RiniApplication_of_2D_spatial_imaging_method_for_identification_of__a_fault_lines_and_subsurface_landslide_at_Taman_Unnes__Semarang_Indonesia

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Submission date: 17-Jun-2022 09:30PM (UTC+0700)
Submission ID: 1858551391
File name: matecconf_scescm2019_03005.pdf (1.79M)
Word count: 4416
Character count: 22930

MATEC Web of Conferences **258**, 03005 (2019) https://doi.org/10.1051/matecconf/201925803005
SCESCM 2018

Application of 2D spatial imaging method for identification of a fault lines and subsurface landslide at “Taman Unnes”, Semarang, Indonesia

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Abstract. In the last five years, landslide occurred many times in this area. The worst landslide was in 2014, which destroyed many houses and infrastructure such as road, water supply utilities and electricity. This study proposed an identification of landslide method by using of geo electricity as subsurface investigation of landslide. This study aims to identify the type of landslide and slip surface potential by using emergence of 2D spatial imaging. The application of geophysical has not been used as a result of landslide identification. The well-known argument state that geophysical is the only way to make images on the type and rock by using resistivity. The geological and soil physical properties required by engineers to analyse landslide potential are not well presented. As a consequence, the solution of soil reinforcement on landslide prone area to minimize the risk is presented as an engineering judgment of problem solving. Therefore, this paper discusses about soil properties and imaging to identify the area affected by future landslide. By using a multi-electrode electrical array, the 2D geophysical imaging was used to investigate the complex structure of soil stratigraphy and geological properties. The results showed that the area of the study was shown as a stable area with andesite intrusion. In addition, some areas were suspected as landslide prone area which was indicated resources by saturated clay of soil beneath.

1 Introduction

As a country that has a tropical climate, Indonesia has two seasons, the rainy season and dry season, as its characteristics. According to the National Disaster Management Agency (BNPB), this situation makes Indonesia experience quite extreme weather changes, temperature and wind direction. This condition is one of the triggers for various hydrogeological disasters such as floods, landslides, forest fires and drought that often occur in Indonesia. Those disasters have physical, psychological and economic impacts for people in disaster prone areas.

Data and Information on Disaster in Indonesia (BNPB) recorded 20.5 percent of disasters in Indonesia is a landslide that occurred in the year 2010 - 2016. That percentage shows that landslide is the second most occurring disaster after the flood in Indonesia. The topographic condition of Central Java is very diverse, consisting of lowlands, highlands and slopes. Especially people living in the slope area, of course, have their own awareness of landslide natural disaster. Landslides may occur in areas with a slope of more than 25% and have a rain duration of 2-7 consecutive days (Qudus, 2017). Landslides result in not only the destruction of public facilities, the loss of agricultural land, the loss of lives, but also the slowing down of economic activities and the development of the affected areas.

Semarang city is a strategic city located in the middle of Java Island in between 600 50' – 700 10' south and 1090 35' – 1100 50' east. The topographic condition of Semarang City consists of hills, lowland and coastal areas. Therefore, the topography of Semarang City shows a variety of slopes and hills. Geographical condition of Semarang City shows various slope of land ranging from 0% - 40% (steep) and altitude of 0.75 - 348.00 above the sea level (Regulation of Mayor of Semarang No. 18 of 2014). The diverse topographic condition make Semarang City alert to landslide disaster. During the last 5 years (2012 – 2017), there are 56 cases of landslides occur in Semarang City. Based on results of the study by Windraswara and Widowati (2010), seven of 16 sub-districts in Semarang City have landslide prone points. The seven districts are Manyaran, Gunungpati, Gajahmungkur, Tembalang, Ngaliyan, Mijen, and Tugu. Some of the land contours in the area are hills and fault areas with unstable soil structures.

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https://doi.org/10.1051/matecconf/201925803005

2 Area of Study

Taman UNNES (UNNES garden) is a plan of the Unnes space program located in the village of Sekaran, Gunungpati district. Based on the disaster map of Sekaran subdistrict in Figure 1, the most frequently occurring disaster in Sekaran village – Semarang is landslide. Sekaran village - Semarang has a hilly land and is located at a fault line. With this topographic condition, the possibility of the area becoming a landslide prone area is high. Along the road of Sekaran, Gunungpati, when the rainy season comes, a fracture on the surface of the asphalt occurs. It indicates that the direction of mass movement of the land. The same indication persists in every rainy season despite the landslide mitigation measures. It can be interpreted that the existing slope reinforcement system moves along with the landslide material because the location of the landslide is below the slope reinforcement (Andiyarto, 2013).

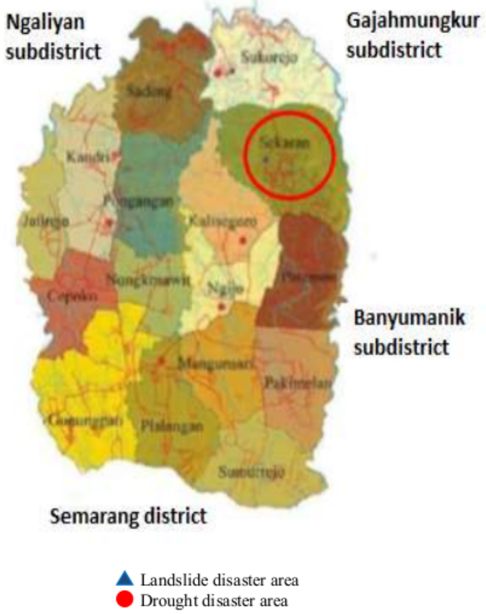


Fig. 1. Map of the occurence natural disaster type in Sekaran subdistrict, Semarang, Indonesia.

Landslides can be caused by factors such as topography, climate, weather change, geological and hydrological conditions and human activities (Hardiyatmo, in Priyono, 2015). In Indonesia, landslides often occur in areas that have steep slopes. However, it is not always the slopes and sloping lands that have landslide potential. Many other factors should be considered regarding the causes of landslides such as physical condition of nature and mankind activity. Landslide on the slopes mostly occur after heavy rain or long period of rain (Priyono, 2015). A good way to overcome this landslide disaster is to figure out where the landslide frequently occurs and how dangerous it is (Tim Davies, 2015). One of the measures that can be done is to figure out the potential of an area against the possibility of landslide. The landslide potential of a region can be identified by recognizing the type of subsurface rocks on the slope. One way to know the type of subsurface soil and rocks is by using geoelectricity method. Geoelectricity method is one of geophysical data gathering method using *resistivity method.* In the geotechnical field, this type of resistance method is used to determine the subsurface structure of the soil. Each layer of soils has different types of resistance. Therefore, the structure of the subsurface layer can be identified by looking at the difference in the resistance value of each type of layer (Hutugalung, 2013). Using this method, the landslide potential can be determined by identifying the location of the cracks and the slip surface. Cracks can be used for field analysis of the slip surface. The depth of the slip surface is measured from the surface, it can be used to analyze the risk and potential landslides.

3 Literature Review

3.1 The definition of landslide

A landslide is a form of erosion where the transport or movement of the soil occurs at some point in a relatively large volume. The event of a landslide is known as the movement of the soil masses, rocks or combination of both, which often occur on natural or artificial slopes. The landslide is actually a nature's dynamic phenomenon to achieve a new condition caused by the disturbance either of the slope balance that occurs naturally or because of human activities or factors affecting it and cause the reduction of shear strength as well as the increase of soil shear stress.

Soil movement can occur because there are natural processes in the change of the earth's surface structure, namely the disturbance of the stability of the soil or rocks on the slope affected by geomorphological conditions, especially slope (Sutikno, 2001). Sainyakit (2016) also states that the movement of the soil will occur on a slope if the instability that causes a mechanical process results in a moving part of the slope with the force of gravity. After the landslide, the slope will be balanced or stable. Therefore, landslide is the movement of soil or rock mass moving down the slope following the force of gravity due to disruption of the stability of the slope. If the mass moving on the slope is dominated by the soil and its movement through a plane on the slope, either on the inclined or curved plane, then the process of movement is called a landslide.

The causes of landslides can be static and dynamic. Static is a natural condition such as the nature of rock (geology) and slopes with a moderate to steep declivity, while the dynamic is human-caused as described in Table 1. Human activities are of many kinds from land use change to the formation of steep escarpment without regard to the stability of the slope (Surono, 2003). Meanwhile, according to Sutikno (1997), the factors that influence the occurrence of soil movement include the level of slopes, soil characteristics, geological conditions, vegetation condition, rainfall / hydrology, and human activity in the area.

Table 1. The causative and triggering factors of landslide (Alhasanah, 2006)

No	The causative factor	The triggering factor
1	The dynamic factor	1. Slope 2. Rainfall intensity 3. Land use (mankind activity)
2	The static factor	1. Soil types and geology structure 2. depth of soil column 3. Soil permeability 4. Soil textures

3.2 Effect of Soil Structure on Soil Stability

Sitorus (2006) states that soil types are critical to the potential for erosion and landslides. Loose soil that easily passes water into the cross section of the soil has more landslide potential than the massive soil like clay. It can also be seen from the sensitivity of soil erosion. According to Siswanto (2009), the value of soil erosion sensitivity or soil erodibility (K) indicates whether or not soil is eroded, determined by soil physical and chemical properties. The smaller K value means less sensitivity to the soil erosion. The value of K can be determined by using the following formula

$$K = \frac{S_t}{R_{h\,x\,LS}}$$

where, K is the erodibility value (ton ha-1 per unit R) with R = erovisity, St is the amount of eroded soil (ton ha-1), Rh is the simulated rain erovisity index (J cm m-2 h-1), LS is the length of the slope (m). The determination of erodibility value (K) of land in Indonesia is presented in table 2.2 below.

The depth, texture, and structure of the soil determine the size of the surface runoff water and the saturation rate of the soil by water. On deep soil (> 90 cm), loose structures, and tightly closed soil cover, most of the rainwater is infiltrated into the soil and only a small part of it becomes surface runoff water. On the other hand, in shallow soil, solid structures, and dense soil cover, only a small percentage of infiltrated rainwater and much of it becomes surface runoff (Indonesian Ministry of Agriculture, 2006).

3.3 Effect of rainfall as a trigger avalanche

Rainfall as an early warning of landslide disaster is defined as the critical limit (maximum or minimum) of the amount of rain to reach the soil (Reichenbach, 1998; Kusumawardani, 2017). The critical rain according to Aleotti (2004) is a rain measured from the beginning of the incident, which is the incident when the rain intensity increases very drastically, until the time of the landslide shown in Figure 2 below. Increased intensity of the rain can cause a sudden spike in the cumulative rainfall curve (Aleotti, 2004).

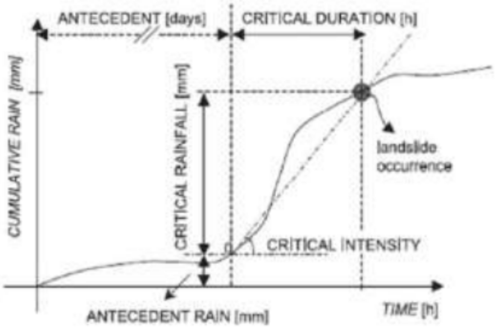


Fig. 2. Definition of rainfall parameter (Aleotti, 2004)

4 Research Methodology

4.1 Soil Formation of Study Area

The study area on the rock formation of the slope was located on the slopes of the hill area of Sekaran Village, Gunungpati District. The data collection in the field began at the coordinate point 07 ° 02'51.2" South and 110 ° 23'07.9 " east up to the coordinate point 07 ° 02'50.2" south and 110 ° 23'06.7" east. The location of the study can be shown in Figure 3 below.

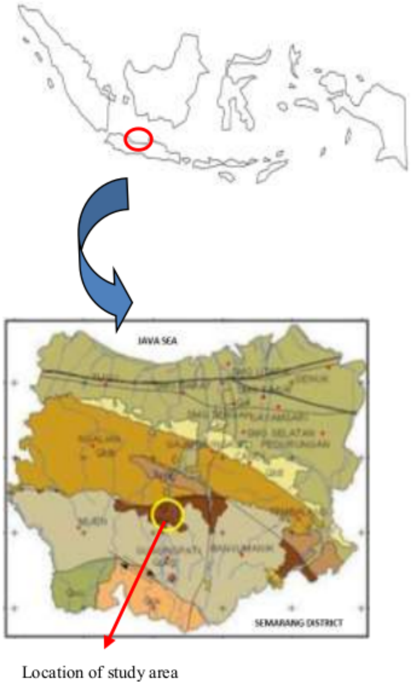


Fig. 3. Map of study area location

4.2 Geo-electricity testing

In the research conducted some measurement and testing in the form of field investigation (In Situ Site Investigation). A field investigation shall be carried out first before a slope stability analysis is performed to obtain the necessary data. In the investigation, field investigation should also be conducted to estimate and evaluate the landslide hazard potentials on the slopes according to the landslide vulnerability map of the landslide in Gunung Pati sub-district (Figure 3) and the vulnerability of occurrence of faults or subsidence. In the field investigation, data on the topographic and geological conditions of the slope can be determined directly in accordance with the conditions in the study area and supported by adjustment of secondary data obtained such as land movement maps.

In the implementation of geoelectricity test, the tool used to know the soil layer in the landslide prone area at the research location is resistivity meter. The electrode configuration used in data collection is the Wenner-Schlumberger sounding configuration as shown in Figure 4.

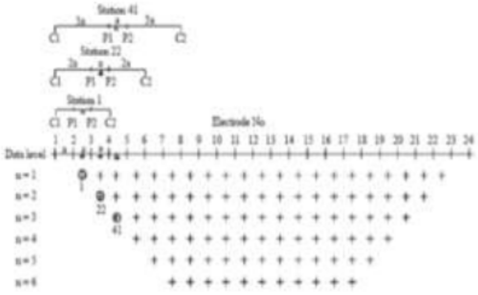


Fig. 4. The electrode array for 2D spatial imaging electrical survey by using Wenner Sclumberger method (Abueladas, 2017).

5 Results and Discussion

5.1 Initial investigation of the topography

In this study, geological data is the most important part to describe the condition of soil structure of the slope. Therefore, in analyzing the slope stability, the appropriate supporting data were required. Interpretation of the 2D spatial imaging data, in addition to using resistivity tables and drill log data, was also performed by 2D interpretation of the research path correlated with the geological map of the area of the study. The geological map used as a reference to determine the geological conditions in the research location is Geological Map Semarang City as follows.

Geological condition of Semarang based on the Geology Map of Magelang Sheet – Upper region of Semarang shows the stratigraphic structure as follows: Alluvium (Qa), volcano rock of Gajahmungkur (Qhg), volcano rock of Kaligesik (Qpk), Jongkong Formation (Qpj), Damar Formation (QTd), Kaligetas formation (Qpkg), Kalibeng Formation (Tmkl), Kerek Formation (Tmk). Based on the above geological map also, the area of the study located in the village of Sekaran area is included as an area with Kerek rock formations (Tmk). According to Jihan and Yusrizhal (2016), on Kerek formation, the rock consists of claystone, vapor, tuff stone, conglomerate, volcanic breccia and limestone. Clay stone with light – dark gray, limestone, partially inserted with silt rocks or sandstone, contains foraminifer's fossils, mollusks and colonies. A thin layer of conglomerate is present in clay in *Kali Kripik* and inside sandstone. The limestone is commonly layered with crystalline and sand, has a total thickness of more than 400 m.

5.3 Geo-electricity investigation

The first section shows the contour of the measured apparent resistivity that is apparent resistivity data obtained from field data acquisition. The second section shows the measured apparent resistivity contours. The third cross-section is the actual resistivity contour after the inverse model resistivity section. The inverse model resistivity section is the result of inversion analyzed to identify the structure of soil formation of the slope that can be divided into several parts showing the weakest and strongest part, shown in the following figure.

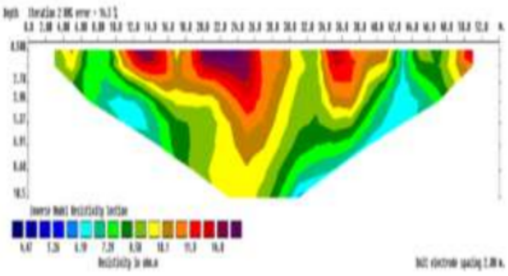


Fig. 5. Inverse model resistivity model.

The results of the processing show layers of different rocks. Differences in layers of rock can be seen from the color difference in each layer. Based on the results of the inversion, the soil formation of the slope is divided into three types of layers. The distribution of soil layers based on the results of the conversion can be shown by the Figure 6. On the area of the study, various resistivity values ranges from the lowest to the largest value of 4.47 Ωm - 14.0 Ωm. From the results based on the 2D geoelectric figure above, the study area consisted of three types of material layers of clays interpreted based on the visualized color difference and different resistivity values.

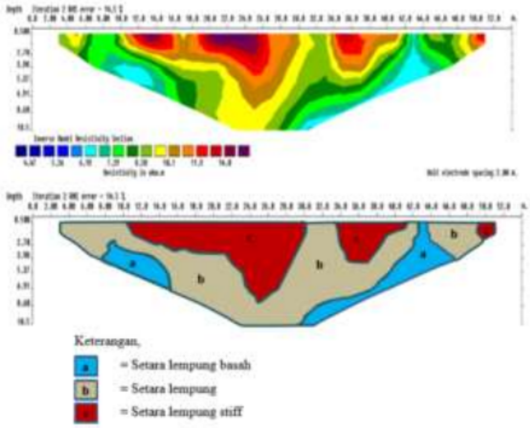


Fig. 6. Distribution of slope material constituent.

From the picture above, it can also be determined the existence of some weak plane shown in blue. The strongest plane on the area of the study is shown by the red color. The weak planes are marked in part a with a low resistivity value of 5.26 Ωm - 7.29 μm which describes the presence of a wet clay equivalent layer at a depth of 2.70 - 6.91 m, at a distance of 7-15 m. The other a part is also found with a low resistivity value with a resistivity value of 4.47 Ωm - 7.29 μm that is the layer equivalent with wet clay found at a depth of 0.5 m - 10.5 m, at a distance of 38 m - 45 m. The second type of layer is the clay equivalent layer shown in part b with a resistivity value of 7.30 Ωm - 10.1 Ωm. In addition to these two layers, in the area of the study, there is a rock layer spread which has a higher resistivity value among other layer resistivity. The layer with it is the hardest, strongest and densest layer. The highest resistivity value in the study area indicates the presence of a hard soil equivalent to a stiff clay that can be found beneath the soil surface. The layer equivalent to stiff clay is shown by part c where at a depth of 0.5 m below the soil surface has been identified. The layer equivalent to a stiff clay is shown with a higher resistivity value between the surrounding layers that is between 10.2 Ωm - 14.0 Ωm and is marked in red.

5.4 Fault investigation

According Agustin (2017) and Kusumawardani (2016), one of the factors that affect the stability of the slope is the cracks formed below the surface. When cracks in the slopes are infiltrated by rainwater, it will be a process of water pressure built up on the slopes causing unstable slopes. One of the geophysical methods that can detect the presence of cracks is by using a geoelectricity testing. This testing revealed the areas with a high water content shown by low resistivity value. Sutikno (2001) also states that, geological structures that potentially encourage landslides are contacts between bedrocks with weathering of rocks, the presence of cracks, fault and overlapping rock layers.

It is predicted that the study area is located around the fault zone. Topographic conditions in the field, visually can be seen that the location of the study had altitude although insignificant. A larger height difference in the form of a ravine can be found to the north of the area of the study (Figure 7). To the north of the study site, there is a small waterways flowing from east to west toward larger waterways. One indication of this fault is characterized by the presence of rivers around the area of the study and the shifting of the layers of rocks. Fitriani et al. (2012) states that generally the fault plane is filled by a relatively more conducive fluid or mineral than the surrounding rock. This leads to a decrease in resistivity. Therefore, the area at the fault has a relatively lower resistivity of the surrounding area. In the study using geoelectricity method, the identification of fault was seen in the processed geoelectricity data. An area is located at the fault if there is material having high resistivity value then separated by material having lower resistivity value from surrounding area. Therefore, it can be concluded that the area of the study is traversed by a fault.

Figure 7 below is the inversion result of geoelectric data on Res2Dinv which has input topographic data in the form of elevation making it easier to see altitude changes on the area of the study. The figure shows the existence of a section on the slope structure which was indicated as a fault, which is shown in Figure 7.

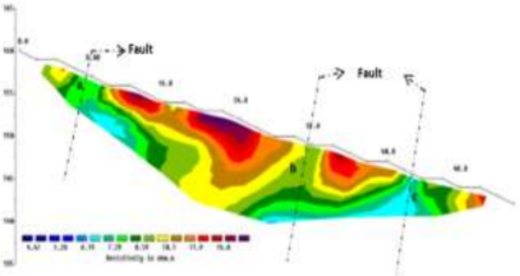
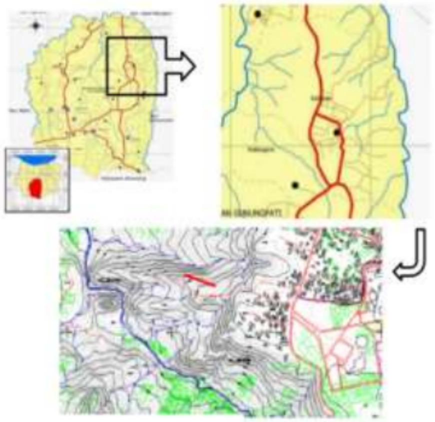


Fig. 7. Fault identification in study area

From the results of the data processing above, a fault indicated as a surface fault can be identified in the area of the study by geoelectricity method. From figure 4.8, at the area of the study site, there are three weak areas which were identified to be a fault in the shown in part a located at the 8 m measurement point. The second fault location is shown in section b at the measurement point 32 m and part c is located at the measurement point between 42 m and 44 m intersects the layer in between the rocks having a higher resistivity value. Therefore, this area was indicated as a fault. The type of fault could not be identified specifically through the interpretation of resistivity profile. Figuring out the type of fault requires further study using a more complex method to reveal the type or pattern of the movement of each fault area. The location of fault along the path of the fault found in the research area can be determined by using the contour map of the study area. The location of the fault was adjusted from the result of Res2Dinv then the fault path was assumed and described in accordance with the contour line. Therefore, the weakest layers or fault layers in the area of the study can be observed in Figure 8 below.



6 Conclusion

A field study was undertaken in "Taman UNNES" area, Semarang, Indonesia. The studied was investigated using 2D geophysical imaging method. Results from the study showed that three points were indicated as the weakest layer which was the fault of the geological formation of slope potentially affecting slope stability, especially during the rainy season. The three points were located at the measuring point of 8 m, 32 m and at the point of measurement between 42 m and 44 m which intersect the layers between rocks and have a higher resistivity value. The type of fault could not be identified specifically through the interpretation of resistivity profile. Figuring out the type of fault requires further study using a more complex method to reveal the type or pattern of the movement of each fault area.

The author would like thanks to Research and Community Service Institute of UNNES for supporting funding research through the DIPA UNNES funds year fiscal 2018 and also Soil Mechanic Laboratory of Universitas Negeri Semarang for the equipment and the students of Final Year Project who is join in GeoRisk and Hazard Management group

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