The value of Vs obtained is 228 – 278.9 m/s, including site class D in the form of medium soil types. A layer of sandy soil dominates the research location, so it is susceptible to soil movement [5].

Based on this explanation, research was conducted using the Spatial Autocorrelation (SPAC) method to identify soil layers in the Ngasinan erosion area, Srondol Kulon Village, Semarang City. This study uses a linear configuration with eight seismometers whose components are vertical to work simultaneously. This study aims to identify the type of soil layer in the Ngasinan landslide area, Srondol Kulon Village, Semarang City, based on a 2D S wave velocity (Vs) model and Vp/Vs ratio. Besides that, it also determines the layer that acts as the slip field in the Ngasinan landslide area, Srondol Kulon Village, Semarang City. The advantages of the SPAC method are that it is the most widely used because of its robustness, ease of application, and efficiency for subsoil exploration to deeper layers [6].

## II. METHODS

The research material used in this study is primary data obtained from the acquisition of microtremor array data in the Ngasinan landslide area, Srondol Kulon Village, Semarang City. This data acquisition used the Spatial Autocorrelation (SPAC) method with a linear configuration with ten paths that placed eight seismometers whose components were vertical at the same distance. This selection is due to adjusting the research location. In this microtremor array measurement, the seismometer distance is 2 meters, and each track is 2 meters apart. A linear configuration path with eight seismometers connected to a data logger is shown in Figure 1. The time required to record the microtremor array was 10 minutes with a sampling rate of 240 Hz.

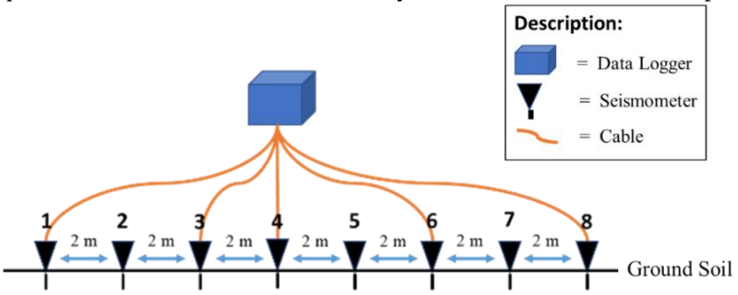


**Figure 1.** Linear configuration with eight seismometers connected to a data logger

Array microtremor recording uses the SPAC method, which is adjusted to the desired depth requirement. Data recording usually takes 10 to 20 minutes, which is usually sufficient for layers less than 100 meters deep. The time is 30 to 40 minutes for layers with a depth of several hundred meters and several hours for layers more than 1 km [7].

Processing of array microtremor data using Geopsy, Spac2disp, and Dinver programs. The results obtained are then modeled using the Surfer program. The model was interpreted and analyzed the results by classifying the value of the S wave velocity (Vs) and the Vp/Vs ratio based on the table of soil layers[8,9].

## III. RESULTS AND DISCUSSION

### 3.1 Analysis of Vs and Vp/Vs

The value of the S wave velocity (Vs) is obtained from the data inversion process using the Dinver software. The value of Vs is directly proportional to the rock density. The higher the value of Vs, the higher the rock density. Rock type is closely related to rock density, so the value of Vs can be used to identify the structure of the subsurface layers of the earth. The value of Vs is also correlated with the ratio of Vp/Vs as a lithological indicator of soil properties. At the research location, the Vs value of 170.89 – 1315.69 m/s and the Vp/Vs value of 2.34 – 5.97 were obtained. The results of Vs and Vp/Vs modeling were analyzed using soil type classification based on SNI 1726 and soil properties according to Kaceli.

This study's modeling was carried out with two profiles: profile 1 with an incision from west to east and profile 2 with an incision from south to north. If, at the research location, it is indicated that the slip field is marked with a Vs value equal to 300 m/s.

### 3.1.1 The incision in profile 1

The incision in profile 1 is from west to east that connects five tracks, namely A, B, C, D, and E. The incision is formed by connecting the paths because each path forms 1 point, represented by seismometer number 4 as the center position. The distance between the tracks is 2 meters with a length of 8 meters. The incision in profile 1 is shown in Figure 2. two-dimensional modeling is done by contouring the values of Vs and Vp/Vs by displaying a depth of up to 100 meters.

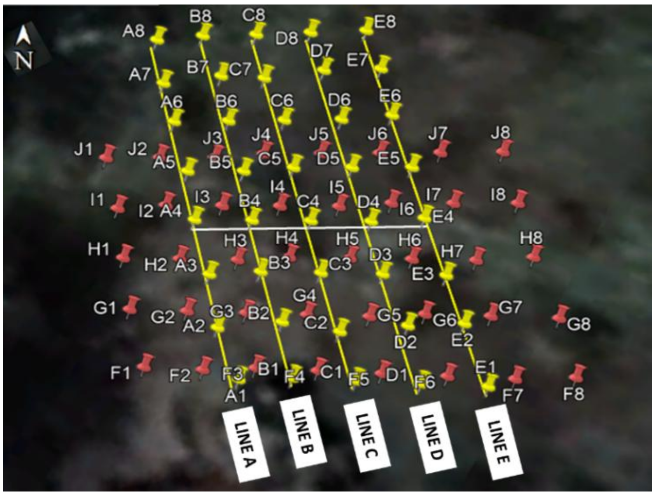


**Figure 2.** The incision in profile 1

**1. Vs analysis on profile 1**

The value of the S wave velocity (Vs) in profile 1 obtained a Vs value of 170.89 m/s – 1315.69 m/s with the most profound depth of 100 meters, as shown in Figure 3.

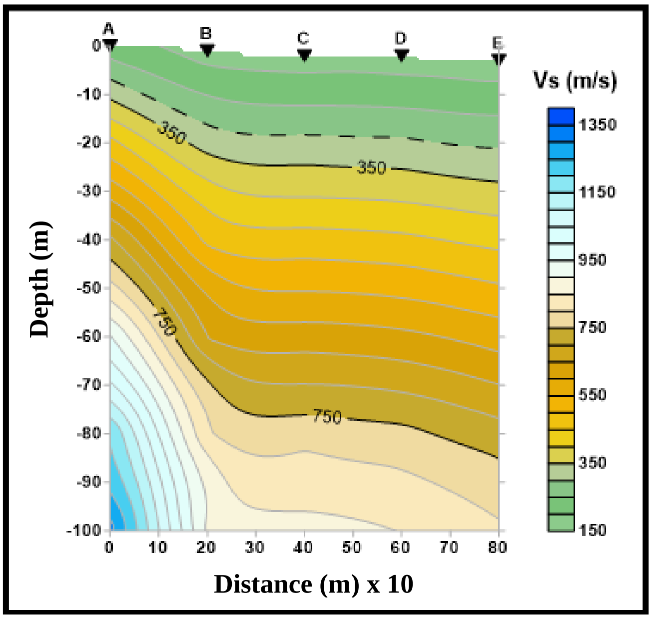


**Figure 3.** 2D model of the value of Vs on the west-to-east incision

Based on the classification of soil types in SNI 1726 in 2012, the research location contained a layer of sediment in all trajectories with a value of Vs < 750 m/s with a depth range of 0 – 85 meters. The Vs value of 170.89 m/s – 350 m/s with a depth of up to 28 meters indicates medium soil. Hard soil and soft rock indicate the Vs value of 350 m/s – 750 m/s with a depth of 11 – 84 meters. A layer of hard soil (bedrock) was also found on all tracks with a value of Vs > 750 m/s with a depth range of 43 meters. In the research area, an indication of a slip field with a depth of 8-21 meters is marked with a black dotted line.

**2. Vp/Vsanalysis on profile 1**

The value of Vp/Vs is obtained from the calculation by comparing the value of Vp with the value of Vs. The research location has a Vp/Vs value of 2.34 – 5.97. The distribution of Vp/Vs values is modeled in 2D, shown in Figure 4.

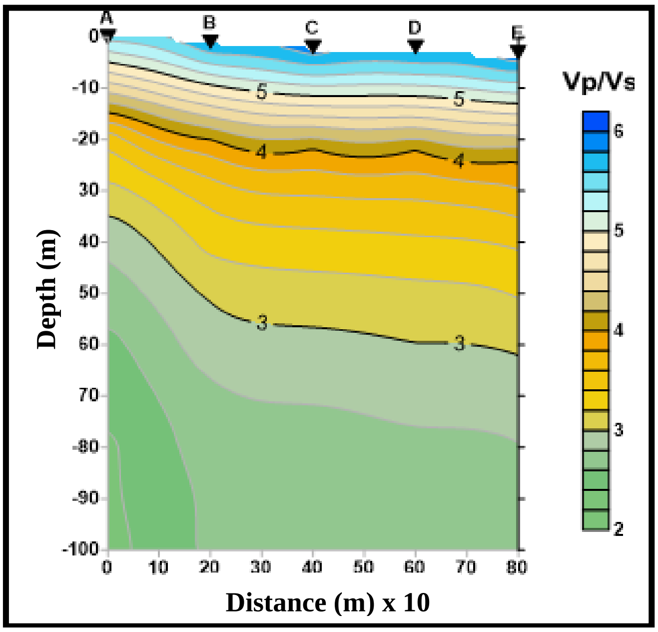


**Figure 4.** 2D model of Vp/Vs values in the west-to-east incision

Based on the classification of Vp/Vs values according to Kaceli, it was found that there is a delicate and loose soil layer with a Vp/Vs value of 4-6 at a depth of up to 25 meters marked in blue and brown. The soil layer is slightly hard with a Vp/Vs value of 3 – 4 at a depth of 14 – 62 meters, and a rock layer with a Vp/Vs value < 3 at a depth of 35 meters as a rigid rock. The highest value of Vp/Vs is on track E, with a value of 5.97. The results show that the surface area has a high value of Vp/Vs because the soil contains fluid.

### 3.1.2 The incision in profile 2

The incision in profile 2 is from south to north that connects 5 tracks, namely F, G, H, I, and J. The incision is formed by connecting between tracks because each track forms 1 point, represented by seismometer number 4 as the center position. The distance between the tracks is 2 meters with a length of 8 meters. The incision in profile 2 is shown in Figure 5. 2-dimensional modeling is done by contouring the values of Vs and Vp/Vs by displaying a depth of up to 100 meters.

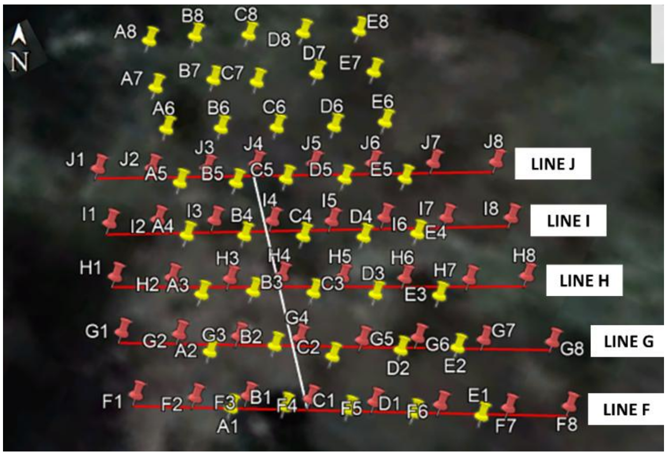


**Figure 5.** The incision in profile 2

**1. Vs analysis on profile 2**

The value of the S wave velocity (Vs) in profile 2 obtained a Vs value of 176.95 m/s – 1112.16 m/s with the most profound depth of 100 meters, as shown in Figure 6.

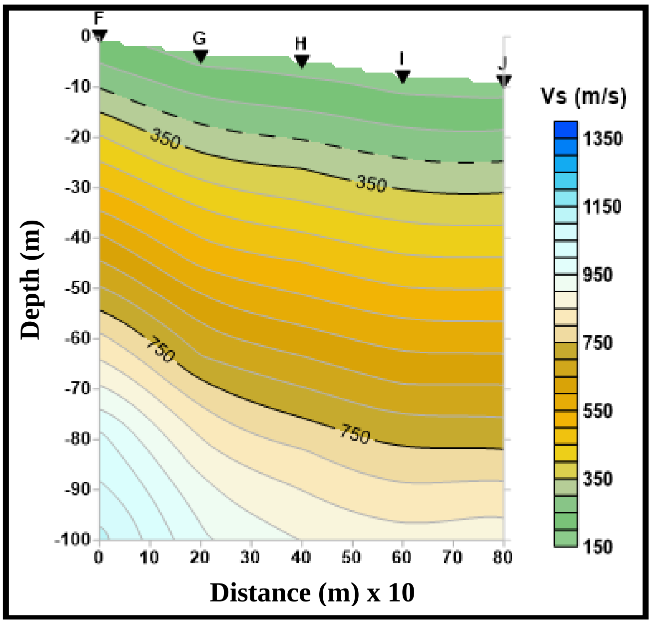


**Figure 6.** 2D model of the value of Vs on the south-to-north incision

Based on the classification of soil types in SNI 1726, the research location contained a layer of sediment in all trajectories with a value of Vs < 750 m/s with a depth range of 0 – 82 meters. The Vs value of 176.95 m/s – 350 m/s with a depth of up to 31 meters indicates medium soil. Hard soil and soft rock indicate the Vs value of 350 m/s – 750 m/s with a depth of 14 – 82 meters. A layer of hard soil (bedrock) was also found on all tracks with a value of Vs > 750 m/s with a depth of > 54 meters. In the research area, a slip field with a depth of 10-25 meters is indicated, marked with a black dotted line.

**2. Vp/Vsanalysis on profile 1**

The value of Vp/Vs in profile 2 was 2.38 – 5.94. The distribution of Vp/Vs values in profile 2 is modeled in 2 dimensions, as shown in Figure 7.

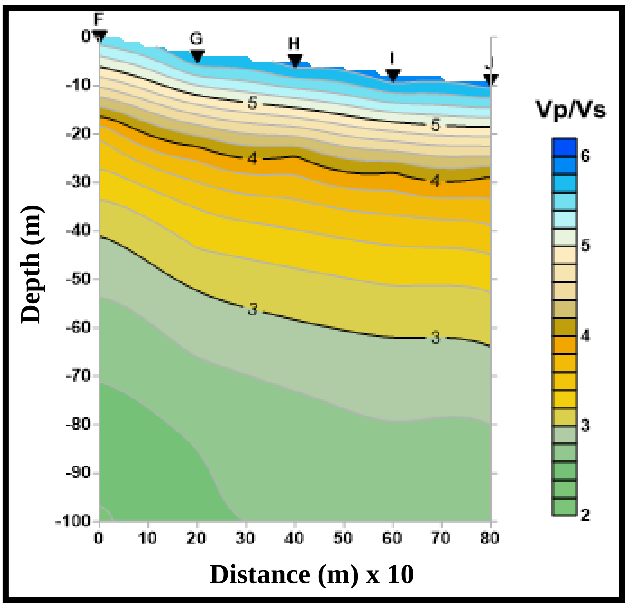


**Figure 7.** 2D model of Vp/Vs values in the south-to-north incision

Based on the classification of Vp/Vs values according to Kaceli, it was found that there is a delicate and loose soil layer with a Vp/Vs value of 4-6 at a depth of up to 30 meters marked in blue and brown. The soil layer is slightly hard with a Vp/Vs value of 3 – 4 at a depth of 16 – 63 meters, and a rock layer with a Vp/Vs value < 3 at a depth of > 41 meters is rigid rock. The highest value of Vp/Vs is on track I and track J, with a value of 5.94.

### 3.2 Discussion

Based on 2-dimensional modeling, profile 1 at a depth of up to 28 meters has Vs 170.89 m/s – 350 m/s, which indicates that the soil is medium and loose. Profile 2 at a depth of up to 31 meters with a value of Vs 176.95 m/s – 350 m/s also shows medium soil types, namely acceptable and loose. The soil layer consists of sand, gravel, and clay. If we look at the 2-dimensional model in profile 1 and profile 2, there is a slip field in profile 1 with a depth of 8-21 meters and a slip field in profile 2 with a depth of 10-25 meters. The C line in the profile is close to the H line in profile 2. The depth of the slip field on the two lines is the same. The depth of the slip field on track H is 20 meters, while the depth of the slip field on track C is 20 meters. Previous studies have explained that claystone is a rock that acts as a slip field [10]. Claystone which acts as a slip field has expansive properties; the coating will expand when wet, and the layer will shrink when dry [11].

The expansive nature of clay affects the occurrence of erosion in Ngasinan. During the dry season, a landslide occurred on June 28, 2020, which caused the asphalt road to collapse as deep as 7 meters and 50 meters long. When entering the rainy season, a landslide occurred on October 27, 2020, and damaged residents' houses. This erosion can occur due to the steep slopes in the surrounding area and high-intensity rainfall. The landslide led to the north of Jalan Ngasinan towards the Srondol Kulon river, which flows from west to east and empties into Kaligarang.

Landslides can occur due to the movement of the fine layer and loose down the slope due to the force of gravity. This layer has a high fracture due to the significant value of the Vp/Vs ratio. The highest value of Vp/Vs is on track I and track J, with a value of 5.94. The smaller the value of Vs in a layer, the layer contains fluid. The decrease in the value of Vs is because the S wave cannot propagate in the fluid, but the P wave can propagate to all mediums as the depth increases, so the value of Vp will increase. If there is high-intensity rain, water will enter the layer, which has permeable properties because it is easy for water to pass through the cracks. When water accumulates continuously in a layer with impermeable properties, the layer above it will be saturated so that the layer is unstable. The fluid layer will move on the slip field by descending the slope to a lower elevation.

Another controlling factor that causes landslides is the slope of the landslide area. Profile 2, shows that landslides occurred from south to north with visible differences in elevation in the model that leads north to low elevations. The slope of the slope can be calculated based on the depth and distance in the two-dimensional profile 2 model with the equation as follows:

$$tan\ \alpha = \frac{Depth}{Distance} = \frac{8\ meters}{8\ meters}$$

$$tan\ \alpha = 1;\ \alpha = tan^{-1}(1);\ \alpha = 45^{o}$$

the resulting angle shows that the landslide area is included in a steep area with a south-to-north direction. Referring to the soil vulnerability map of the Banyumanik sub-district, the Ngasinan area is included in the high-security category [12].

At depths of up to 14 – 82 meters, profile 2 has a value of Vs 350 m/s – 750 m/s, indicating complex soil types and moderately hard soft rocks. The soil has clay and limestone types. The rock types are indicated by limestone, conglomerate, and sandstone at a depth of > 54 meters with a value of Vs > 750 m/s. Based on the geological map of Semarang City, Srondol Kulon Village has a hoist formation consisting of claystone, sandstone, conglomerate, limestone, and breccia. Some claystone and limestones (limestone) are interlocked with sandstones. In claystone and sandstone, there is a layer of conglomerate [13]. In profile 2 there is a thick layer of fine and loose soil to a depth of 31 meters. This layer is composed of sedimentary rock that is not compact and includes loose material so that the soil is easily eroded and vulnerable if there is a follow-up of soil movement.

## IV. CONCLUSION

Based on research that has been done, the value of the S wave velocity (Vs) at the research location is 170.89 m/s to 1315.69 m/s. At the research location, there is a layer of fine and loose soil in the form of sand, gravel, and clay with a Vs value of 170.89 – 350 m/s to a depth of 31 meters, a slightly hard soil layer in the form of clay and limestone with a Vs value of 350 m/s. – 750 m/s at a depth of 14 – 82 meters and bedrock in the form of limestone, conglomerate, and sandstone with a Vs value > 750 m/s at a depth of > 54 meters.

The 2D modeling shows a slip field at a depth of 10-25 meters from south to north. The research site has a soft and loose layer of soil that is thick enough so that the soil is easily eroded and vulnerable to subsequent soil movement.

The calculation results obtained that the velocity ratio value (Vp/Vs) at the research location has a value of 2.34 – 5.97. In the 2D model, all paths look green in color contours on the surface. The green color indicates that there is a reasonably thick, smooth, and loose layer at the research site with a Vp/Vs value of 4-6 to a depth of 30 meters.

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