Determination of bed rock depth using joint geoelectric and HVSR methods

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Abstract. To obtain hard rock (bed rock) as the pedestal of the toll road, it had been measured of the thickness of layers of soft or weathered rock that covers the bed rock. Direct measurements carried out by drilling will require a long time and great cost. Therefore, indirect measurements were made by geophysical estimation using resistivity method and were cross-checked with the HVSR method. To get the resistivity data in the research area, in this survey was conducted geoelectric sounding acquisition as much as 16 points whereas data acquisition by using microtremor measurements performed at nine measurement points. The result of the analysis of geoelectric data with HVSR data gives slightly different layer thickness value. The survey area consists of two layers of soil with soft rock layers one were suspected to be sandy silt, and silty sand whereas the soft layer 2 was sandy gravel silt, each with varying thickness. The bed rock in this area is breccia that applies as half space with the thickness is not detected by the measurement. The apparent resistivity curves were obtained from geo-electrical resistivity data have similar curves with the HVSR ones. From the inversion, the result of the bedrock depth from geo-electric resistivity compared to HVSR ones give difference slightly.

1. Introduction
To obtain bed rock as the base of a toll road, it is necessary to measure the thickness of the soft or weathered rock covering the bed rock. Direct measurement by drilling will require a long time and large costs. Therefore, indirect measurements were taken by geophysical estimation using (resistivity) geoelectric methods and some of them were cross-checked with the HVSR method. The rock resistivity value is determined by the type of rock, compactness and hardness and the fluid content in it [1]. Thus the bed rock layer can be interpreted from the resistivity value based on the geo-electric measurement data. On the other hand the wave propagation velocity in rocks is also determined by the hardness and compactness of the rock in question, so that the presence of a soft layer covering the bed rock can be determined by the HVSR measurement [2][3][4][5][6][7][8]. This study aims to obtain subsurface geological layering structure, especially the lithological composition and depth of the bed rock, and to determine the thickness of the soft or weathered layer so that the bed rock is known.

2. Geological aspect of the location of study
Local geological studies were carried out by reviewing existing geological studies from various previous studies for areas related to the location where geoelectric and HVSR surveys were conducted (Figure 1) so that the geological position of the area of investigation in the regional geological framework was known. By the Central Java Physiography [9], the study location is generally located on hills which are part of the Volcano Quarter zone which is located between a series of Merbabu-Ungaran quarter.
volcanoes. Regional stratigraphy around Ungaran-Salatigawere composed of the Kerek Formation, Kaligetas Formation, Basalt igneous units and Alluvial Deposits [10].

Location of study is part of the steep hills in the southeastern part of Semarang Regency with a slope of 30 – 45% and an elevation of more than 480 m above sea level. Lithology of this area is in the form of volcanic breccia with a grayish black color with igneous rock fragments, medium sand, and open containerized matrix, slightly weathered, compact and hard. Fragmentations in the form of igneous rocks of basalt and andesite in black gray and blackish brown, 4 - 100 cm long, not weathered-rather weathered, angled in shape, porphyritic texture, and very hard. The matrix in the form of sand tuff with medium sand color is yellowish gray, slightly weathered - moderately weathered, and rather soft. The surface layer has a red soil form which has plastic properties, medium-high permittivity, low–medium compressibility, and easily excavated with non-mechanical equipment.

![Figure 1. Location of Geoelectric (yellow circles) and HVSR measurement points (green triangles)](image_url)

3. Method
The research method refers to the research method commonly used in similar studies, which is analytically described to determine the aquifer system and groundwater flow pattern and is conducted-exploratively for the entire study area. In resistivity geoelectric measurement low frequency alternating electric current were channeled into the earth through the electrode current and the resulting potential distribution were measured through a potential electrode [1]. The usual electrode configuration setting is the Schlumberger and Wenner configuration. The first configuration has advantages regarding vertical resolution, while the second one is very sensitive to lateral changes, so it is very good for surveying areas with many lens lithologies or fault lines. Considering that the research area is located in quaternary sedimentary rocks and the possibility of tertiary sediments at the bottom, then in the field data collection, Schlumberger configuration was used. As described above, to support this geoelectric study measurements based on Schlumberger's electrode configuration was carried out. To get the resistivity data of the study area, in this survey 16 soundings acquisition line were made with the distribution of sounding points as seen in Figure 1.

Based on the field data, the interpretation was then conducted to get an overview of the lithological order below the surface of the area of investigation. Field data interpretation was done by curve matching to the standard curve by using IP2WIN 2.1 software to determine the type of mathematical resistivity
parameters on a rock layer model. Thus the thickness of each layer had been obtained along with the value of the type of rock resistivity. Finally, the soft lithology or weathering thickness interpretation and the hard rock lithology layer or bed rock were performed. Interpretation procedures for field data are carried out in two stages, namely: determination of thickness and resistivity of layers and interpretation of lithology. The results of field data plots are in the form of field curves in logarithmic paper between the measured resistivity value and the distance of the electrode stretch. This curve provides an overview of the number of layers to be encountered. To get the thickness of each type of rock layer, the resistivity value were carried out using a computer with IP2Win 2.1 software. The lithological resistance value obtained in step 1 shows the rock layers and their resistivity value. Furthermore, by observing the value of rock resistivity, the type of lithology is interpreted, considering the resistivity is the typical physical properties of the rock. In this interpretation, besides referring to the rock resistivity value compared to the existing references, also consider the local geological conditions obtained from field observations and regional geological conditions from the study of literature.

4. Result and Discussion

4.1. Geoelectric method

From the results of measurements and analysis of geoelectric data, the value of rock type and thickness of rock layers as shown in Table 1. Furthermore, based on these data an iso-resistivity map of the thickness of the soft layer and the hard rock layer were made to describe the thickness distribution of the soft layer.

| Point | Resistivity layer 1 (ohm-m) | Resistivity layer 2 (ohm-m) | Bed rock Resistivity (ohm-m) |
|-------|-----------------------------|-----------------------------|-----------------------------|
| a     | 25 - 103                    | 7.1                         | 34.5 – 96.9                 | 101 |
| b     | 19.2 – 86.4                 | 26                          | 50.4                        | 45  |
| c     | 13.8 – 40.1                 | 13.9                        | 54.8                        | 45  |
| d     | 24 - 133                    | 11.6                        | 15.9–35.4                   | 9.5 |
| e     | 18 - 165                    | 7.7                         | 53.1                        | 57.7|
| f     | 20 - 68                     | 8.3                         | 52.6                        | 54.8|
| g     | 43 - 147                    | 14.1                        | 52.6                        | 53.2|
| h     | 14.2 - 87                   | 23.6                        | 68                          | 30.7|
| i     | 76 - 134                    | 22                          | 59.7                        | 33.5|
| j     | 29.8 - 131                  | 23.9                        | 35-79                       | 49.8|
| k     | 19.6 -154                   | 21.6                        | 15.4-248                    | 67.7|
| n     | 12 - 52                     | 7.37                        | 15–51.6                     | 40.03|
| o     | 48 - 178                    | 35.3                        | 23-62                       | 40.8 |
| p     | 48.9 - 135                  | 5.13                        | 21–57.8                     | 22.17|
| q     | 26.8 - 132                  | 13.4                        | 15-87                       | 60.2 |
| r     | 28 - 75                     | 13.7                        | 30– 85.5                    | 42.4 |

Based on Table 1 and by paying attention to the drilling results that coincide with the point 16 of geoelectric resistivity measurement, it can be interpreted that layer 1 is relatively soft rock in the form of sand silt and silty sand which sometimes contains gravel, while layer 2 is sand gravel silt. The bed rock is breccia in drill-log identified as hard sand silt containing boulder. The thickness of the soft layer has the thickest pattern in the middle of the survey area and gradually thinning towards the north and south.

4.2 HVSR method

4.2.1. Calculation of sediment thickness using the $V_{530}$ method

Calculation of sediment thickness using the $V_{530}$ method is carried out using the equation [11][12]:

\[ V_{530} = \frac{S}{530} \]

where $S$ is the sediment thickness.
where \( h \) is the sediment thickness, \( V_{s30} \) is the wave velocity \( V_s \) at the measurement point \([13]\), and \( f_o \) is the dominant frequency of the ground obtained based on HVSR measurements. The results of the calculation using the \( V_{s30} \) method are given in Table 2.

Calculation of sediment layer thickness above the bedrock layer to the north of survey areas by using inversion of microtremor measurements was conducted in 9 measurements. The points B, C, D, E, F, and I were the measurement points with soil conditions not cut yet. The method used in this calculation was the ellipticity curve inversion obtained based on the ratio of the microtremor spectrum to the horizontal component to the vertical component spectrum (HVSR) \([14]\). By using HVSR ellipticity curve inversion method, \( V_s \) profile can be obtained. The ellipticity curve and profile \( V_s \) of the inversion results, for example for point 1, were given in Figure 2. By using \( V_s \) of 760 m/s as reference \( V_s \) for bedrock \([11][12]\) then the sediment thickness beneath the measurement points can be obtained.

**Table 2. Sediment thickness**

| Point | \( f_o \) (Hz) | \( V_{s30} \) (m/s) | Sediment thickness by using the \( V_{s30} \) method (m) | Sediment thickness from inversion (m) |
|-------|----------------|---------------------|-------------------------------------------------|-----------------------------------|
| 1     | 3.7            | 423.01              | 29                                              | 27                                |
| 2     | 2.94           | 429.82              | 37                                              | 32                                |
| 3     | 3.79           | 429.54              | 28                                              | 27                                |
| 4     | 3.59           | 428.42              | 30                                              | 27                                |
| 5     | 6.26           | 426.45              | 17                                              | 16                                |
| 6     | 4.46           | 424.38              | 24                                              | 22                                |
| 7     | 3.77           | 428.08              | 28                                              | 27                                |
| 8     | 5.8            | 426.53              | 18                                              | 15                                |
| 9     | 3.93           | 429.6               | 27                                              | 25                                |

**Figure 2.** Ellipticity curves of point 1(a) and \( V_s \) profiles result from inversion (b)

The comparison of the thickness of the sediments from the \( V_{s30} \) calculation method with the inversion method is given in Table 2, it appears that the two methods give results that are not much different, with a sediment thickness value from inversion method relatively a little bit less than from \( V_{s30} \) calculation.

**4.3 Comparison bed rock depth from geo-electric and HVSR methods**

The apparent resistivity curves were obtained from geo-electrical resistivity data have similar curves with the HVSR ones (Fig. 3). From the inversion, the depth of bedrock from geo-electric resistivity data compared to HVSR result give slightly difference. For geo-electric point \( p \) which coincides with HVSR 1 measuring point gives thickness sediment 27.3 m, while HVSR analysis results are 27 m.
5. Conclusion

Based on the description in the previous section concerning the geological conditions of the area of investigation about the geoelectric and HVSR data, it can be concluded that based on geoelectric measurement data, soft rock layer one is suspected to be sandy silt and silty sand with a thickness varying between 7.1 - 35.3 m. The second soft layer has a thickness of 9.5 - 60.2 m in the form of gravel sand silt. While the bed rock is in the form of breccias whose thickness are not detected by this geoelectric measurement, the apparent resistivity curves were obtained from geo-electrical resistivity data have similar curves with the HVSR ones. From the inversion, the result of the bedrock depth from geo-electric resistivity compared to HVSR ones give difference slightly.
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