Identification of Construction Failures Due to Landslide Using Resistivity Methods on Kayulangi - Tarengge Km 531 + 600 Road

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Abstract. Landslides are one of the natural indications of equilibrium their morphological forms, mass transfer in landslide countermeasures. Various research methods can be carried out both in general and detail. causes of landslides. The purpose of conducting the research is to identify the behavior of landslides in terms of soil/rock layers and groundwater availability with the aim of identifying potential indication of construction failure. Based on the results of the research, the landslide on the north side of KM 531 + 600 based on the results of the field identification shows that the landslide material is in the form of sandy clay with the type of landslide is creeping with a maximum landslide depth of 3m and a slope length of 30m. Recommended treatment is the construction of a retaining wall with a distance of at least 3m from the shoulder of the road combined with the arrangement of surface water flow drainage on slopes. The retaining wall is equipped with a pipe to drain groundwater with a pipe diameter of at least 2 inches and a maximum space between the pipes of 1m, and on the KM 531 + 600 drainage channel it is necessary to carry out construction rehabilitation and equipped with a sediment pond and channel construction designed to reduce flow speed surface water.

1. Introduction

Landslides are geological events that occur due to the movement of rock or soil masses. Landslides can also be interpreted by the event of moving material from a high place to a lower place. Landslides are one of the natural indications of equilibrium their morphological form, the mass transfer of material in a landslide event is a behavior that can occur both naturally and as a result of human action. In the countermeasures of landslides, various research methods can be carried out both in general and in detail. One of the identification methods that can be used is by using the soil/rock layer identification approach and groundwater availability which is part of the parameters causing landslides.

The implementation of Resistivity Testing is the act of identifying landslide behavior using an electrical approach where each soil/rock material has a different electrical conductivity, this electrical conductivity character is then interpreted as a layer of soil/rock, besides the interpretation of soil/rock layers can also be used to identify locations groundwater layer and slip plane. In the Resistivity Investigation study of the Kayulangi-Tarengge Road Section KM 531+600, resistivity testing was carried out as supporting data to support construction activities, especially to review the design of the construction plan and groundwater availability in the soil/rock layer in the road layer.
2. Methodology
The geoelectric resistivity is a method in geophysics that studies the properties of electricity in the earth. The detection on the surface includes the measurement of potential, current, and electromagnetic fields that occur either naturally or as a result of an injection of currents into the earth. In the resistivity geoelectric method, an electric current is injected into the earth through two current electrodes (located outside the configuration). The stages of research implementation are;

2.1 Preparatory work
Preparatory and preliminary work includes:
- Collecting existing data and can support the implementation of work (topographic maps, hydrogeological maps, geological maps with a scale of 1: 250,000, and other supporting literature).
- Prepare personnel and equipment that will go to the field and calibrate the equipment used.
- Prepare equipment for each person who will go to the field.
- Taking care of equipment delivery, field orientation, and others

2.2 Geoelectric Investigation
Data was collected directly in the field using the Wenner configuration with the following steps:
- Determine the direction of the stretch using a compass
- Determine the track distance
- Installing the current and potential electrodes
- Assembling the device by connecting the S-Field unit with a laptop and a current source

2.3 Data Analysis and Result
Processing of geoelectric resistivity data in this work begins with processing synthetic data results (forward modeling). This data is obtained from a synthetic model created using Res2Dinv software which generates apparent resistivity, which is then converted using Res2Dinv software which generates a 2D true resistivity profile. The parameters in this synthetic model are then used as field parameters for data acquisition. The inversion result using Res2Dinv software is in the form of a 2D vertical profile that can show the true depth and resistivity distribution. The Res2Dinv output from the inversion result can also be a number/value in the form of coordinate data (x, y, z). The data in question consists of the accumulated distance of the electrode from the first electrode, the depth of penetration, and the true resistivity value. This data can be used as input data in the Surfer 10 software to describe 2D profiles

3. Result and Discussion
3.1 Geological Review of Research Sites
The interpretation of the general geological conditions referred to is the lithological arrangement/rocks that make up the work location which is reviewed regionally. The work location according to the Center for Geological Research and Development is included in the Regional Geological Map Sheet Malili, Sulawesi-2114 published by the Center for Geological Research and Development in 1991 (Figure 1).

Regionally, the work location and its surroundings are composed of 5 (five) rock formations in order of the youngest to the oldest, namely;
- The Bonebone Formation (Tmpb) consists of alternating sandstones, conglomerates, marl, and tuff claystone.
- Meta Limestone (Mtmm) consists of alabaster and left limestone.
- The Pompangeo complex (MTmp) is composed of schists, gneiss, marble, quartzite, batusabak, filite and local breccia.
- The Matano Formation (Kml) is composed of crystal limestone and calculative, marl and shale, chert inserts, and marl.
e. Ultrabasa complex (MTosu) composed of Haszburgit, lherzolite, wert, serpentinite, dunite, gabbro, and diabase.

Referring to the regional geological review, it is known that the details on the work location are composed of the Bone Bone Formation (Tmpb) and Lime stone Meta (MTmm). Considering that the secondary data is regional in nature, it is necessary to conduct a detailed review. Based on the results of the surface geological review, the soil/rock layers at the work location are described as follows;

The sandy loam layer is a brown surface layer of soft consistency - very soft

Clay sand mixed with gravel is a porous layer which is a layer of the aquifer with a relatively loose-very loose density

The brown claystone layer is semi-permeable with moderate to a stiff consistency

3.2 Field Testing Implementation

The technique of implementing field measurements using the Wenner method has the same spatial distance between each electrode, namely 15m with a length of each measuring path of 225m with a penetration depth of 40m (Figure 3).
Field testing is carried out on road segments, namely the KM531 + 600 segment on the side of the road body and slopes (Figure 4).

3.3 Test result

Determination of the resistivity value in rocks other than referring to the existing theoretical concept, in this case, the rock resistivity class value according to M.H.Loke, Lowrie & Milsom must be combined with surface geological conditions and data from the results of drilling, this is because theoretically the resistivity value between one rock with other rocks having almost the same or overlapping value classes so that surface geological data and drill data are needed as calibration parameters. Based on the results of data correlation and in situ testing in the field, the resistivity value at the job location can be classified as shown in Table 1.
Table 1. The resistivity value of the research

| No | Types of lithology exist on the surface | Resistivity Value (Ωm) |
|----|---------------------------------------|-----------------------|
| 1  | Sand Gravel (Road Embankment)          | >300                  |
| 2  | Sand gravel (Groundwater-intrusive Road Embankment) | 10-300               |
| 3  | Sand gravel (aquifer layer)            | 10-300                |
| 4  | Sandy loam (Semi impermeable layer)    | 0-10                  |
| 5  | Sandy loam (topsoil)                  | 0-10                  |
| 6  | Claystone (impermeable layer)         | >300                  |

Source: in situ test results

Measurements on the geoelectric path of KM 531 +600 are divided into 4 tracks, namely:

a. Tracking 1 and 2 parallel the road from the east-west direction
b. Pass 3 and 4 intersect perpendicular to the road in the north-south direction.

3.4 The results of these tests are described.

3.4.1 Tracks 1 KM 531 + 600

Based on the results of geoelectric testing and field observations, the stratigraphy on the 1 KM 531 +600 line is divided into 3 (three) types of bedding, sorted from the top layer, namely;

a. Sand mixed with gravel (road heap)
b. This layer is the top layer in the form of a road embankment divided into 2 parts, namely a layer of groundwater intrusion with a resistivity value of 10-300 Ωm at the electrodes E4, E8, E13 and while the layer that is not intruded by groundwater with a resistivity value > 300 Ωm is at the electrode. E1-E3, E5-E6, E8-E12, and E15-E16. The thickness of this layer varies between 4-8m. The layer with groundwater intrusion is a weak zone.
c. Clay sand mixed with gravel (aquifer layer)
d. This layer is a groundwater carrier layer with a resistivity value of 10-300 Ωm, divided into 2 zones, namely surface aquifers, and deep aquifers.
e. Sandy loam (semi impermeable layer)
f. This layer is a semi-waterproof layer with a resistivity value <10 Ωm, in the form of an insert with a thickness of 4-5m that forms the boundary between the surface aquifer and the deep aquifer.

The resistivity section and the results of the 1 KM 531 + 600 track interpretation can be seen in Figure 5.

3.4.2 Tracks 2 KM 531 +600

Based on the results of geoelectric testing and field observations, the stratigraphy on the 2 KM 531 +600 line is divided into 4 (four) types of bedding sorted from the top layer, namely;

a. Sand mixed with gravel (road heap)
b. This layer is the top layer in the form of a road embankment divided into 2 parts, namely a layer of groundwater intrusion with a resistivity value of 10-300 Ωm at the electrodes E1-E3, E8-E9, E13-E16 and while the layer that is not intruded by groundwater with a resistivity value > 300 Ωm is at the electrodes E4-E7 and E10-E12. The thickness of this layer varies between 4-10m. The groundwater intrusion layer is a weak zone with an indication of material shifting in the E7-E9 segment.
c. Clay sand mixed with gravel (aquifer layer)
d. This layer is a groundwater carrier layer with a resistivity value of 10-300 Ωm, divided into 2 zones, namely surface aquifers, and deep aquifers.
e. Sandy loam (semi impermeable layer)
f. This layer is a semi-impermeable layer with a resistivity value <10 Ωm, in the form of an insert with a thickness of 4-10m into the boundary plane between the surface aquifer and the deep aquifer.
g. Clay Rocks (impermeable layer)

h. This layer is a waterproof layer with a resistivity value > 300 Ωm.

The resistivity section and the results of the 2 KM 531 + 600 track interpretation can be seen in Figure 6.

3.4.3 Tracks 3 KM 531 +600

Based on the results of geoelectric testing and field observations, the stratigraphy on the 3 KM 531 +600 line is divided into 5 (five) types of bedding sorted from the top layer, namely:

a. Sandy loam (surface soil)
   It is a surface soil layer with a resistivity value <10 Ωm, has a very soft-soft consistency <5m thickness, scattered on the north and south sides of the road body. The landslide zone is on the north side of the road at electrode E5-E8 with an indication of the maximum landslide depth of 3m from the ground

b. Sand mixed with gravel (road heap)
   This layer is an intruded pile of groundwater with a resistivity value of 10-300 Ωm at the E8-E9 electrode.

c. Clay sand mixed with gravel (aquifer layer)
   This layer is a groundwater carrier layer with a resistivity value of 10-300 Ωm, divided into 2 zones, namely surface aquifers, and deep aquifers.

d. Sandstone Clay (semi impermeable layer)
   This layer is a semi-waterproof layer with a resistivity value <10 Ωm

e. Clay Rocks (impermeable layer)

f. This layer is a waterproof layer with a resistivity value > 300 Ωm.

The resistivity cross-section and the results of the 3 KM 531 + 600 track interpretation can be seen in Figure 7.

3.4.4 Tracks 4 KM 531 +600

Based on the results of geoelectric testing and field observations, the stratigraphy on the 4 KM 531 +600 line is divided into 5 (five) types of bedding sorted from the top layer, namely:

a. Sandy loam (surface soil)
   It is a surface soil layer with a resistivity value <10 Ωm, has a very soft-soft consistency <5m thickness, scattered on the north and south sides of the road body. The landslide zone is on 2 sides, namely the north side of the road at electrode E5-E8 with an indication of a maximum landslide depth of 3m from the ground surface and the south side at electrode E9-E11 with a maximum landslide depth of 6m from the ground level

b. Sand mixed with gravel (road heap)
   This layer is an intruded pile of groundwater with a resistivity value of 10-300 Ωm at the E8-E9 electrode.

c. Clay sand mixed with gravel (aquifer layer)
   This layer is a groundwater carrier layer with a resistivity value of 10-300 Ωm, divided into 2 zones, namely surface aquifers, and deep aquifers.

d. Sandstone Clay (semi impermeable layer)
   This layer is a semi-waterproof layer with a resistivity value <10 Ωm

e. Clay Rocks (impermeable layer)

f. This layer is a waterproof layer with a resistivity value > 300 Ωm.

The resistivity cross-section and the results of the 4 KM 531 + 600 track interpretation can be seen in Figure 8.
Figure 5. The resistivity section (A) and the interpretation of the resistivity section (B) of the 1 KM 531 +600 line

Figure 6. The resistivity section (A) and the interpretation of the resistivity section (B) of the 2 KM 531 +600 line

Figure 7. The resistivity section (A) and the interpretation of the resistivity section (B) of the 3 KM 531 + 600 cross-section
Figure 8. The resistivity section (A) and the interpretation of the resistivity section (B) of the 4 KM 531 +600 line

3.5 Identification of Construction Failures
On the KM 531 + 600 road section, 3 (three) types of construction failures were identified, namely:

a. Slide side of the northern road
Landslides based on the results of field identification show that the landslide material is in the form of sandy clay with the type of landslide is creeping, this is based on the formation of massive and irregular scraps (Figure 9).

Material movement occurs during rainy conditions which weakens the bonds of particles between the materials and stops when the groundwater level decreases, the incident occurs repeatedly so that the movement of material occurs gradually. The maximum depth of the landslide based on the geoelectric test results is estimated to be 3m with a slope length of 30m (geoelectric reference for trajectories 3 and 4 KM 531 + 600)

b. Drainage
The failure of drainage construction at the worksite is divided into 2 parts based on the cause, namely:
   • Failure due to landslide material
     Creeping landslides on the north side cause damage to the drainage channel in the form of a roll on the channel wall so that the channel is closed (Figure 10).
• Failure due to surface water runoff
The flow of water in the channel that is quite heavy carrying sand and gravel material causes scouring of the foundation of the channel walls so that the channel walls collapse (Figure 11).

• Landslide on the Cliffside of the southern road
The results of field identification and geoelectric testing show that the construction failure on the soil retaining wall on the south side is caused by 2 factors, namely:
  a. Failure due to surface water runoff
As a result of the closed channel in the northern part, the water flow from the slope side overflows the road area. The flow of water that is quite heavy causes the pile of material on the road shoulder to be eroded and transported to the side of the valley, this causes the geotextile layer to be exposed to the surface (Figure 12).
b. Failure due to landslides

The results of the geoelectric test show that the existence of creeping landslides is identified at the base of the construction, namely at the E9-E11 electrode with a maximum landslide depth of 6m from the ground surface (link reference 4).

In Figure 13, a map of the construction failure situation on the KM 531 + 600 road is presented.

![Figure 13. Map of the KM 531 + 600 construction failure situation](image)

4. Conclusion

Referring to the results of the analysis, it can be concluded that;

The landslide on the north side of KM 531+600 based on the results of the field identification shows that the landslide material is sandy clay with the type of landslide is creeping with a maximum landslide depth of 3m and a slope length of 30m. Recommended treatment is the construction of a masonry retaining wall with a distance of at least 3m from the shoulder of the road combined with the arrangement of surface water flow drainage on the slope. The retaining wall is equipped with pipes to drain groundwater with a pipe diameter of at least 2 inches and a maximum spacing of 1m between the pipes.

In the KM 531 + 600 drainage channel, it is necessary to rehabilitate the construction and be equipped with a sediment pond and channel construction designed to reduce surface water flow velocity. Landslides on the south side of KM 531 + 600, the results of geoelectric testing show that the presence of creeping landslides is identified at the base of the construction, namely at electrode E9-E11 with a maximum landslide depth of 6m from the ground (reference path 4). It is recommended to treat sheet piles with a minimum mounting depth of 8m from the ground.

References

1) Ardi, N. D., and Mimin, I. 2009. 2D Resistivity Profiles in Underground Caves Using Geoelectric Method Wenner Schlumberger Configuration (Case Study Dago Pakar Cave, Bandung). MIPA Teaching Journal. Vol. 14 No 2 ISSN: 142-0917: hal 81.
2) Muslihudin, dkk. 2012. The Study of Slipping Field as an Initial Step for Landslide Disaster Mitigation in Ledok Village, Sumberpucung District, Malang Regency Using the Geoelectric Method of Dipole-Dipole Configuration. Journal of Physics, Universitas Brawijaya.

3) Oke, M.H., 2000. Electrical Imaging Surveys for Environmental and Engineering Studies, A practical guide to 2-D and 3-D surveys. Mualifah, Faqih. 2009. Design and Manufacture of Soil Resistivity Measuring Instruments. Neutrino Journal Vol. 1.

4) Noor, Djauhari. 2014. Geology for Planning. First EditionYogyakarta; Graha Ilmu.

5) Reynolds, M.J. 1997. An Introduction to Applied and Environmental Geophysics. Second edition. Wiley-Blackwell.

6) Sugito, dkk. 2010. Landslide Slip Field Investigation Using Geoelectric Method. Journal.