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Electrical Resistivity Tomography for Sliding Plane Identification in Nanggulan Formation, Yogyakarta-Indonesia

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ABSTRACT: Landslide on the eastern side of Kulon Progo Mountains was triggered by claystone from Nanggulan Formation, which contains montmorillonite and saponite. This clay is expansive and can be used as a sliding plane. The pattern of claystone subsurface is assumed to match the surface. Purpose of the research was to figure out the depth and pattern of claystone. Research method used was Electrical Resistivity Tomography (ERT) in a Dipole-Dipole configuration. ERT measurements were conducted on two lines, each 300 meters long, with an electrode spacing (a) of 10 meters and layers (n) of 7. Data processing was performed using Res2Dinv. ERT measurements revealed evidence of ground disturbance (bumpy roads, subsidence, and shifting); the mudstone is dark, slippery, impermeable, and contains volcanic material. Mudstone has a resistivity of <30 ohm.m, sandstone ranges from 31 to 190 ohm.m, and igneous rock >190 ohm.m. Line 2 is made entirely of mudstone, whereas line 1 is made up of claystone, sandstone, and breccia, or igneous rock boulders. The claystone, acting as a sliding plane, generated the landslide, which continued westward and reached depths of up to 25 meters.

KEYWORDS: *Electrical Resistivity Tomography (ERT), expansive, sliding plane*

I. INTRODUCTION

In 2021, there were 1.056 landslides in Indonesia, with Java Island accounting for around 60% [1]. The Kulon Progo Mountains, in the western region of Yogyakarta, are a location with the potential for landslides. The Kulon Progo area has the highest rate of landslides, with 243 incidences, accounting for more than half of all landslides in Yogyakarta [2]. Landslides in Kulon Progo occur not only in steep mountainous places with volcanic rock lithology [3], but also in undulating hills or lower morphology [4] [5] [6] [7].

Samigaluh, Nanggulan, Kalibawang, and Kokap, which are located on undulating hills and have experienced landslides, have a lower risk of disaster [8]. The Nanggulan area is divided into four zones based on landslide vulnerability: highly vulnerable, vulnerable, less susceptible, and not vulnerable [9].

The undulating hills are mainly formed of sedimentary rocks from the Nanggulan Formation, such as claystone (which is the most dominant rock), sandstone, fossiliferous sandstone, quartz sandstone, coal inserts, carbonate claystone, and quartz carbonate sandstone [10]. Winarti et al. [11] identified five types of claystone in the Nanggulan Formation: claystone, fossiliferous claystone, carbonate claystone, black claystone, and tuffaceous claystone. Based on X-Ray Diffraction (XRD) research, claystone was discovered as the most dominant, with the presence of montmorillonite and saponite [12]. This type of clay is capable of triggering land movement. Furthermore, this claystone is referred to as expansive claystone.

According to other research, claystone in Kulon Progo is composed of a type of clay mineral, including kaolinite (70.64%), smectite/montmorillonite (15.12%), hallite (4.33%), illite (2.99%), quartz (2.91%), cristabolite (2.28%), feldspar (1.34%), and geothite (0.39%) [13]. Smectite has the property of absorbing a lot of water, which can cause landslides. The expansive claystone is mainly located in the Banjararum area [11].

As claystone typically is not layered (massive), it is assumed that the distribution pattern of claystone under the surface corresponds to the distribution pattern on the surface. For proof of this, subsurface geological research is required, namely geoelectric data. The problem in this investigation is determining how much expanding claystone is present at what depth and what the distribution pattern is based on Electrical Resistivity Tomography (ERT) data readings.

The study aimed at identifying the subsurface distribution pattern of expansive claystone. Based on the claystone's characteristics, it is estimated that the rock is a slip plane from the Naggulan landslide. Knowing the distribution pattern of claystone can be utilized to delineate the presence of a slip plane, as well as to reduce landslide disasters.

The research region is concentrated in the eastern Kulon Progo Mountains, particularly in places with undulating hill morphology. Administratively, the study site is in Banjararum, Kalibawang District, Kulon Progo Regency, Yogyakarta.

II. METHODS

The method used in this study is petrographic analysis and geophysical surveying using Electrical Resistivity Tomography (ERT). ERT measurements have been taken to collect current and potential data. The resistivity value will be determined based on the current and potential data. The resistivity value is used to understand lithology variations, including mudstone, which has the potential to form a slip plane. ERT can be accomplished with the Dipole-dipole or Wenner configurations. ERT with the Wenner arrangement is utilized for determining rock properties using resistivity data [14]. Res2Dinv software is used to calculate cross-section resistivity from field measurement data.

This study used ERT measurements on 2 lines with dipole-dipole configurations and line lengths ranging from 230 to 300 meters (Figure 1). The electrode spacing (a) is 10 meters, and there are 7 layers (n).

ERT measurements were taken on four lines, each of which measured 300 meters long, with the electrode spacing (a) being 10 meters and a total of 7 layers (n).

Figure 1. Focus of the research area

A. Nanggulan Formation

In general, the Nanggulan Formation is made up of clastic sedimentary rocks. Based on the resistivity value, volcanic rocks can be found in the Nanggulan Formation in the form of tuffaceous sandstone inserted between the mudstone [15]. The Nanggulan formation is mostly surrounded by volcanic rocks defined as the Old Andesite Formation.

Several studies reveal that the age of the Nanggulan Formation varies: Middle Eocene-Oligocene [16], Middle Eocene-Early Upper Eocene [17], and Early Oligocene-Middle Miocene [18]. According to the density values obtained from gravity measurements, the thickness of the Nanggulan Formation is 240 m in the west and 960 m in the east and exists in a wavy morphology with a 45-meter height differential and a slope of 20.34% [19].

The Nanggulan Formation is exposed to the surface for a variety of reasons, including the presence of a reverse fault at the contact boundary with the Old Andesite Formation [20], which is controlled by the Kalibawang dextral fault system, the Giripurwo sinistral fault, the Nanggulan reverse fault, and folds [16]. The Nanggulan Formation, which is exposed in the center section of the Kulon Progo Mountains and consists of fragments, is mostly due to the roof pendant [21].

B. Electrical Resitivity Tomography

Electrical Resistivity Tomography is a geoelectric method for determining subsurface configuration in two dimensions. This is an unconventional geophysical approach that describes underneath geological conditions vertically and laterally [22]. ERT is utilized for a variety of causes, including determining hydrological conditions in mining sites [22]. The ERT approach in geotechnics is used to create profiles of mining waste materials [23], and it can also be used to identify landslides [24]. The ERT approach is used to conserve springs, particularly in volcanic areas [25].

The basic concept behind the founding of the ERT method is Ohm's Law, a law of electricity. Current electrodes are used to inject current into the soil, whereas the potential difference is monitored from the potential electrode [22]. The apparent resistivity value (ρa) is determined by three variables: current (I), potential difference (ΔV), and geometric factor (k), as shown in formula 1 [26].

$$\rho_a = k\frac{\Delta V}{I} \qquad (1)$$

Resistivity values of various rocks and minerals have been identified, including sandstone (4–8.10^3 ohm.m) and water (10–100 ohm.m) [22], quartzite (297–4381 ohm.m) [24], andesite breccia (<600 ohm.m), lava (>12,000 ohm.m) [25], and unconsolidated sediments (30–70 ohm.m) [23]. Sandstone and silt in the Tebidah Formation have low resistivity (<30 ohm.m), making them shallow aquifers [27]. Resistivity values for wet mudstone in the Nanggulan Formation range from 0.84–28 ohm.m, while tuffaceous sandstone ranges from 32–185 ohm.m [15].

This ERT measurement employs a dipole-dipole setup, in which the current electrode (AB) and potential electrode (CD) are separate, and each electrode forms a pole. Each electrode is distanced by a, and the poles are separated by L. Figure 2 illustrates the setting of dipole-dipole electrodes [28]. The resistivity (ρa) of a dipole-dipole configuration is determined using equation (2) [28].

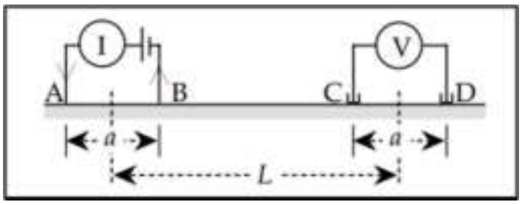

Figure 2. Dipole-dipole configuration [28]

with AB: current electrode; CD: potential electrode; $r_{AB} = r_{CD} = a$; $r_{AC} = r_{BD} = L$; $r_{AD} = L + a$; $r_{CB} = L - a$.

$$\rho_a = \pi \frac{\Delta V}{I} \frac{L\,(L^2) - a^2}{a^2} \qquad (2)$$

C. Land Slide

Landslides are defined as a kind of mass movement of soil or rock, or a combination of the two, that occurs down or out of a slope due to disruptions in the stability of the soil or rock that composes the slope [29]. Landslides are classified into six types: translational landslides, rotational landslides, block movements, rock falls, soil creep, and debris flows [30]. The type of landslide that kills the most people is debris flow. Losses from land movement include damage to agricultural land, residential areas, roads, irrigation, and other physical facilities [31]. Rainfall, human activity, earthquakes, erosion at the slope's foot, and human activity are all common triggers for landslides [32].

Other research suggests that landslides can be triggered by slope, lithology, geological structure, and land use [33]. Landslide vulnerability is divided into four categories: very high, high, medium, and low [33]. Landslides in mountain slopes or mountains, hillsides or hills, cliffs, or river valleys with slope gradients above 40% are often in the form of falls, slides, flows, and combinations with rather quick movements [30]. Landslides in foothills, mountain foothills, and river cliffs or valleys with slopes of 21%-40% typically take the form of land creep, which results in cracks and soil subsidence with slow to medium movement velocities (<2 meters/day) [30].

III. RESULTS AND DISCUSSION

A. Field Observations

The Electrical Resistivity Tomography measurement site is found in the Nanggulan Formation. The surrounding morphology shows undulating hills, but in several locations, signs of landslides, such as bumpy roads, subsidence, and shifting, were found (Figure 3). The identified lithology is a dark claystone that is slippery, waterproof, and contains volcanic material (tuff) (Figure 4).

Figure 3. Shows the symptoms of landslides, which are characterized by collapsed and moved roads

B. Resistivity Value

Lines 1 and 2 are 300 meters long and 20 meters deep (Figures 4 and 5). Both lines have about the same direction, north-south. Line 1 is on the east side, and line 2 is on the west side. Line 1 resistivity ranges from <0.094 to >2.608 ohm.m, whereas line 2 resistivity is less than 20 ohm.m.

A large range of resistivity values shows the presence of various rock types. Claystone resistivity is <30 ohm.m, sandstone resistivity ranges from 31 to 190 ohm.m, and resistivity values >190 ohm.m indicate breccia or fragments of igneous rock. The resistivity data indicate that line 2 is entirely made of claystone. Along line 1, there is claystone, sandstone, and breccia, or fragments of igneous rock. Claystone dominates line 1 from north to south, while sandstone and breccia, or fragments of igneous rock, were discovered in many areas.

Winarti et al. [12] utilized X-ray diffraction investigation to identify montmorillonite and saponite clay types. Both types of clay are quite expansive and can cause landslides. According to the findings of electrical resistivity tomography studies, the spread of expansive claystone layer is expanding westward.

Figure 4. Claystone outcrops around the landslide site

CONCLUSIONS

Field observations showed the existence of mudstone around the landslide. Line 1 resistivity data shows mudstone along a north-south trajectory. Certain areas contain sandstone and breccia. Mudstone can be found along line 2. Mudstone can be discovered to a depth of 25 meters on both courses, with a relative distribution to the west (Figure 6). As a result, the western part of the study area is more susceptible to landslides.

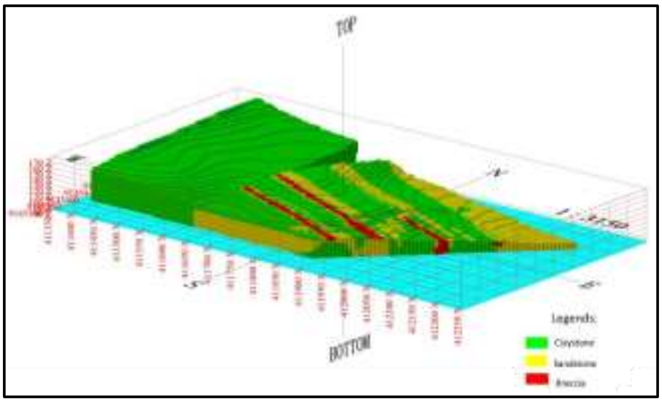

Figure 6. Claystone spreading model as a sliding plane

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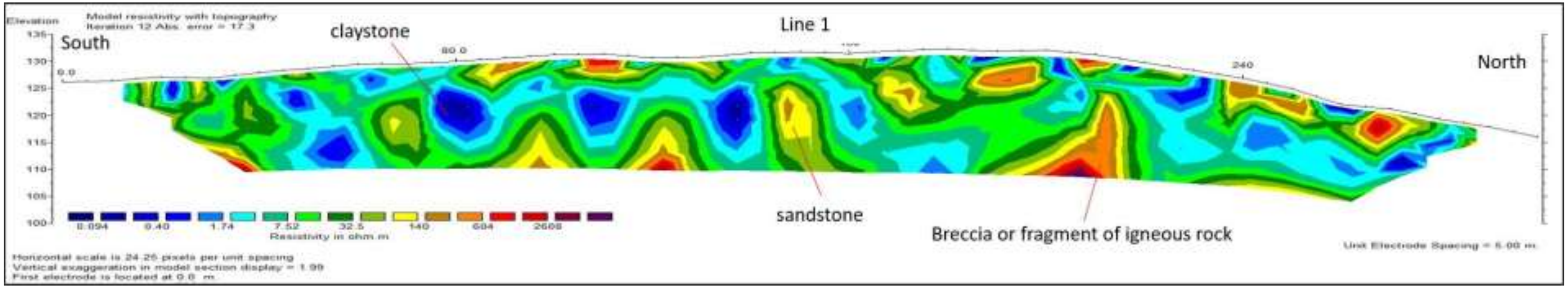

Figure 4. Electrical Resistivity Tomography profile at line 1

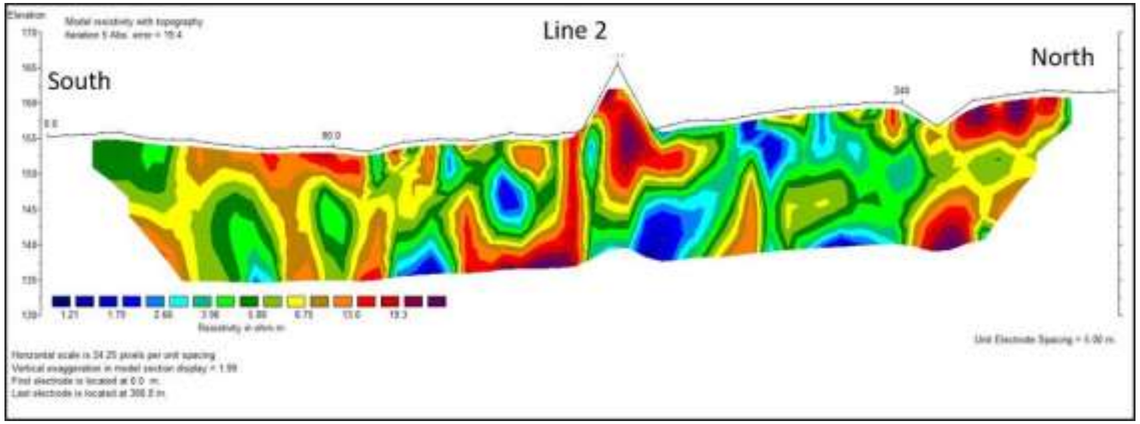

Figure 5. Electrical Resistivity Tomography profile at line 2