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Geoelectrical characterization for liquefaction at coastal zone in South Aceh

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Abstract. The paper presents a case study of liquefaction investigation, carried out in an area of the South Aceh coast. The zone lies on low flat plain at Tanjung Harapan Village, west coast of Aceh. The process of site investigation is controlled by: occurrence of groundwater, nature of bedrock, and presence of clays. Prediction of liquefaction zones in high seismicity regions will be a great help to mitigate hazards. Geoelectric resistivity using a combination both vertical electrical sounding and horizontal resistivity images of Wenner-Schlumberger configuration have been carried out and can be of help to delineate the liquefaction zones. With this backdrop, it believe that in conjunction with soil and sediment characteristics indicating high susceptibility to liquefaction, and resistivity anomalies will provide vital information to predict and identify the liquefaction zones. Results of this study revealed the surface layer consists of loose sediments, sandy clay, and silty sandy layer are potentially liquefied during earthquake. The 2-D model sections at 10 m electrode spacing were described, together with subsurface structures can be used to predict the resistivity values at a approximately 48 m depth.

Key words: earthquake, liquefaction, resistivity, seismicity, coastal zone

Introduction

Liquefaction is one of main hazard for developing cities that located at coastal areas in many regions. Chang et al*..* (2003) investigated about the wave induced seabed liquefaction at nearshore based on the viewpoint of marine geotechnical engineering. The assessment was also conducted including the stability of the nearshore area by evaluating the wave induced liquefaction potential of seabed sand. Wave-induced seabed liquefaction is one of the possible reasons for the erosion of the sandy shore. (Sassa and Sekiguchi, 2001). The term "liquefaction" is a mechanical process by which the saturated sandy soil is rendered cohesionless due to repeated shaking by the vibrations of the earthquake waves (Trifunac, 1995, Geotechnical Engineering Bureau, 2007). The damage from the earthquake was substantial and included collapse of industrial buildings, homes, schools, and campus buildings. The shaking resulted in damage to buildings structures as well as ground failure and liquefaction (Todorovska and Trifunac, 1999). Thus, the evaluation of subsurface response at coastal zone under earthquake action is important for various installations that would planed. This research serves as a contribution about the analyzing of how engineering properties of subsurface materials affect their electrical response. Characteristic electrical parameters are extracted from the electrical responses of the subsurface, and the variations of these parameters with the textural properties of the soils are investigated and analyzed.

The study area is at coastal zone in Tanjung Harapan Village which are located in Northern Aceh. There are many known cases of loose soils that liquefied in coastal zone under earthquake loading, that causing severe damage. The location of investigated sites is shown in Figure 1 (a). Geologically, the Sumatran Fault System is interpreted as the result of oblique subduction of the Indian Ocean Plate beneath Sumatra. Earthquake activity indicates that movement along the fault, continues to the present day. The Tapaktuan Volcanic Formation occurs in faultbounded lenses, within sequence of the Anu-Batee Fault Zone, parallel to the west coast of Aceh north of Tapaktuan. It consists of massive epidotised andesites and basalts, commonly porphyritic, and intrusive dykes of a similar composition. The formation also includes agglomerates, breccias, tuffs, red and purple volcaniclastic sandstones and shales, the latter often as slates, and a limestone member, composed of sparite and calcilutite, all as lenses and much disrupted by faults. Scattered outcrops of gneiss (Meukek Gneiss Complex) occur within the Tapaktuan Volcanic Formation in the Barisan Mountains to the north of Tapaktuan, between sequence of the

Anu-Batee Fault. The rocks of the Woyla Group in Aceh commonly show the effects of intense deformation. The finer grained sedimentary and volcaniclastic rock types have been altered to slates and phyllites (Figure 1 (b)). Garnetiferous amphibolites of the Meukek Gneiss in the Tapaktuan Volcanic Formation suggest that gabbroic rocks of the oceanic assemblage were subducted into the mantle, before being returned tectonically to the surface (Barber, 2000).

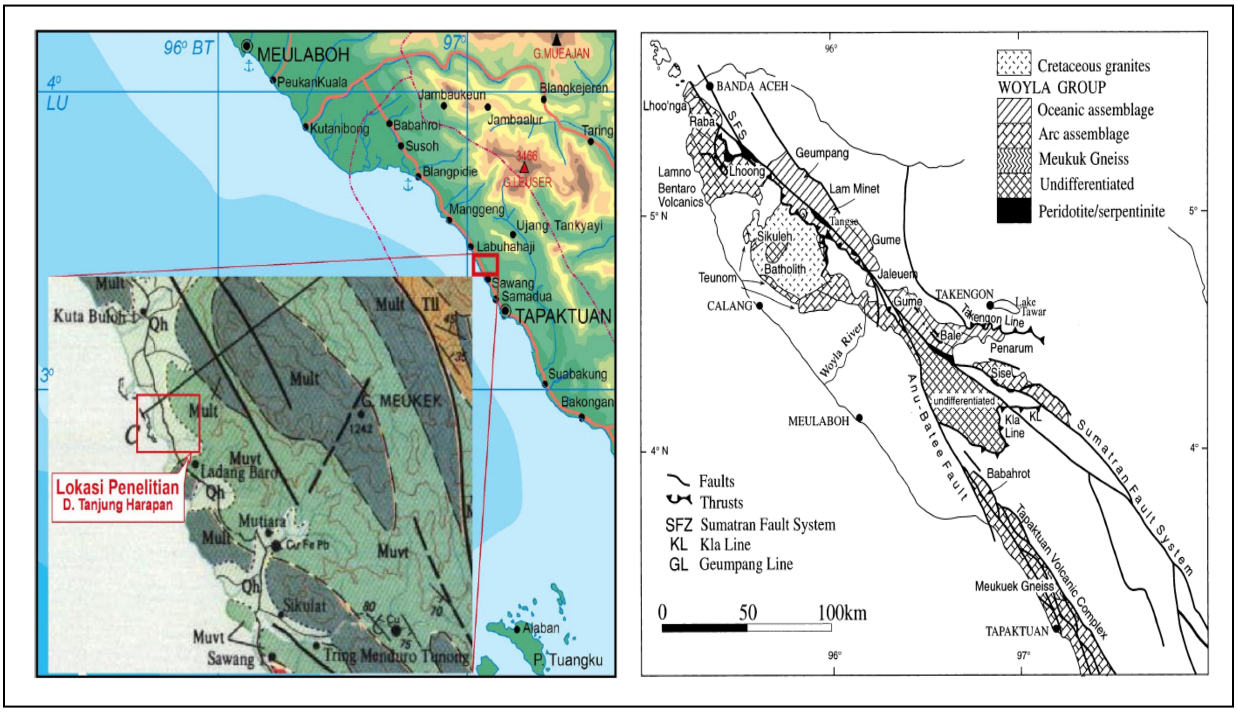

Figure 1. (a) Map of the study area at North Aceh and (b) Geological map of northern part of Sumatra (Barber, 2000).

Methodology

Currently, electrical resistivity methods are mostly used in geohazard and environmental investigations to help characterize the liquefaction potential region. In many geological situations, 2D imaging surveys can give useful results that are complementary to the information obtained by other geophysical methods. The Schlumberger array is very sensitive to horizontal changes in resistivity, so it can be addressed to map vertical structures such as dykes and cavities, and buried objects. On the other hand, Wenner array can give useful information on vertical discontinuities, so the integration of the two methods (Wenner-Schlumberger) can be very important to understand the subsoil structure (McNeill, 1994; Jordant and Costantini, 1995; Loke, 1999). These two resistivity methods were used in the present fieldwork. The objective of electrical sounding is to deduce the variation of electrical resistivity with depth below a given point on the surface, and to correlate it with geological knowledge in order to infer the subsurface structure in the greater detail. The horizontal resistivity profiling technique normally is used for the detection of lateral variation in a certain subsurface layer. Generally, the Wenner and Schlumberger arrays provide good vertical resolution for horizontal structures (Barker, 1981; Dahlin and Zhou, 2004). The technique involves measurements at a grid of observation points using an electrode array deployed at a fixed spacing. The electrode spacing was chosen based on the analysis of the measurements made at selected sites in the study area.

The Naniura Autorange Resistivity Meter was used for data acquisition, which consist of resistivity meter, two set of electrode cables, a computer, steel electrodes and various connectors etc. The electrodes were connected to a central switching system. In the setup, current was sent into the ground by two current electrodes on one side of the square and a potential difference was measured at two electrodes on the other side. The electrodes spacing were chosen at 10 m to probe the electrical properties of the vertical fractures below the surface. The readings are usually converted to an apparent resistivity, corresponding to the resistivity of a homogeneous half-space that would give the same result. The investigated volume can be changed by moving the electrodes. Large separations give larger investigation depths. The potential difference between the potential electrodes was measured and the resistance of the ground was calculated automatically by the meter. The measured resistances were recorded on a data entry sheet. The electrode configuration used in the survey is the Wenner-Schlumberger Array (Figure 2). Resistance values were converted into apparent resistivity values using the equation:

$$\rho_a = 2\pi a R$$

where (*a*) is the spacing used in the measurement and (*R*) is the resistance of the ground recorded by the Meter. The measurement position along the resistivity traverse, the electrode spacing and the calculated apparent resistivity values were entered into data files which were subsequently used by the RES2DINV, 2-Dimensional Resistivity Imaging Interpretation software. The interpretation program essentially calculates the true resistivity and true depth of the ground from the input data file and forward modeling procedures. The results of the interpretation are displayed as a 2-D electrical resistivity image of the subsurface along the line of the traverse. In this study, three resistivity survey lines at study area running south to north with a length of 300 m. The electrical resistivity images of these three lines will be discussed.

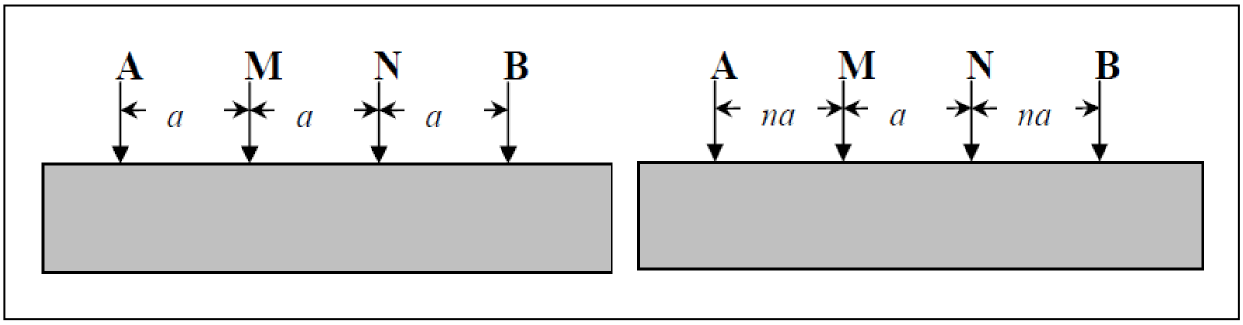

Figure 2. Electrode configurations (a). Wenner array, and (b). Schlumberger array, a, is the electrode spacing; A, B current electrodes; M, N potential electrodes).

Result and Discussion

The three resistivity pseudo-sections obtained from the study area during the 2011 measurements are presented in model section below. This 2-D resistivity model characterizes both the lateral as well as vertical variations along a profile. Pseudo-section resistivity data gives a pictorial representation of resistivity in the subsurface. The inverse model for electrical resistivity data obtained along line 1, 2 and 3 are shown in Figures 3, 4, and 5, respectively. This inverse model of electrical response of soils have been shown to be dependent on water content, degree of saturation, bulk density and pore structure and have been suggested an accurate image of subsurface (Barker, 1981, Smith and Vozoff, 1984, Griffiths and Barker, 1993, and Loke and Barker, 1996).

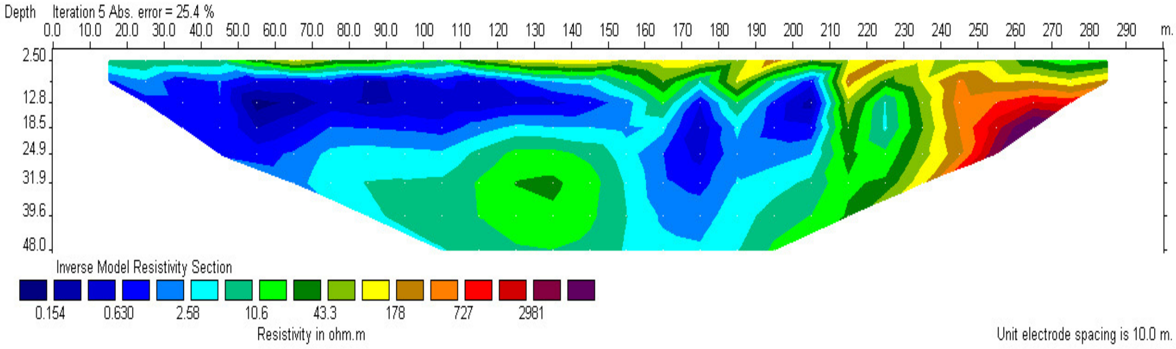

Figure 3. Interpreted resistivity-depth section from line 1 trending profile.

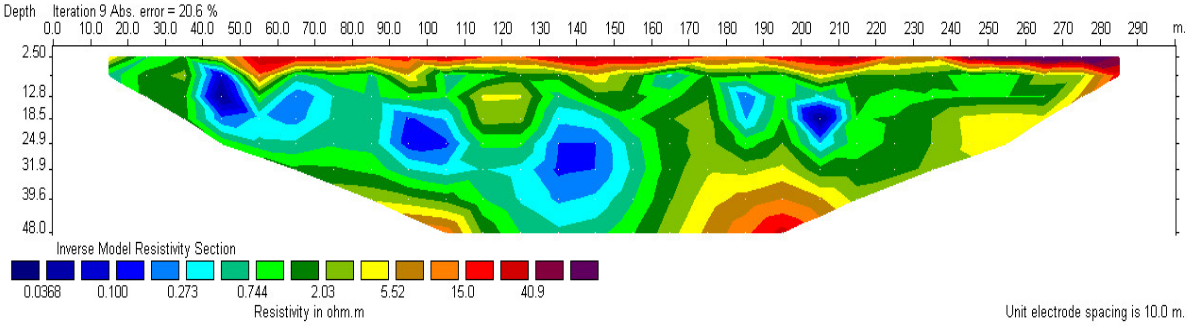

Figure 4. Interpreted resistivity-depth section from line 2 trending profile.

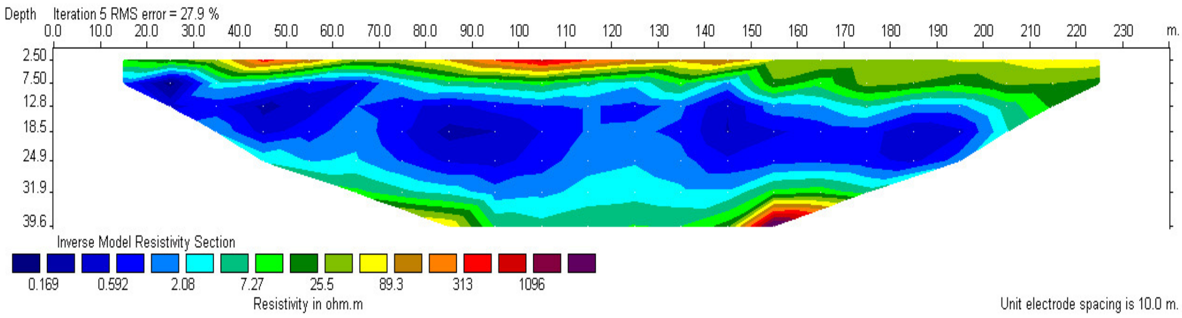

Figure 5. Interpreted resistivity-depth section from line 3 trending profile.

The resistivity inverse model had shown a low to fairly resistivy zone can be notice around 7-20 m of the the pseudo-section from 20 m to about 210 m. The variation of the resistivities is less than 3.0 Ohm.m which may reflect that some parts are water saturated and some are not. This low resistive zone in broad area can be interpreted as clay, sandy clay and silty sandy, soil or sand saturated with water. At the northern side shows high resistivities values above 100 Ohm.m, which is correlated with quite dry material. This high resistivity zone can be interpreted as dry sands and gravels. This is because of coastal areas sometimes formed by loose deposits and silty sand. Moreover, it is also instances of uncompacted granural fills, similar in properties to loose sands. It is thus expected for soils with low porosity, low water saturation and/or low pore water salinity. However, the electric resistivity is also influenced by phenomena at the mineral grain-pore water interface. Therefore, unsaturated soils can have lower resistivity than what otherwise might be expected. It reflects varying degrees of subsurface structures.

The variation in resistivity within surrounding low resistivity structures suggest that the soil quality in the study area in unstable. The grain characteristic, combined with the soil compactness is important for the liquefaction behaviour of sandy layer. This relationship between the resistivity values and subsurface structures reveals that the probability of liquefaction. The liquefaction is a very complex phenomenon, which can appear in sandy soils under different hydrogeological conditions initiated by strong earthquakes. The model section of site conditions in study area shows the possible of potential of liquefaction.

The physics of electrical current flow in subsurface soil suggest that the possible relationship between the engineering behavior of subsurface materials and electrical resistivity should be based on the parameters which control the engineering behavior as well as electrical resistivity such as composition, grain size distribution, fluid type and content, porosity and effective stress.

Conclusion

This study illustrates the application of an geoelectrical resistivity methodology to characterizing of liquefaction potential at coastal zone. Here, it can note two important features. First, the model sections show good correspondence with the regions of low resistivity, particularly in the central and south regions. It can be suspected from the resistivity images of model sections that there are low to fairly resistivity at subsurface was predict as clay, soil or sand saturated with water. Second, at the northern side shows high resistivities which is correlated with quite dry material, and can be interpreted as dry sands and gravels. The variation of resistivity values in subsurface structures that is characterized as a low resistivity zone and suspected as sandy soil reveals that the probability of liquefaction in the study area.

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References

Barber, A.J., 2000, The origin of the Woyla Terranes in Sumatra and the Late Mesozoic evolution of the Sundaland margin, Journal of Asian Earth Sciences 18 (2000), pp. 713–738.

Barker, R.D. (1981): The offset system of electrical resistivity sounding and its use with a multicore cable. Geophys. Prosp., v. 29: pp. 128-143.

Chang, C.H., Chien, L.K., And Chang, Y.H., 2004, 3-D Liquefaction Potential Analysis Of Seabed At Nearshore Area, Journal of Marine Science and Technology, Vol. 12, No. 3, pp. 141-151.

Dahlin T, and Zhou B (2004). A numerical comparison of 2D resistivity imaging with 10 electrodes array. Geophysical Prospecting, 52: 379-398.

Geotechnical Engineering Bureau, 2007, Liquefaction Potential Of Cohesionless Soils, Geotechnical Design Procedure Gdp-9, New York.

Griffiths, D.H.,and Barker, R.D. (1993): Twodimensional resistivity imaging and modeling in areas of complex geology. Jour. Applied Geophys., v. 29: pp. 211-226.

Jordant, E. and D. Costantini (1995): The use of Non-Invasive electromagnetic (EM) techniques for focusing environmental investigations, in Ground ConductivityMeters for Environmental Site Evaluation (Geonics Limited, Ontario, Canada), pp. 4-9.

Loke, M.H. (1999): Electrical imaging surveys for environmental and engineering studies, *Technical Notes.*

Loke, M.N. and Barker, R.D. (1996): Practical techniques for resistivity survey and data inversion. Geophys. Prosp., v. 44: pp. 499-523.

McNeill, J.D. (1994): Principles and application of time domain electromagnetic techniques for resistivity sounding, *Technical Note TN27* (Geonics Limited, Ontario, Canada).

Sassa, S. and Sekiguchi, H., "Analysis of Wave-Induced Liquefaction of Sand Beds," *Geotechnique*, Vol. 51, No. 2, pp. 115-126 (2001).

Smith N.C. and Vozoff K. (1984): Two-dimentional DC resistivity inversion for dipole-dipole data. IEEE Transactions on Geoscience and Remote Sensing, GE -22, pp. 21-28.

Todorovska, M.I., and M. D. Trifunac, 1999, Liquefaction Opportunity Mapping Via Seismic Wave Energy, Journal of Geotechnical and Geoenvironmental Engineering, Vol. 125, No. 12.

Trifunac, M.D., 1995, Empirical criteria for liquefaction in sands via standard penetration tests and seismic wave energy, *Soil Dynamics and Earthquake Engineering* 14 (1995) 419-426.