Integrated geophysical methods for determination of lithology and unstable slope, case study: Cipogor area, PSK-1 mini hydro power plant

G A Prawira¹, F Arphan¹, Darrian¹, D D Warnana¹, Sugiyono², T O Anggrea³

¹Department of Geophysical Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia
²Medco Hidro Indonesia, The Energy Building, Jenderal Sudirman Lot 52-53, Jakarta 12190, Indonesia
³Department of Physics Engineering, Sepuluh Nopember Institute of Technology, Surabaya 60111, Indonesia

*Corresponding author e-mail: adri.prawira@gmail.com

Abstract. Cipogor is an area in PSK-1 Power Plant located at West Java. This area has a damaged flushing canal due to landslides at 2018. Therefore, integration of two-dimensional resistivity (ERT), one-dimensional resistivity (VES), and Digital Elevation Model is conducted to determine lithology and unstable slope that characterized by water saturated weak zone. Resistivity models from ERT and VES method are integrated with elevation data from DEM. Lithologies from interpreted VES model are as follows: Alluvial (6 – 70.06 Ωm), Tuff sediments (12 – 28.44 Ωm), sandstone sediments (1.96 – 9 Ωm) and Breccia (42.07 – 88.6 Ωm) from Koleberes Formations. There is an anomaly (12 – 28.98 Ωm) within sandstone layer. From ERT model, there is low resistivity zone (2 – 5 Ωm) interpreted as weak zone and moderate resistivity zone (16 – 24 Ωm) around 9 - 17 m in depth, interpreted as sediments transported during previous landslide. From the interpretation, it can be concluded that there is weak zone in depth 5-6.91 m and 17 - 20 m which is a weathered sandstone of Koleberes Formation and a sediment layer that transported from previous landslide in depth 9-17 m. Heaving is occurred in this layer and preventing any large landslide to occur but cannot prevent soil creeping in the area.

1. Introduction
Landslide is a downhill movement of slope-forming material under the influence of gravity and water [1]. PSK-1 Hydro Powerplant reside in a foothill located at Cianjur, West Java. Because of this, it has steep slopes. There are water springs located on upper part of the hill. This condition is one of the primary factors of the landslide.
Based on Regional Geology Map of Sindang Barang and Bandar Waru from Koesmono, Kusmana & Suwano (1966), PSK-1 Powerplant have four geological unit [Figure 1], which are:

- Mount Patuha lava and volcanic mudflow \( [Q_v(p, l)] \), consists of andesite lava from Mount Patuha. This geolocal unit are deposited at surface, estimated from Holocene era.
- Lava and volcanic mudflow Mount Kendeng \( [Q_L(K, W)] \), consists of lava flow interspersed with lava mudflow deposit like andesite breccia and tuff breccia. It is located at North side of the powerplant. It is estimated that this unit is deposited at Pleistocene era.
- Inseparable pyroclastic deposited \( [Q_Tv] \), consists of breccia andesite, breccia tuff, and lapilli tuff. This unit is deposited at Pleistocene – Pliocene era.
- Koleberes Formation \( [T_{mk}] \) consists of finely laminated tuff sandstone, crystal tuff, breccia tuff and breccia with andesite. It is located at the South side of the powerplant and deposited during Late Miocene era.

The Cipogor area itself located near a headpond that is used to control the flow of water. Not only that, this area is passed by flushing canal. South of the flushing canal is a slope leading down to Cibuni River below the study area. Based on the previous geological analysis by Medco Energi geology survey team in 2018, Cipogor consists of three main lithologies; alluvial, pyroclastic deposit and sandstones from Koleberes Formation. This area has suffered continuous landslide in 2018, resulting massive damage to flushing canals near headpond. Up to this day, there are some indications of soil creeping in the area.

Our aim of study is to interpret the subsurface condition of the area to determine landslide or soil creeping potential in the area. To achieve this, we use resistivity methods integrated with remote sensing data. Resistivity method is a geophysical method that measures the soil ability to “resist” the electrical current. This method is divided into two methods, which are Vertical Electrical Sounding (VES) or one-dimensional resistivity and Electrical Resistivity Tomography (ERT) or two-dimensional resistivity method. One-dimensional method resulted vertical soil boundary, meanwhile two-dimensional method could give clearer view on weak zones and estimated landslide slopes. ERT method is used because it
can provide effective and useful information on the distribution of resistivity contrast that often correspond with to the boundaries between sliding material and bedrock by identification of water saturated zone. Not only that, ERT method can be considered suitable for geometrical characterization of a landslide body. This method still requires calibration results from other geophysical or geological data, especially when a very wet material is investigated [2]. Therefore, we integrate one-dimensional, two-dimensional resistivity and remote sensing data with geological and environmental condition information to give accurate analysis of Cipogor area.

2. Methods

2.1 Resistivity Method

Resistivity is the physics parameter of rock that explains the ability of rock to conduct electricity. The greater the resistivity, then the smaller the rock's ability to conduct electricity. Resistivity is invariant, it means that it does not depend on the shape or length of the medium, as opposed to electrical resistance [3].

\[ \rho_a = \frac{\Delta V_{MN}}{I}.K \]  
\[ K = 2\pi.\left\{ \frac{1}{AM} - \frac{1}{MB} \right\} - \frac{1}{AN} \cdot \frac{1}{NB} \right\}^{-1} \]  

**Figure 2.** Illustration of electrical current propagation and its equipotential field when using 2 Current Electrodes. Reprinted from Geoelectrics, BGR, retrieved 21 October 2019, from https://www.bgr.bund.de/EN/Themen/GG_Geophysik/Bodengeophysik/Geoelektrik/geoelektrik_node_en.html. Copyright by Ursula Noell. Reprinted with Permission

The resistivity method itself is an active geophysical method by measuring the potential difference generated due to the injection of an electrical current. From the measured potential difference value and the amount of current injected, we can determine the resistivity variation of each layer below the measurement point. Figure 2 shows the current injection and flow from point A and B. The electrical potential of that current is detected from point M and N using steel electrode.

The resistivity value is also influenced by water content in the soil due to high electrical conductivity of water. Therefore, the resistivity method can be used to detect subsurface saturated zones [4]. Soil, rocks or other material where water is difficult to fill or flow (impermeable), can resulted to high resistivity value.

In reality, subsurface rocks are not a homogeneous medium so the value obtained is no longer actual resistivity but an apparent resistivity (\(\rho_a\)). Apparent resistivity is not a physical property of the subsurface media, unlike the original resistivity. In the sense that all data obtained in the field is apparent resistivity. The resistivity value can be formulated as follows [5]:

\[ \rho_a = \frac{\Delta V_{MN}}{I}.K \]  
\[ K = 2\pi.\left\{ \frac{1}{AM} - \frac{1}{MB} \right\} - \frac{1}{AN} \cdot \frac{1}{NB} \right\}^{-1} \]  

**Figure 2.** Illustration of electrical current propagation and its equipotential field when using 2 Current Electrodes. Reprinted from Geoelectrics, BGR, retrieved 21 October 2019, from https://www.bgr.bund.de/EN/Themen/GG_Geophysik/Bodengeophysik/Geoelektrik/geoelektrik_node_en.html. Copyright by Ursula Noell. Reprinted with Permission
Variable $\rho_a$ is apparent resistivity of the measured location in $\Omega$m. $V_{MN}$ is potential difference of the location measured from M and N electrode in Volt. $I$ is the injected electrical current in Ampere. Factor $K$ is called geometric factor of the configuration used for acquisition. The distance between AM, MB, AN, NB are length between electrodes in meter.

The value of apparent resistivity depends on the geometry factor $K$ value of the electrode configuration used. Each configuration has its own characteristics. There are factors to consider when choosing a configuration when measuring, which are: amount of space available to lay out the configuration, the sensitivity level of the electrode configuration to vertical and horizontal changes below the surface, horizontal data coverage, and also which method (one or two-dimensional) that is used [6].

In this study, we use Vertical Electrical Sounding and Electrical Resistivity Tomography. One major difference between two methods is each method used different configuration. Our aim for this method is to create a model where we can determine the weak zones and the landslide plane caused by water impermeable layer.

VES acquisition were carried out with 7-point VES measurements. The location of the VES point can be seen in Figure 3. The acquisition of the VES method uses Schlumberger configuration to obtain sufficient penetration depth as well as good vertical resolution. The length of VES measurement range is 50 m - 140 m, so that expected maximum depth can reach 25 m - 75 m. The measurement data were processed using one-dimensional inversion program to make one-dimensional resistivity modeling.

The ERT acquisition was carried out on the west side of Cipogor area and close to the damaged flushing canal. Measurements were made with a track length of 100 m and electrode spaces is 4 m. The expected maximum depth is 20 m. Electrode configuration used in ERT measurements is Wenner-Schlumberger configuration to produce good horizontal resolution as well as sufficient vertical resolution. The measurement data are then processed two-dimensional resistivity inversion program to create a two-dimensional resistivity cross section model. All of the data are then correlated to create three-dimensional model.
2.2 Digital Elevation Model

Digital Elevation Model or DEM is a digital representation of land surface topography. DEM is the most widely used basis for making digital maps of the earth. In digital mapping, each part of the map is divided into several blocks. The slope of the land in each block is irregular so it is necessary to minimize the slope variability in one block. In theory, this variability can be reduced by reducing the slope angle intervals used for the block division criteria [7]. In remote sensing, image analysis is carried out on an image with an overhead perspective (top view perspective) that is represented digitally. Our aim of using this model is to produce elevation data at each coordinate and integrated it to resistivity model to create three-dimensional model based on resistivity value.

Digital Elevation Model was processed from drone aerial photos taken by Medco Energi Lead Geologist using satellite image/overhead image with coordinates processing program. This program produces DEM and Orthophoto. DEM was validated using Google Earth by converting it into .kml file. If the results are off, DEM is georeferenced using mapping program by comparing landmark coordinates of an established map to the topography of that landmark. From this model, resistivity measurement points elevation can be extracted and it’s used to correlating resistivity data.

3. Results and Discussion

Aerial drone photos were used to produce Digital Elevation Model. All of the photos were merged and then processed to produce Digital Elevation Model by using satellite image processing program.

Figure 4 shows the processed Digital Elevation Model of Cipogor area. Yellow to red colour shows an elevation of 620 m – 729 m above mean sea level. From the produced DEM, it is known that Cipogor area has an elevation around 650 - 720 meter above mean sea level.

Resistivity measurements are carried out during the rainy season. Therefore, the resistivity value is estimated to have smaller value than normal resistivity value of rocks. In this Paper, we interpret the data based on resistivity contrast of the data, rather than standard resistivity value of rocks. In VES method, each VES point are interpreted and then correlated to form a model. After all points are processed and interpreted, the results showed five rock or soil layer with the following resistivity range;
Table 1. Interpreted Layer Resistivity from VES Method

| Rock layer type                          | Resistivity                                      |
|-----------------------------------------|--------------------------------------------------|
| Alluvial                                 | 6 – 70.06 Ωm (varying because easily affected by surface condition) |
| Pyroclastic tuff deposit                | 12 – 28.44 Ωm (varying because near surface) and 50 Ωm (very high anomaly in VES 4F) |
| Saturated sandstone from Koleberes Formation | 1.96 – 9 Ωm                                      |
| Anomaly sediment                         | 12 – 28.98 Ωm                                    |
| Breccia sandstone from Koleberes Formation | 42.07 – 88.6 Ωm                                  |

Table 2 shows interpreted one-dimensional resistivity model from VES method. Based on this interpretation, Cipogor area has 5 layers. At the top there are alluvial and tuff deposits which have varying resistivity value possibly because of external factor, for example there are hard rocks at the surface that could produce higher resistivity value. Based on previous study, the surface of this area is covered by alluvial layer, and followed by thin pyroclastic tuff deposits that tend to thin toward Southern direction. Below the tuff deposits, there is a sandstone layer from Koleberes Formation.

Figure 5 shows the two-dimensional resistivity model from inversion of ERT data. Red coloured resistivity contrast indicates a high resistivity value of 40-60 Ωm, while the yellow colored indicates a medium resistivity of 20-30 Ωm. Green indicates medium-low resistivity of 10-19 Ωm and blue indicates low resistivity of 0.2-8 Ωm. There is high resistivity contrast at the surface to 5 meters below
the surface that can be interpreted as an alluvial layers and tuff deposits, whereas the low resistivity zone can be interpreted as a weak zone where underground water flows. There is a possibility that underground water flow originates from water springs on the upper North side of the area (left to the ERT model), indicated by the presence of rice fields owned by local community or from fracture of the old flushing canal which was damaged by landslides in the previous year. There is a small quantity of water flowing in the damaged canal. The water flows into fractures of the damaged canal and become a water infiltration points. On the meter 47 there is a medium resistivity zone (15-29 Ωm). This can be interpreted as a soil sediment that have been lifted as a result of sediment transportation during the landslide in 2018. Heaving occurred in this sediment so that the direction of the water flow changes and water discharged onto the surface.

![Figure 6. 3D Interpretation Model from VES Data Correlation](image)

Figure 6 shows three-dimensional interpretation model from correlation of one-dimensional resistivity models of each VES points. The North side of the model is a former flushing canal and road, while the South side leads to a slope. The East side leads to headpond and the west side is a road that lead to the power house. From the three-dimensional model above, it can be seen that the area is dominated by Koleberes Formation. The surface is covered by Alluvial layer, which is proved by a landfill at the surface of the northern part of Cipogor. The beige color indicates pyroclastic tuff deposits. Yellow color indicates water saturated layer from weathered Koleberes Formation sandstone, while the orange color indicates anomalous sediment due to landslides in 2018. The gray color indicates breccia sandstone of the Koleberes Formation. From the model, it can be seen that the presence of a sediment due to landslides in 2018 have a North-South direction. This sediment has a greater resistivity compared to weathered sandstones and it is interpreted as an impermeable layer.

ERT inversion model correlated with VES model shows an alluvial layer and tuff deposits at the surface with high resistivity (40 – 70.06 Ωm). Furthermore, it appears that the presence of anomalous sediments in VES model Has a very similar position with moderate resistivity layer in the ERT model. This proves the anomalous sediments exist at 10-12 m depth below the surface, and that layer was lifted and heaving occurred. That phenomenon caused the anomalous sediments to obstruct the soil movement so that no large landslides occur. However, based on Medco Power Geological Survey Report there is still soil creeping. It shows that the sediment doesn’t entirely stopped subsidence in Cipogor.

4. Conclusion
From the interpretation of ERT and VES model with topography values from Digital Elevation Model, it can be concluded that there is a weak zone at 5 - 6.91 m and 17 - 20 m in depth that indicates a water-saturated layer from weathered sandstone layer due to 2018 landslide. Furthermore, there is an
anomalous sediment (12 – 29 Ωm) at 9-17 meter in depth. It is possible to become a landslide plane but at the same time heaving occurs and prevent potential large landslide.

Special Thanks
Special Thanks to Mr. Widya Utama from Geophysical Engineering Department ITS, Mr. Pramadi Praja, Mr. Ishom Subkhan from Medco Energi for administration support during study and Iqbal Hamami from Gatupa Consultant for the help during data acquisition.

Appendix A

Figure A1. Cipogor Area in 2018. The new Flushing canals has been built near the water flow from Headpond to Power House. Reprinted from “Formulir Investigasi dan Monitoring : Longsoran Area Jalur Flushing Headpond Lama Desember 2018” by S., Sugiyono, 2018. Copyright PT. Pembangkitan Pusaka Parahiangan.

Figure A2. water presence at 50 meters to the South of ERT line
Figure A3. Correlation Between Interpreted ERT result with Interpreted VES Result

Reference
[1] Clague J J 2012 Landslides : types, mechanisms and modeling (New York: Cambridge University Press) p 2
[2] Perrone A, Lapenna V, and Piscitelli S 2014 Electrical Resistivity Tomography Technique for Landslide Investigation: A Review Earth-Science Rev. 135 65-82.
[3] Pierce Kristen 2012 Geophysical Investigation Electrical Resistivity Survey (California : U.S. Department Of Interior Bureau Of Reclamation Technical Service Center Seismotectonics And Geophysics Group) p 8
[4] Anderson N L 2006 Selection of appropriate geophysical techniques generalized protocol based on engineering objectives and site characteristics Proc. Highway Geophysics-NDE Conf. (Missouri : Missouri S&T) pp 29-47
[5] Telford W M, Geldart L P, Sheriff R E 1990 Applied Geophysics, 2nd ed (Cambridge: Cambridge University Press) p 524
[6] Reynolds J M 2011 An Introduction to Applied and Environmental Geophysics. 2nd ed. (Sussex: Wiley-Blackwell) p 294
[7] Riyanto L 2009 Pemetaan Daerah Potensi Banjir dengan Segmentasi Data Digital Elevation Model. Studi kasus: DAS Ciliwung di DKI Jakarta 2007 (Jakarta: Universitas Indonesia) pp 7-8