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Geophysical survey of landslide movement and mechanism in Gorontalo Outer Ring Road, Gorontalo

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Abstract. Gorontalo infrastructure development focus on improving transport efficiency through the development of Gorontalo Outer Ring Road (GORR). The Government has set the cost 750 billion rupiahs for GORR and planned will be completed by 2019 but constrained by landslides. This research aims to reconstruct and identify the type and mechanism of a landslide at GORR. The result of this research is landslide type and mechanism in the research area. The method used is 2-dimensional electrical resistivity sounding with Wenner-Schlumberger configuration. Landslide mechanism is analyzed based on the resistivity value table on Vingoe resistivity value supported by geological data. Based on geophysical data, subsurface conditions showed blocks of limestone with a resistivity value about 132 Ωm and marked red-purple colors. These blocks of limestone interpreted as the result of the weathering process and buried in weathered clastic limestone. Landslide movement type is sliding movement and concluded as a rockslide. There is a potential for subsurface landslide blocks occur caused by the weathering process on fractures in the research area. The future prevention steps are by increasing the surface water absorption by planting in the geotextiles or prevent water infiltration in the landslide area. In addition, manufacturing retaining wall is also required.

1. Introduction

Sulawesi Island is formed by the collision of three large plates, namely Eurasian, Indian-Australian, and Pacific-Philippine Sea [1]. These conditions making Sulawesi Island have various geological conditions [2] and the typical Sulawesi Island formation such as the letter "K" with steep mountainous morphology around it [3].

The North Arm of Sulawesi is the Tertiary Island arc [3]. Most of The volcanoes in the North Arm Sulawesi is a stratovolcano, type of volcano with a slope of 10 – 30^{o} [4]. In addition, the structural events that occurred during the two periods [5] in the North Arm of Sulawesi resulted in intensive fractures pattern formed on the northern arm of Sulawesi, particularly the Gorontalo region.

Gorontalo is a part of island arc formed by subduction of Celebes Sea plate and North Arm of Sulawesi during Eocene [6]. This event deformed the rocks and form a Gorontalo fault. Gorontalo fault is an active fault that extends from Kwandang Bay to Gorontalo Bay. This fault passes through Limboto Lake as a fault zone and affects the vulnerability of landslides in the surrounding area.

Infrastructure development of Gorontalo is focusing on improving transportation efficiency, especially roadway access. According to Petriella [7], the government has prepared 750 billion rupiahs for the construction project of Gorontalo Outer Ring Road (GORR). This development is targeted to be completed in 2019, but the construction process obstructed by landslide occurring along the GORR.

This problem has a major impact on infrastructure development of Gorontalo, so it needs a proper and efficient preventive solution. Preventing solutions related to landslide problems can be found by identifying the type of landslide. The results can become a reference to construct a landslide disaster management plan in order to handle the landslide problem.

Figure 1. Aerial view of a landslide in Gorontalo Outer Ring Road.

Previous research of Usman et al [8] shows the landslide type in this area is plane failure based on Hoek and Bray classification [9]. The slip plane material of the plane composed by clay due to weathering process. Landslide in this area is influenced by fractures resulted in the main regime in an east-west direction.

This landslide needs to be further investigated. Subsurface surveying is required to determine the condition of the material under the surface in detail. This research aims to identify the condition of subsurface and the mechanism of a landslide at GORR by using 2-dimensional type electrical resistivity surveying method. This research is expected to be a reference for the government in terms of handling and prevention of landslides on the GORR.

2. Location and Research Method

The study area is located at coordinates N 00º39'42,62"; E 122º52'11,27", is administratively located in Isimu Raya, Tibawa District, Gorontalo Regency, Gorontalo Province. The research area is located 34,2 Km from Universitas Negeri Gorontalo with travel time about 1 hour and 5 minutes by using a car (figure 2).

The research area is located at the GORR project development area which was started in 2013. This project is a Gorontalo local government mega project which is included in the main priority of Gorontalo Future Construction Plan. The development project is targeted to be completed by 2019 and can be functioned soon. However, the development process is disrupted due to landslides.

Observation based on the principles of basic field geology observations. Data acquisition using electrical resistivity method with Wenner-Schlumberger configuration to detect subsurface conditions in 2-dimensional and to identify landslide conditions in the study area.

Figure 2. Research area location from Universitas Negeri Gorontalo.

The method used in this research is field observation and data acquisition by using 2-dimensional electrical resistivity surveying with Wenner-Schlumberger configuration for getting subsurface data. Field observations included observations on the geomorphological and geological aspects of the research area. Observation based on the principles of basic field geology observations. Data acquisition using electrical resistivity surveying with Wenner-Schlumberger configuration to detect subsurface conditions in 2 dimensions and to identify landslide slip plane in the study area.

Electrical resistivity is a geophysical instrument that can identify subsurface conditions. The principle is using electricity injected into the earth to identify the value of material resistivities in the subsurface. These measurements include the measurements of potential differences, current strength, and electromagnetic fields occurring naturally in the earth as well as by injection of currents into the earth [10].

Generally, Electrical resistivity method often uses 4 electrodes mounted on a straight path as on figure 3. The electrode is divided into two functions, the current electrode (C1-C2) with the furthest point from the datum point and the potential electrode (P1-P2) located between the current electrodes [11].

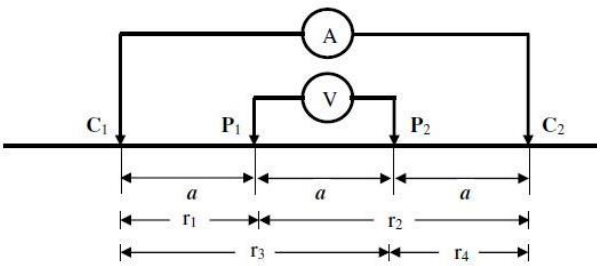

Figure 3. Electrical resistivity configuration scheme. V stand for potential difference, A for strength current, C for current electrodes, and P are potential electrodes [12].

One way to be able to know the subsurface condition is by performing 2-dimensional electrical resistivity surveying [12]. According to Ohm's Law, the relationship between the electrical potential differences (V), the current strength (I), and the value of the material resistance (R) are show on equation (1):

$$V = I\ x\ R \tag{1}$$

The current electrodes (C1, C2) and potential electrodes (P1, P2) configuration used in the measurement in the research area is the Wenner-Schlumberger configuration. This configuration can show subsurface conditions in 2D so as to facilitate the interpretation of the landslide slip plane.

The research stages consist of 4 stages. Research stages consist of research preparation, collecting and acquisition, analysis and interpretation, and scientific publications.

2.1. Preparation phase

The preparatory stage of the research is a preliminary stage before conducting research and data collection in the field, and also consist of preliminary study on geomorphology, lithology and regional tectonic setting, study of landslide disaster history in the research area to find out general description about geological condition and potential of landslide that will occur in the study area. This stage also includes preparing libraries/literatures related to the issues to be studied.

The field equipment used in this research is: GPS (Global Positioning System) type Garmin Oregon 550; geological hammer (point tip); 1 set of Electrical Resistivity Meter IPMGEO 4100 to measure material resistance value of material; Mineral and grain size comparator; Loupe 30x and 60x magnification; 50m roll meter; Digital camera; Sample bags; 0.1 N HCl solution; Stationeries (pens, pencils, colored pencils, color markers, marker markers, notepads, description sheets, clipboards); other supporting equipment, such as field clothes, field shoes, and others.

2.2. Collecting and acquisition phase

Data collection consisted of field observation consisting of observation of geomorphology and lithology aspect and undertaking subsurface data acquisition by using Electrical Resistivity Meter type IPMGEO 4100 using Wenner-Schlumberger configuration to identify the resistance value of subsurface material.

2.3. Analysis and interpretation phase

The results of the subsurface data acquisition using geometrical resistance of the Wenner-Schlumberger configuration type with the number of 16 electrodes, spaced between the 10 meters electrodes and the topographic correction will feature a subsurface profile in 2-dimensional view. The process of reconstruction of the inversion model is carried out continuously by the program to obtain maximum results in interpreting subsurface conditions in GORR.

Table 1. Resistivity value of material [13].

Material/Soil/Rocks	Resistivity (Ωm)
Clay	1 – 100
Soil	60 – 130
Clayey Soil	100 – 150
Sandy Soil	600 – 6000
Unconsolidated Sand	1000 – 100000
Pebble, Gravel, and Sand	100 – 6000
Limestone	90 – 5000
Basalt	15 – 9000
Crystalline Rocks	1000 - 1800000

Interpretation of these subsurface conditions is based on data analysis and interpretation by comparing the results of geomorphological observation, field lithology observation, and 2-dimensional inversion model derived from the acquisition of 2-dimensional electrical resistivity data of subsurface material types interpreted using Vingoe type resistance value in table 1 [13].

3. Result and Discussion

3.1. Geological condition of research area

The study area is included in a denudational hill area, with lithologic conditions composed by limestones. Rocks in the study area are white colored, bedded, grain size varies from silt to sand size, and carbonaceous. The rocks contain a number of fossils of gastropods and bivalve. Referring to Bachri et al [14], the rock type is a member of Clastic Limestone Formation (TQl) with an estimated age of approximately Pliocene-Pleistocene age.

Figure 4. Limestone outcrop in the research area.

Rock conditions affected by weathering due to tectonic processes and dissolution by surface water as in figure 4. The tectonic process causes the formation and distribution of fractures in rock outcrops. These fractures form intensively on the rock outcrops so that landslides can occur easily. Then the dissolution process occurs due to the influence of meteoric water that passes through the crack and dissolves the material of the slip plane into a clay-sized material. Thus, the role of biological factors, such as plants, also speeds up the weathering process in rocks and makes the fracture opening widen.

According to Usman et al [8], the main force regime on this area is relatively East-West. The regime direction affects the process of rocks deformation in this area. With the main force regime direction relatively East-West, it will result in a relatively southern-oriented weak zone following the slope, and precisely moving towards the GORR. This requires efficient and careful handling of government for the landslide prevention steps.

3.2. Subsurface conditions

The subsurface data is taken around the landslide area. The data was collected using the IPMGEO 4100 Electrical Resistivity Meter instrument to measure the resistivity value of materials and rocks beneath the surface. Data acquisition using the Wenner-Schlumberger configuration with a 100-meters trajectory trending North-South.

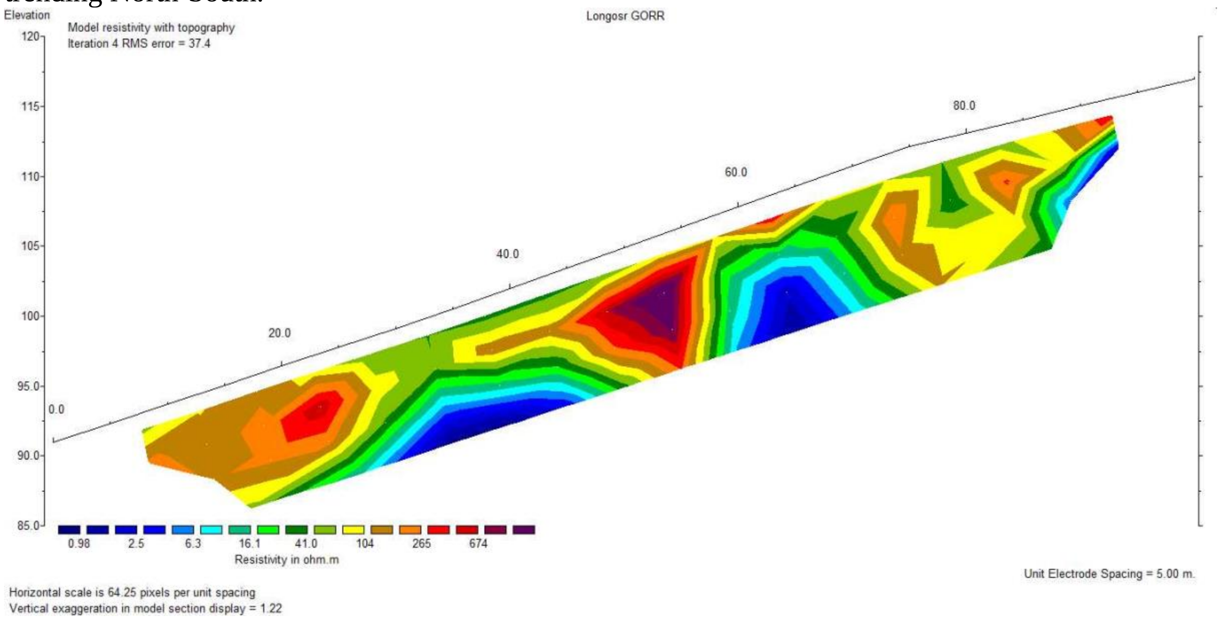

Figure 5. Inversion result from resistivity value of subsurface materials.

The subsurface cross-section shows in figure 5 is the result of the analysis and interpretation of field measurement data. The results of the data interpretation show varying resistance values in the research area with a range of about 0.5 μm marked by blue to 700 μm marked by purple.

Data collection is done on the hillside, so it is necessary to make a topographical correction on geophysical data. This will facilitate the interpretation of the landslide slip plane. Interpretation indicates the existence of a normal fault that triggers the occurrence of the landslide. Evidence of a descending fault observable on the surface is the presence of a depression zone in surface morphology.

The landslide slip plane is indicated by the green color with a resistance value of the type ranging from 15.1 - 40 μm. Based on this value, the slip plane composed of clay material as a result of dissolution and weathering (figure 5). This result is in accordance with material evidence on the surface found by Usman et al [8]. Clay material has waterproof characteristics due to its poor permeability but can shift very easily. This material composed the landslide slip plane in the study area and increase the chance of sliding to happen.

In addition, there is an identification of the existence of another slip plane with a steep slope. This field of slip through the GORR below the surface. This slip field can have a more massive impact on the GORR segment if there is movement resulted by the fault.

The blue zone indicates a low resistivity value. This zone is interpreted as a subsurface cave. This is a common feature of limestone areas. This cave can be formed from the process of dissolving by meteoric water and forming holes that can become groundwater channels.

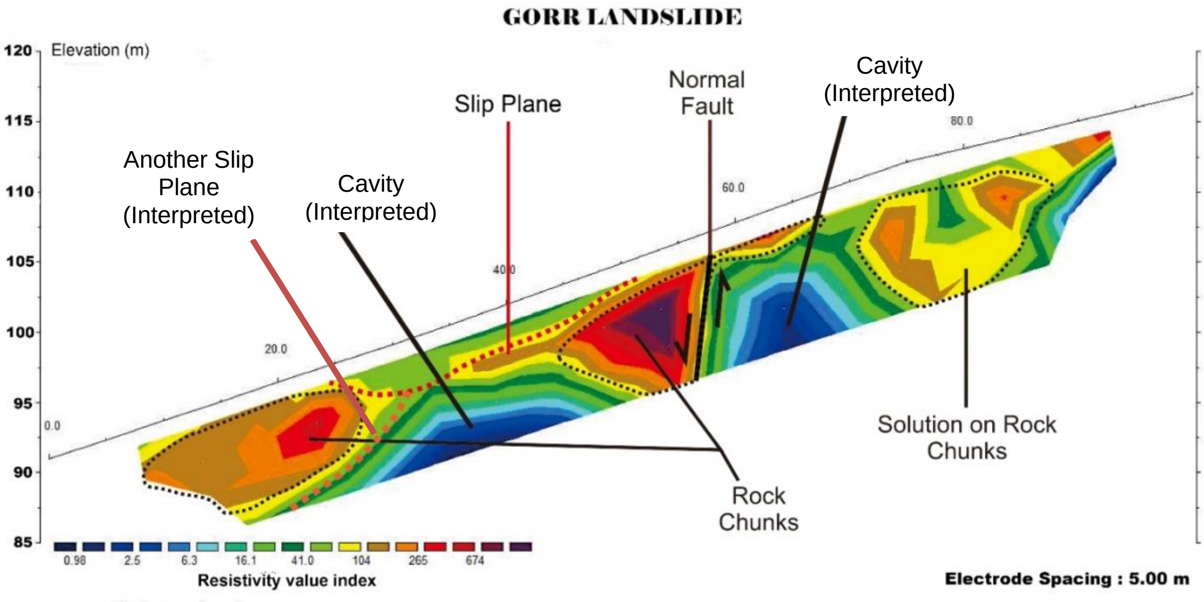

Figure 6. Interpreted subsurface condition based on resistivity value.

3.3. Landslide movement and mechanism
According to the observation and research data, Landslide movement right towards the GORR. The type of movement is rockslide because of the landslide material predominantly by rock chunks material sliding downslope. This result is similar to Usman et al [8] research before.

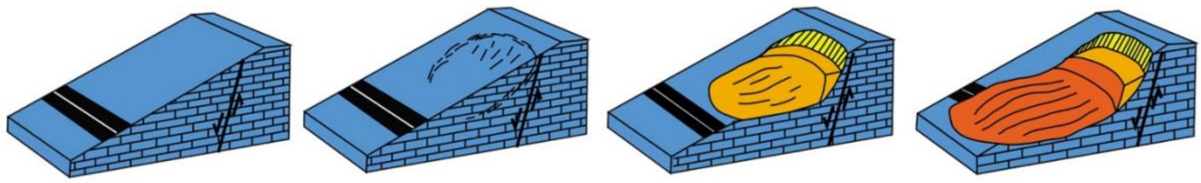

Figure 7. Landslide mechanism in research area.

Landslide mechanism affected by the tectonic process resulting in fracture sets in the study area as showing in figure 7. This fracture later becomes the way of the meteoric infiltrated and start to solute the rocks. As the time going on, the landslide slip plane formed due to tectonic influence and advanced by the dissolution of the material along the landslide slip plane. The active tectonic process supported by dissolving processes results in massive landslide happen and give a bad impact on the GORR.

This landslide problem requires an appropriate handling solution from the government. This is to prevent and resolve any future landslides hazard that potentially endangered the local infrastructure around GORR. Several ways of handling that can be done such as reduce the infiltration of meteoric water using geotextile and revegetation, build a landslide retaining wall or anchor works at the landslide slip plane, and injecting cement (grouting) in the fault so as to reduce the effects during mass movement.

4. Conclusion
The results show that avalanches on the GORR are affected by a normal fault. The movement of this fault resulted in the rock mass movement and form a landslide slip plane at the GORR segment due to intensively weathering process. This problem requires an appropriate governmental enforcement solution to avoid further landslides in the future. For that, more detailed research needs to be done related to construction and engineering to overcome the landslide problem.

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