

PREDICTION OF SOIL LIQUEFACTION PHENOMENON IN BANDA ACEH AND ACEH BESAR, INDONESIA USING ELECTRICAL RESISTIVITY TOMOGRAPHY (ERT)

*Muhammad Syukri¹, Sabrian Tri Anda², Rini Safitri¹, Zul Fadhli² and Rosli Saad³

¹Department of Physics, Faculty of Sciences, Syiah Kuala University, Banda Aceh, Indonesia

²Department of Engineering Geophysics, Faculty of Engineering Syiah Kuala University, Banda Aceh, Indonesia

³School of Physics, Universiti Sains Malaysia, 11800 Penang, Malaysia

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ABSTRACT: One of the global geohazard issues discuss among scientists is soil liquefaction phenomenon. The incidents occurred at Palu in September 2018 and Aceh in December 2004, triggered soil liquefaction phenomenon which lead severe damages and lives. The common research on the geohazard issue include geotechnical methods (SPT and CPT) and geophysical methods (MASW and seismic). This study was conducted at Meuraxa district (Banda Aceh) and Baitussalam district (Aceh Besar) to introduce the capability of Electrical Resistivity Tomography (ERT) to predict the soil liquefaction phenomenon. The 2-D resistivity data were process using res2dinv inversion software to produce resistivity inversion models which then correlated with published results. The study identified that the resistivity values of 0.1 – 10 Ωm is a soil saturated zone which affected by seawater intrusion and concludes that the study areas predicted by ERT have a high potential of soil liquefaction phenomenon to be occurred.

Keywords: Soil liquefaction, 2-D resistivity, Saturated zone, Seawater intrusion.

1. INTRODUCTION

Soil liquefaction phenomenon is a global issue that has been discussed for decades, which contribute to geohazard issue. Soil liquefaction is formed when a granular material transformed from solid to a liquefied state which is caused by the increasing of pore-water pressure and the reducing of effective stress [1, 2]. According to Geotechnical Engineering Bureau, 2007 in Syukri [3], the term of “soil liquefaction” is a process that transform the saturated sandy soil into a cohesionless form due to the repeated shaking caused by the waves of earthquake. Syukri [3] also stated that soil liquefaction is considered as one of the main hazards that occurred in cities located nearby the coastal area. Therefore, the comprehensive study of the subsurface response at the coastal area under tectonics activities is essential to be conducted since the result of this phenomenon can cause severe damage for buildings and also casualties. The soil liquefaction also occurs in soil with poor drainage and loose to moderately dense granular soils such as silty sand, saturated sandy soils, alluvium layers (fine sand or fine sandy silt) and gravelly soils, due to cyclic

shear deformation that triggered by earthquakes [2, 3, 4]. The relative density and the finest content of soil would affect the occurrence of soil liquefaction. The major Niigata earthquakes in 1964 defined that the soil with relative density of less than 50% would liquefy, while the soil with relative density of 70% or higher is remain unchanged [5].

The studies of soil liquefaction can be carried out using Cone Penetration Test (CPT) and Standard Penetration Test (SPT) or the integration between those two methods. However, the two methods are expensive, time consuming and require a complex permission to utilize. Another option to encounter the invasive, cost and time consuming is the utilization of geophysical method such as Multi-channel Analysis of Surface Wave (MASW) method [2]. The application of shear wave was applied to estimate the degree of liquefaction severity at Banda Aceh refer to liquefaction potential index value (PL). The study shows that Banda Aceh is classified into three zones; high, medium and low liquefaction susceptibility (Fig 1).

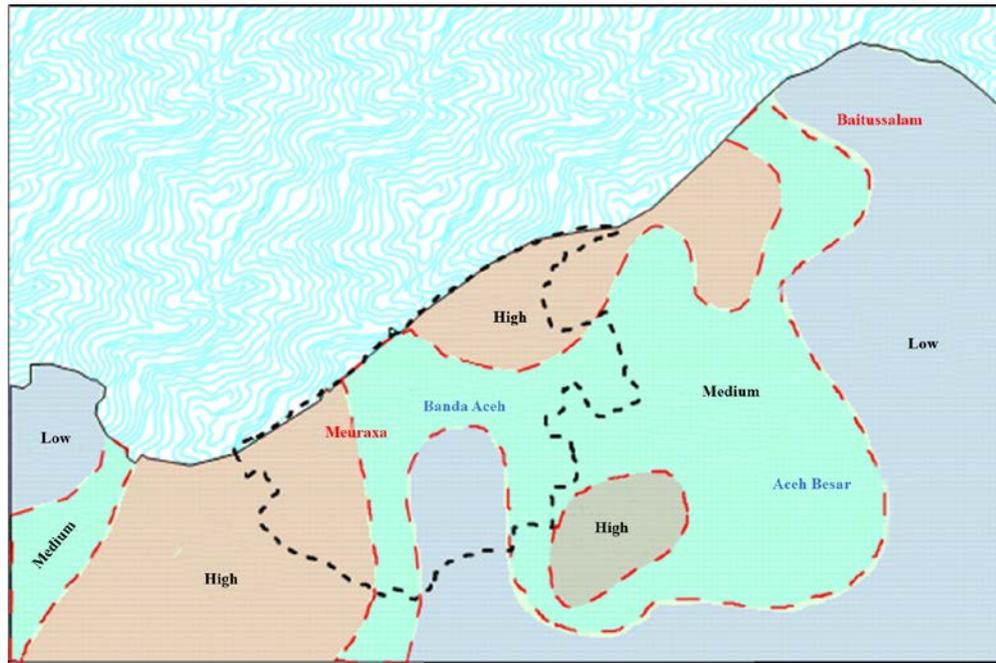


Fig 1. Microzonation map of liquefaction potential area in Banda Aceh, modified from [6].

The 9.0-9.3 M_w Aceh earthquake which is occurred in 26th December 2004, also induced the soil liquefaction phenomenon in several places along the coastal line of Aceh which is lead to severe damages [3]. Massive soil liquefaction occurred at Palu in 28th, September 2018 has proven that intensive study on geological structure near the coastal line is important [7, 8]. The author assumed that the comprehensive study of soil liquefaction is substantial since the phenomenon is closely related to the development of an area and the effect of the soil liquefaction can cause severe damage to buildings, residential areas, and casualties. Moreover, Aceh is situated on the Great Sumatran Fault (GSF) which is runs throughout the Sumatra Island from Lampung (Southern part of Sumatra) to Weh Island (Northern part of Sumatra), which the activity of the GSF might be the main agent that trigger the soil liquefaction to be occurred [9].

2. GENERAL GEOLOGY OF STUDY AREA

The study was carried out in two separated area, first site was located at Meuraxa district of Banda Aceh while the second site was located in Baitussalam district of Aceh Besar. The site classification was carried out along the shoreline to characterize the type of soil surrounding the area of interest. Geologically, Banda Aceh laid on the depositional of Alluvium and marine sediment deposited from graben structure of GFS [14]. According to Rusdi, M. [9] the alluvium is unconsolidated since the Holocene age and the soil is still loose. Basically, there are no geological

The Electrical Resistivity Tomography (ERT) obtain a high-resolution image of the ground subsurface resistivity distribution. At present days, the utilization of geophysical method has been spread out in an effort to characterize soil/rock for geotechnical data, delineate the water-bearing zone, bedrock, and thickness of subsurface layer [10, 11, 12, 13]. The method is classified as non-invasive method since the ERT method does not required a complex permit like boring technique to be conducted. Since the ERT method describe the subsurface information using the resistivity distribution, the method is closely related to the water content of subsurface. It is essential in an attempt to identify the conductive area which is indicates that the zone is saturated. Hereinafter, this study employs the ERT to predict the ground subsurface structure in delineating the prone area of soil liquefaction along the coastal line of Banda Aceh and Aceh Besar.

tectonics such as major fractures and faults in Banda Aceh, however the geological condition of Banda Aceh is affected by geological structures that flanking it. The activity of GFS which is runs constantly along the Sumatra island assumed to be the major causes that trigger the geological activity in Banda Aceh. Similar to Banda Aceh, the geological condition of Aceh Besar is classified as Alluvium, which is composed by gravel sand, gravel, sandy clay, sandy silt, clayey silt, silty clay and other sediment that originated from swamp. Based on topography, the area is respected to be

undulated, spread out from northwest to southwest. The district is also known as Krueng Aceh basin according to Iwaco and Far & Djaeni [15, 16]. The rock types are classified as Tertiary and Pre-

tertiary rock while the eastern part delimited with hills composed of Plio-Plistosen which originated from Seulawah Agam Volcano [17].

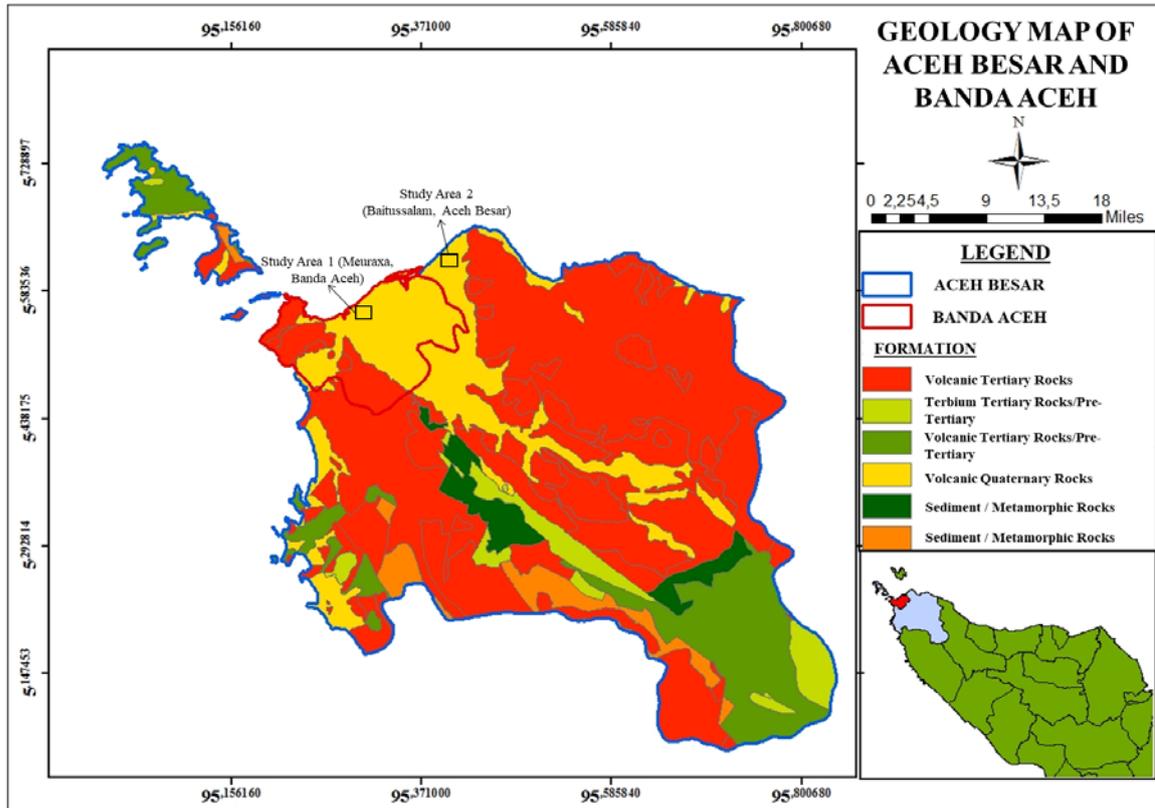


Fig. 2. Geology map of Banda Aceh, modified from [18].

3. METHODOLOGY

Electrical resistivity is a common method in delineating liquefaction potential zone/area, since it closely related to conductivity of saturated layer. Electrical resistivity is classified as an active geophysical method which carried out by injecting controlled direct current (d.c.) into the subsurface. The subsurface is classified by calculate the apparent resistivity (ρ_a) from measured resultant electrical potential at a specific point/depth and model the subsurface using inversion software by identify the true resistivity [19].

The study was conducted using ABEM SAS4000 system with minimum electrode spacing of 5 m in the two districts along the coastal line. The first study area (Meuraxa district) consist of 3 spreads, named M1, M2 and M3 while the second study area (Baitusslam district) consist of 2 spreads, named B1 and B2.

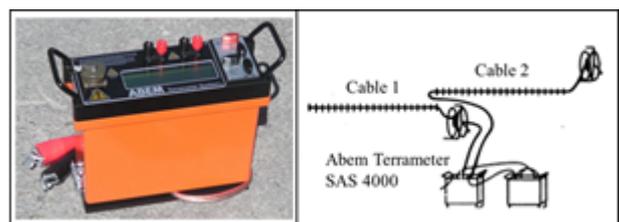


Fig 3. Abem Terrameter SAS 4000 and general setup [20].

The raw data are process using res2dinv software to produce true resistivity value and create a resistivity inversion model. The final models are finally imported into surfer8 software for presentation and interpretation which refer to Fig 4 and Fig 1.

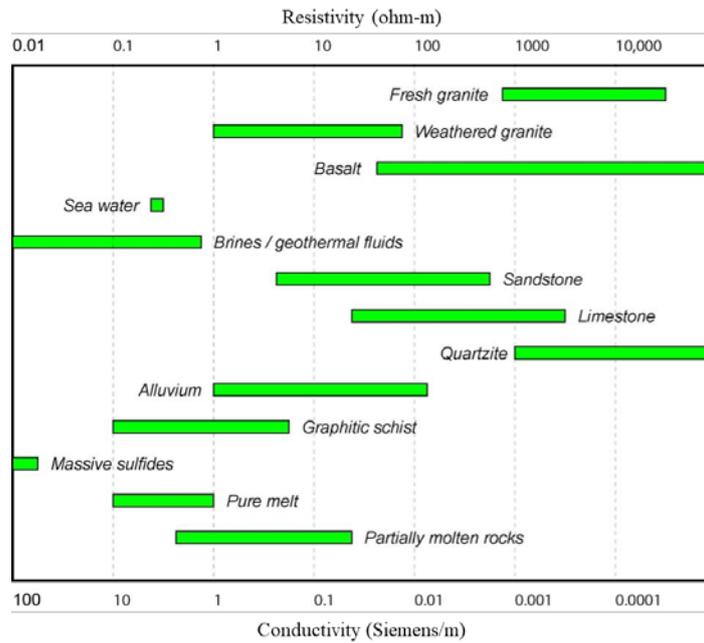


Fig. 4 Resistivity values for common geologic materials, modified from [19]

4. RESULTS AND DISCUSSION

The results gained based on field measurement, processing and interpretation. They are classified based on the resistivity value of the resistivity inverse model and Fig 4.

Fig. 5 describe the resistivity inverse model of spreads M1, M2, and M3, which classified into two to three main zones based on the resistivity values. The M1 inverse model depict that the first zone with depth of <6 m is interpreted as topsoil which is formed by deposited alluvium and marine sediment with resistivity values of >14 Ωm . The second zone is suspected as saturated zone with resistivity values of 2 – 10 Ωm with depth of 6 – 18 m. The third zone is described as weathered sedimentary rocks with resistivity values of >10 Ωm with depth >7 m. The M2 resistivity inverse model is classified into two main zones; the first zone is classified as saturated alluvium with depth of <15 m with resistivity values of 2 – 10 Ωm , while the second zone is classified with resistivity values of 10 – 38 Ωm with depth of 5 – 20 m. The M3 resistivity inverse model depicted that the first zone is classified with resistivity values of 2 – 42 Ωm with depth of <10 m. The second zone (saturated) with resistivity values of <6 Ωm . It is suspected that the saturated zone is affected by the intrusion of seawater with depth of 6 – 18 m while the third zone with depth of >18 m is suspected to be weathered sedimentary rocks with resistivity values of 14 – 42 Ωm .

Fig. 6 shows the resistivity inverse model of spreads B1 while Fig. 7 depict the resistivity model of spreads B2. Generally, the inversion results of both spreads indicate that the area is suspected to be mainly influenced by seawater intrusion. this is the fact that the measurement lines were situated nearby the coastal line. The both results of B1 and B2 spread depict the area has a low resistivity value due to the intrusion of seawater. The resistivity inverse models are segregated into two main zone. First zone, the overburden of B1 and B2 spreads is classified with resistivity value of 0.2 – 15 Ωm with depth of <10 m, while the second zone is classified with resistivity values of <0.1 Ωm with depth of >10 m.

The resistivity anomalies that affected the 'heavy - burden' with thin and undulating layers structure, which is characterized by high resistivity values that befall over lower resistivity zones. The irregular morphology and bumpy of the low resistivity layer ($\rho < 10 \Omega\text{m}$) suggest the occurrence of a seismically induced liquefaction phenomenon. The position of the suggested features corresponded with geological characteristics that is dominated by gravel sand, sandy clay, sandy silt, clayey silt, and silty clay. This top layer with higher resistivity distribution is induced by that sediments that gain pressure and has compacted the deposits.

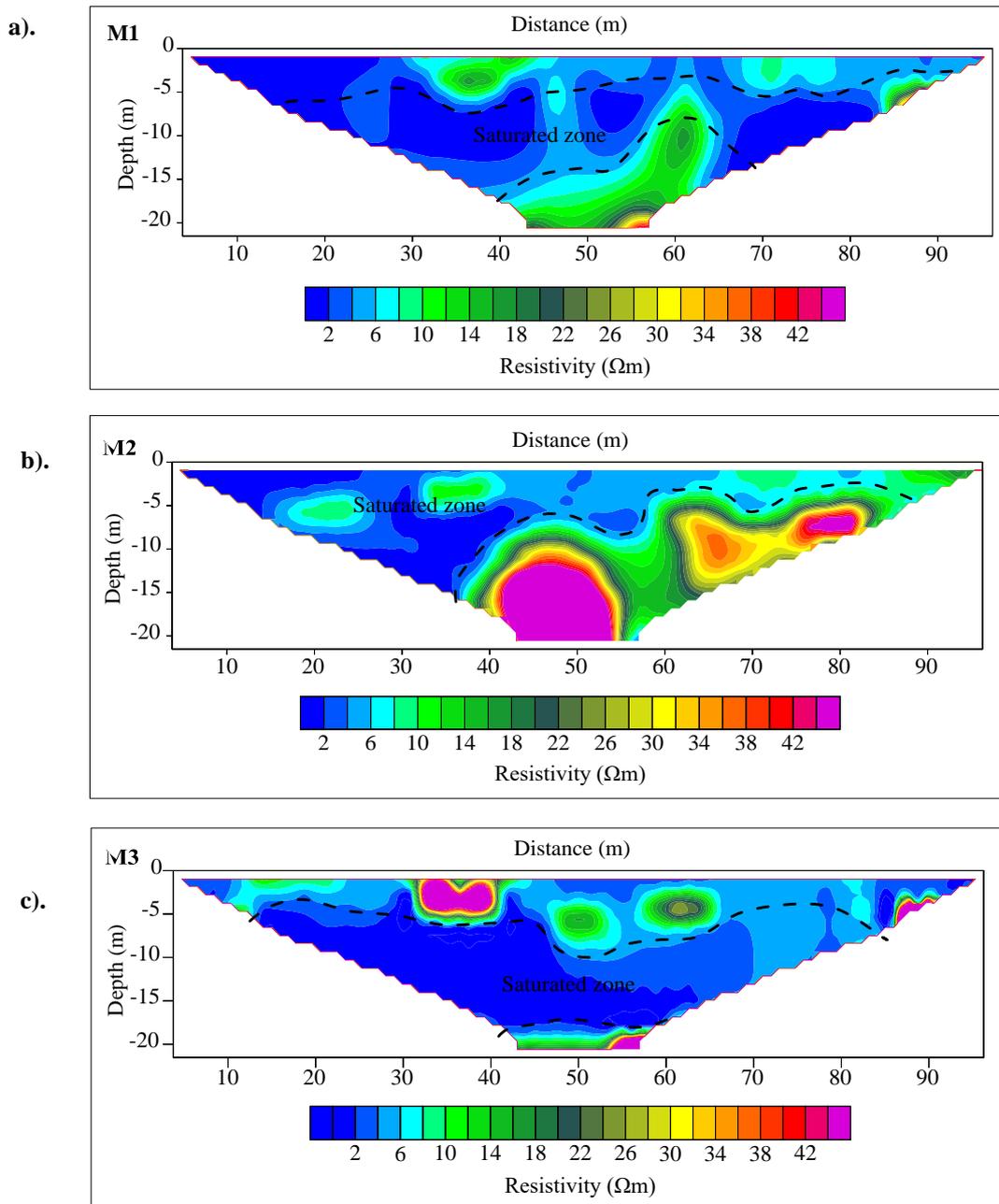


Fig 5. Resistivity inversion model of Meuraxa district; (a) spread M1, (b) spread M2 and (c) spread M3.

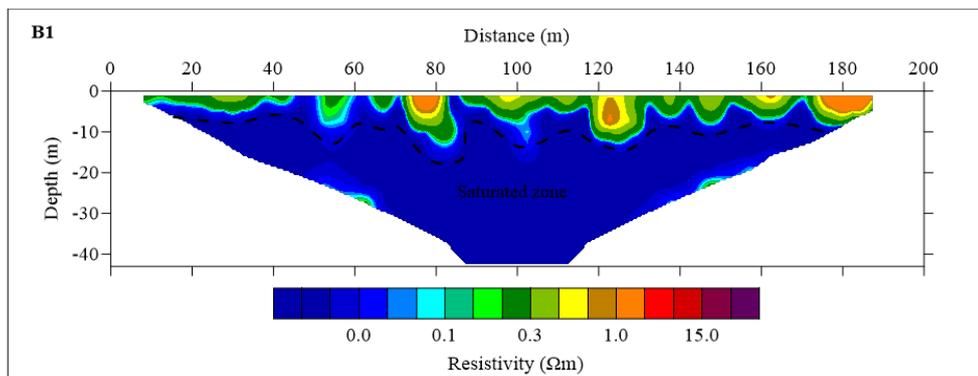


Fig 6. Resistivity inversion model of Baitusslam district; spread B1

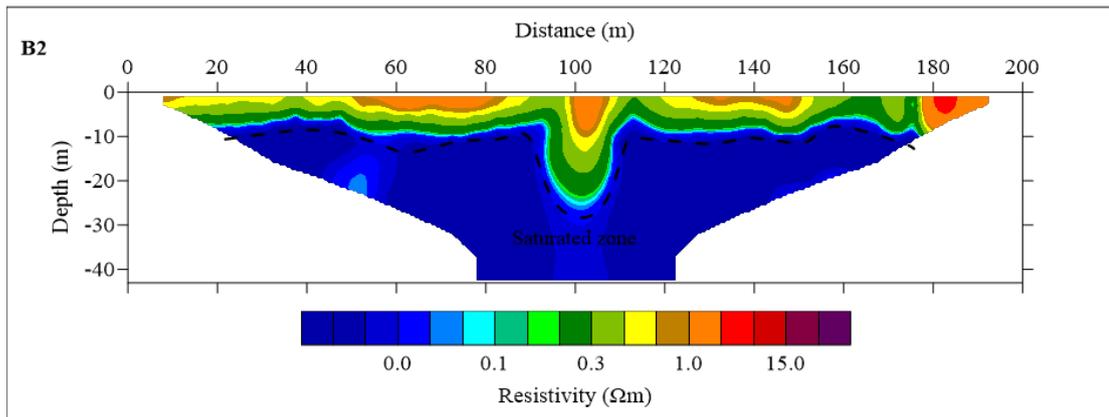


Fig 7. Resistivity inversion model of Baitusslam district; spread B2.

Based on field measurement and data analysis, the liquefaction phenomenon can be identified by classifying the saturation zone. In resistivity method, the signature of saturation zone is described by the low resistivity value of the subsurface on the pseudosection. It is the initial stage of author in describing the soil liquefaction phenomenon. The liquefaction zone also determined by characterizing the resistive anomaly above the conductive substratum. It is believed the fact can be associated with liquefaction phenomenon wherein the superficial geological condition which more compact befall over lighter sediments. The irregular morphology of the higher resistivity layer from the surface to the depth of about 8 m and lower resistivity at the second layer provided evidence of the liquefaction phenomenon. The authors suspect that the low resistivity value of both study area is influenced by seawater intrusion, since the area of interest is located along the shoreline. According to Werner, D.A., [21], one of the phenomena. The Mega Tsunami that occurred in Aceh, 2004 believed to be the major agent of the seawater intrusion occurred along the shoreline of Banda Aceh and Aceh Besar. Based on the previous explanation, it is predicted that the coastal area of Meuraxa and Baitussalam district, indicated a high potential of soil liquefaction phenomenon to be occurred. The prediction is based on the low resistivity values of 0.1 – 10 Ωm occurred in the two study areas which refer to geology record [14, 15, 16], resistivity values for common geologic materials [19], and microzonation map of liquefaction potential area in Banda Aceh [6]. From these results, the ERT profiles clearly reveal the sediment stratifications. It can be speculated that the stratification pattern closes to the resolving power of the ERT method.

Based on the previous explanation, results gained and evidences, he authors assumed that the tectonics activities of Aceh Province can stimulate the seawater to be intruded and affecting the soil condition nearby area and cause the soil

liquefaction to be happened since Aceh Province lies on three active segment and the tectonics activities is considered active.

5. CONCLUSION

The research about the prediction of soil liquefaction phenomenon based on ERT method has been conducted in two study areas; Meuraxa (Banda Aceh) and Baitussalam (Aceh Besar). Based on the data analysis and interpretation, the results indicated that the two-study areas are classified have a high potential of soil liquefaction phenomenon to occurred. The prediction is due to a saturated zone affected by seawater intrusion with resistivity values of <math><10 \Omega\text{m}</math> and the observed anomaly that indicate the superficial geological condition which is more solid lies on top of the lighter sediment. Hence, since Aceh province lies on three active segments, the tectonic activities were considered as the main agent to trigger the soil liquefaction to occur. The prediction of soil liquefaction phenomenon is also supported by the previous microzonation map of liquefaction area in Banda Aceh and Aceh Besar and based on the information given by the geology map.

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