Identification of potential liquefaction in Kabonena

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Abstract. The research was conducted in Kabonena village, which aims to see the subsurface structure and the liquefaction potential. The research was conducted using the geoelectric resistivity method with the Wenner system. The parameters used are geological data, hydrogeology and formation values to obtain between the resistivity value and the lithology of the study area. Furthermore, by considering the geological, hydrogeological conditions and formation factor values, the specific resistance values for each layer are interpreted. The results obtained show that the layers with specific resistance values of 39.16 - 97.9 \(\Omega m\) are dominated by water-saturated sand/gravel. The resistivity value above 97.9 - 200 \(\Omega m\) is the layer of molasses and alluvium deposits / coastal deposits, and the resistance value above 200 \(\Omega m\) is the layer of crushed granite and granodiorite. The existence of a subsurface structure like this, so that in Kelurahan Kabonena it is called a liquefaction event. The location has a layer of saturated air that points to the east with a depth of less than 24 meters.

1. Introduction

The earthquake with a magnitude of 7.5 Mw that struck Palu on 28 Sept 2018 triggered several other natural phenomena that claimed many lives [1-3]. One of them is liquefaction that occurred in Balaroa Village. Liquefaction is the process of increasing pore water pressure and consequently decreasing the effective pressure of the soil on a layer of water-saturated sand suddenly due to tectonic earthquakes. The phenomenon of liquefaction occurs when a layer of sand turns into a liquid so that it is unable to support loads of buildings inside and/or above it [4]. Balaroa is composed of layers of rock that are very saturated with water and then it gets a very big shock because this area is passed by the Palu Koro fault which causes an earthquake so that liquefaction occurs [3]. The research area is Kabonena Village, Ulujadi Subdistrict, located adjacent to Balaroa Village. The geological and physiographic structures in Kabonena are almost the same as Balaroa. The relatively high liquefaction potential is due to the physical characteristics that are composed of Quaternary deposits with the density and engineering properties of the subsurface soil characterized by very loose to somewhat dense material, having a shallow groundwater level, physiographically facing the sea which causes the sediment to compose it, saturated with water, and is in a location prone to major earthquakes [5-7]. There is a concern from the community that another big earthquake will trigger liquefaction in Kabonena. Therefore, it is necessary to research subsurface structures in Kabonena to identify the potential for liquefaction in Kabonena.

This research was conducted using the geoelectric resistivity method. The geoelectric resistivity method is one of the geophysical methods used to measure the physical, electrical parameters of the subsurface material [8-10]. This method is widely used in mineral exploration and groundwater [8, 11]. The geoelectric resistivity method has the principle of capturing the response and measuring the
potential difference from the material below the surface by providing a dynamic disturbance of electric currents on the earth’s surface [10], [12], [13]. This configuration can describe the subsurface conditions horizontally and can be presented in a 2D model which is supported by the geological conditions above the surface of the research location.

2. Geologic Settings
Overview of the regional geological conditions of the study area, both surface and subsurface, are based on two aspects, namely stratigraphy and regional structure. The existence of these two aspects reinforces and controls the regional geological conditions of the research area.

2.1. Stratigrafi Regional
Based on the Geological Map Review Sheet Palu, Sulawesi with a scale of 1: 250,000, the stratigraphy of the study area is composed of granite and granodiorite (gr), Molasse Celebes (QTms), as well as alluvium and coastal sediment (Qal) (Figure 1).

Figure 1. Geology of research area Kabonena Urban Village

2.2. Regional geological structures
Regionally, the important structure in the study area is dominated by the Palu-Koro fault line. The Palu-Koro Fault is a shear fault system that forms high and low. This fault runs north-west-south-southeast. Palu City is thought to be located between the two segments of the Palu-Koro Fault which resulted in the formation of the Palu Valley. On land, this fault is characterized by a fault valley that is flat at its base, with a width of 5 km around Palu, and its walls reaching an altitude of 1,500-2,000 m above the valley floor, while at sea it is characterized by bathymetric straightness, which is the straightness of the bottom slope. the sea is steep and ends at the Poso Rise Fault [1-3, 15-21].

3. Methods
According to Telford (1990), the type resistance geoelectric method measures the electrical properties of the earth’s material by injecting an electric current (I) into the ground using two electrodes and measuring the amount of voltage (V) using the other two electrodes. The ratio between the injected and the measured voltage is the impedance of the earth which enters the form of apparent resistivity (ρa) based on the principle of Ohm's Law [22]:

\[ \rho_a = k \frac{V}{I} \]  

(1)
The apparent resistivity value as a measurement function is then numerically inverted into the actual resistivity to the weakness model. The electrode arrangement used in this study is the Wenner configuration (Figure 2) [23].

\[
K = 2\pi \left[ \frac{1}{(\frac{1}{r_1} - \frac{1}{r_2})} + \frac{1}{(\frac{1}{r_3} - \frac{1}{r_2})} \right] \quad (2)
\]

because \( r_1 = a, r_2 = 2a, r_3 = 2a, \) and \( r_4 = a, \) so

\[
K = 2\pi a \quad (3)
\]

thus equation (1) can be written:

\[
\rho_a = 2\pi a \frac{\Delta V}{I} \quad (4)
\]

The resistivity relationship in Equation (1) is reflected in the size of the formation factor \( F \) by Taib (2000), namely [10],

\[
F = \frac{\rho}{\rho_w} = \frac{a}{\phi^{-m}} \quad (5)
\]

The resistivity of porous fill water \( \rho_w \), apart from being directly measured, can also be calculated using the equation:

\[
\rho_w = \frac{10000}{DHL} \quad (6)
\]

where DHL is the electrical conductivity expressed in (μs).

Data collection was carried out by installing R8IP superstring geoelectric equipment at points that have been determined based on a geological survey. The electrodes were arranged using the Wenner configuration with a spacing of 3 m. The electrode is then injected with an electric current which results in current data \( I \) and potential difference \( \Delta V \) as well as the pseudo-type resistance value \( \rho_a \). Data were collected for 4 stretches using 56 electrodes and a length of 165 m. To obtain a topographic picture of each stretch, elevation measurements were made using GPS. Also, the electrical conductivity (DHL) of water was carried out to support the interpretation stage in determining the value of the type of pore-filling water resistance using a conductivity meter. The data is then used to determine the value of the rock formation factor.
In each physical property of rocks and minerals, the electrical resistivity value shows a fairly large variation. Igneous rocks have the highest resistivity, lowest sedimentary, with intermediate metamorphic rocks. However, there is a lot of overlap, as with any other physical trait. Generally, sediment, wet soil, and groundwater have lower resistivity values. Clay soils usually have lower resistivity values than sandy soils, but the resistivity values of rock and soil overlap. This is because the specific resistivity or soil sample depends on several factors such as porosity, degree of water saturation, and dissolved salt concentration [23]. Below is a table of some of the resistivity values of materials and rock minerals.

**Table 1. Resistivity Value of Materials and Rock Minerals [23]**

| No | Materials  | Resistivity (Ωm) |
|----|------------|------------------|
| 1  | Water      | -                |
| 2  | Pyrite     | $3 \times 10^{-1}$ |
| 3  | Galena     | $2 \times 10^{-3}$ |
| 4  | Quartz     | $4 \times 10^{10} \pm 1 \times 10^{14}$ |
| 5  | Calcite    | $1 \times 10^{12} \pm 1 \times 10^{13}$ |
| 6  | Rock Salt  | $30 \pm 1 \times 10^{13}$ |
| 7  | Mica       | $9 \times 10^{12} \pm 1 \times 10^{14}$ |
| 8  | Granite    | $10^{2} \pm 1 \times 10^{6}$ |
| 9  | Gabbro     | $4 \times 10^{3} \pm 1 \times 10^{6}$ |
| 10 | Basalt     | $10 \pm 1 \times 10^{7}$ |
| 11 | Limestone  | $50 \pm 1 \times 10^{7}$ |
| 12 | Sandstone  | $1 \pm 1 \times 10^{8}$ |
| 13 | Flake Rock | $20 \pm 1 \times 10^{3}$ |
| 14 | Dolomite   | $10 \pm 10^{4}$ |
| 15 | Sand       | $1 \pm 10^{3}$ |
| 16 | Clay       | $1 \pm 10^{2}$ |
| 17 | Groundwater| $0.5 \pm 3 \times 10^{2}$ |

Data processing was performed using the *EarthImager2D* inversion program by entering apparent resistivity ($\rho_a$), electrode distance and electrode elevation. The result of data processing is in the form of a 2D subsurface pseudo-type barrier, which causes 3 iso-resistivity sections.

The first section shows the measured apparent-type resistance (measured apparent resistivity), the second section shows the calculated apparent-type resistance (Calculated Apparent Resistivity), and the third section shows the actual type resistance obtained through the inversion modeling process (Reverse Resistivity Section). The scale in the third section shows the color comparison to see the resistance value using a logarithmic scale. The horizontal section in each section provides invincible electrodes with positions from 0 - 165 m, while the horizontal section displays positions up to 30.8 m deep. The inversion data shows the variation in the resistivity value ($\rho$) and the depth of each layer. The results of the inversion are then interpreted based on the value of the type resistance.

4. **Results and discussion**

4.1. **Results of geoelectric resistivity**

The results of data analysis obtained from 3 iso-resistivity sections for each stretch are as in Figure 3 below. Based on the results of the inversion, the measured minimum resistivity value was 14.4 ohmmeters and a maximum value of 834 ohmmeters with an RMS error value ranging from 4.07% to 13.71%.
From Figure 3 it can be seen that the research location is in a sloping area. The conditions around the first stretch are in the form of springs and the other stretch around the settlement there are drilled wells that are clear and odorless.

Figure 4 is a 2D cross-sectional model of the actual resistivity value obtained through inversion modeling. The resistivity value obtained in the near-surface layer with a depth of ± 3 m below ground level has a value between 39.16 - 97.9 Ωm which indicates that this layer is a layer of soil and sand, which is 1 to 140 m from the bottom of the electrode. In the lower layer, it is suspected as molasses deposit and at the end of the cross-section or the southwest part, there is a granite/granodiorite deposit. This layer has a resistivity value of> 97.9 Ωm with a formation factor value of> 5. In the middle of the cross-section, there is a spring that corresponds to the strain surface conditions.

In the second strain, the results of non-dominant and varied bedding were obtained. It can be seen in Figure 5 that the near-surface layer is dominated by sand with a specific resistance value> 97.9 Ωm. The aquifer layer looks uneven with specific resistance values 39.16 - 97.9. The granite layer was also seen to be spread unevenly, from a depth of 1 to 20 m below ground level. In the vicinity of the stretch, there is Sumur 1 which has a depth of ± 6 m with a fresh taste. by the field conditions, the results of the western section have a water surface. However, the groundwater layer was not found to have a thick or wide layer. According to information from the surrounding community, it is suspected that the water arose due to the seepage of the river channel to the west of the measurement location.

In Figure 6, according to the order of the three layers near the surface with a specific resistance value> 97.9 Ωm to a depth of 6 m below the ground which is a granite shale material. In the second layer, an aquifer layer is found consisting of sand and gravel and interspersed with clay. This layer is at a depth of 7-24 m underground and thickens to the east. This layer is a relative zone of saturated water. The third layer under 24 m is a sand layer with a specific resistance value> 97.9 Ωm. This layer is considered as molasses precipitate. At this location, land subsidence and ground movement of ± 1.5 m occurred after the earthquake. This is due to the influence of the ground water zone which spreads to the
east which makes the surface unstable. In this expanse, you can find Sumur 2 with a depth of ± 9 m which tastes fresh and doesn't care. It is possible that the water in the well comes from the aquifer layer zone in the second layer. About 100 m to the east of the location are sago groves and shallow groundwater levels. In addition, information from residents around the location that no water comes out of the ground is artesian. However, in the eastern part of the cross-section, about 200 m from the measurement point, there is a surface well/spring.

Based on Figure 7, it was found 1 layer near the surface to a depth of 24.5 m underground level. This layer has a specific resistance value with a specific resistance value of > 97.9 Ωm, which is a refined granite/granodiorite. This is in accordance with the condition of the location which is a hill area with a hard and dense surface. In the vicinity of the site, you can find Sumur 3 with a depth of ± 130 m underground level with freshwater conditions and odorless.
4.2. Discussion
From the results of the overall interpretation of the cross-section, it is found that the Kabonena sub-district is covered by subsurface structures composed of aquifer layers in the form of water saturated sand and gravel, granite/granodiorite rocks, and molasses deposits. The subsurface layer which is evident by liquefaction is the sediment layer in the form of sand or silt (non-cohesive), is decomposed or loose (not solid), is below the groundwater level or is saturated with water, the groundwater level is shallow, and there are strong and long earthquakes [5]. From the results of the interpretation obtained for the four passes that have been implemented, it shows that in the third stretch of the subsurface structure is dominated by sand/gravel which is saturated with water, so this location is called a liquefaction event. The potential liquefaction zone is at a depth of fewer than 24 meters. The type resistance value obtained in the water saturated layer is 39.16 - 97.9 Ωm. The results of research by the Geological Agency Team in 2018 showed that the liquefaction that occurred in Balaroa Village was due to the rock layer below the surface that was very saturated with water which then received major shocks because of its location close to the source of the earthquake. This does not rule out the possibility that in Kelurahan Kabonena, especially in the surrounding areas that involve third parties which occur due to the occurrence of earthquakes with large intensity for a long time.

Based on research conducted by the BPBD of Palu City (2018), the size of the soil shear-strain in Kabonena is $10^{3.105}$, lower than the average shear-strain value of Palu City which is $10^{2.36}$. The lowest score in Kabonena is $10^{4.63}$. At this figure, the behavior/properties of the soil to earthquake shocks does not cause cracks or changes in the position of the soil surface. The highest soil shear stress value is $10^{2.3}$. Based on this value, cracks and land subsidence occur in this area and there is the potential for small-scale liquefaction.

5. Conclusion
Based on the results, analysis, and interpretation of research data, it can be revealed that the subsurface structure in Kabonena is composed of aquifer layers, granite/granodiorite rocks, and molasses deposits. In the northern part, it has a subsurface fracture structure of granite/granodiorite and alluvium. The southern part of the hill is dominated by granite/granodiorite rocks. The eastern part has a varied subsurface structure consisting of crushed granite, aquifer layers, and molasse deposits. In the western part, it has a subsurface structure consisting of molasse deposits and has a lot of surface water. According to the three Kelurahan Kabonena, it has the potential for liquefaction because it has an air-saturated zone at a depth of fewer than 24 m with a groundwater level at a depth of 6 m underground level. At this location, soil movement and subsidence are also found due to the instability of the soil layer and the potential for small-scale local liquefaction.
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