STRATIFIED SOIL CHARACTERIZATION USING 1D RESISTIVITY INVERSION ALONG THE PASURUAN COASTLINE, EAST JAVA

Syaiful Alam[1], Yanwar Yusup[1], Nur Khoirullah[1], Aditya Lesmana[2]
[1]Faculty of Geological Engineering, Universitas Padjadjaran
[2]Institut Teknologi Bandung
Corresponding author: syaiful.alam@unpad.ac.id

ABSTRACT

The inversion has been widely used in subsurface modeling of numerous data. The number of stratified soil layer and thickness were driven by damped least-squares inversion method. This study integrated five borehole logs and six vertical electrical sounding measurements. The inversion result is able to predict an unsampled of borehole data. The resulting maximum rms error is 0.22 and minimum rms error is 0.011 from 1D inversion. The borehole datas indicated gravelly soil layer, sandy soil layer, and clayey soil layer with the resistivity values respectively range from 33.6-7.45 (Ohm.m), 7.45-3.98 (Ohm.m), and 3.98-0.016 (Ohm.m). Based on the study result there were possibilities of seawater intrusion indication according to the soil stratigraphic profile based on resistivity properties and borehole data.

Keyword: Pasuruan coastline, stratified soil, 1D resistivity inversion.

INTRODUCTION

Pasuruan Region is located along the coastline of North Java Island. This region has numerous vital objects. One of the vital object is a power plant in Perak-Grati region. The coastal area has the possibilities being intruded by sea water. Seawater intrusion may occur naturally, by tidal or artificial. This phenomenon should be the awareness linked to the construction in such a situation.

The geoelectrical survey is an effort to characterize the soil stratigraphic layers. This method is one of the geophysical methods to describe the number and resistivity properties in soil layers. Among the factors affecting the resistivity properties are grain size, porosity, compaction, mineral,and water, as well as the salinity of the soil. The study location had been conducted on several area of interest in the surface facilities of the Perak-Grati Power Plant (Figure 1). The surrounding area is inferred to have higher corrosive soil due to the direct interaction between seawater. To characterize this problem, soil resistivity must be understood.

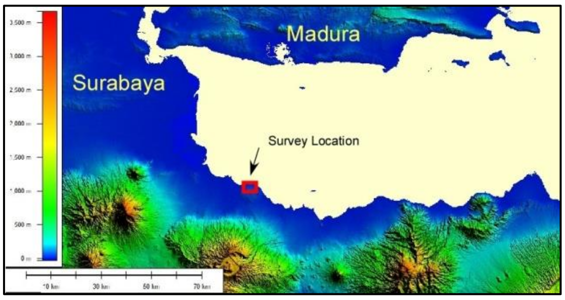

Figure 1. Study location

This paper presents a stratified soil characterization and the possibilities of seawater intrusion along the Pasuruan coastline based on resistivity properties to assist the construction engineering. The use of vertical electrical sounding (VES) has become an increasingly important technique for exploration of relatively shallow features (Nyman, D and Mark, 1977).

Table 1. Point Measurement Coordinate

Point	Longitude	Latitude
GL-01	113,027^0	-7,64927778^0
GL-02	113,033^0	-7,65^0
GL-03	113,0307^0	-7,6512^0
GL-04	113,0251^0	-7,6515^0
GL-05	113,0245^0	-7,6513^0
GL-06	113,017^0	-7,65^0

RESEARCH METHOD

The field resistivity survey is divided into the stage of acquisition/design survey, processing and interpretation combining with borehole data (Figure 2). Five borehole logs data were conducted previously and six field geo electricity measurements were executed in the same track. The 1D inversion scheme then complemented for unsampled borehole to predict the number of soil layers and thickness based on resistivity inversion.

The following equation is used to consider the configuration of depth target (Telford et al., 1990). The fraction current changes exponentially to the length of configuration as the following formulation;

$$\frac{I_x}{I} = \frac{2}{\pi} tan^{-1} \frac{2Z}{L} \quad ....(1)$$

E-ISSN : 2579 – 3136

In the question (1) above, if L = Z, then the fraction of the current that passes through the depth of only approximately 30%, and when L = 2Z the fraction of the flow will be around 50% passing through a depth Z. To achieve the target depth with a fraction of the current flowing optimally, it should be a long stretch beyond L> 2Z.

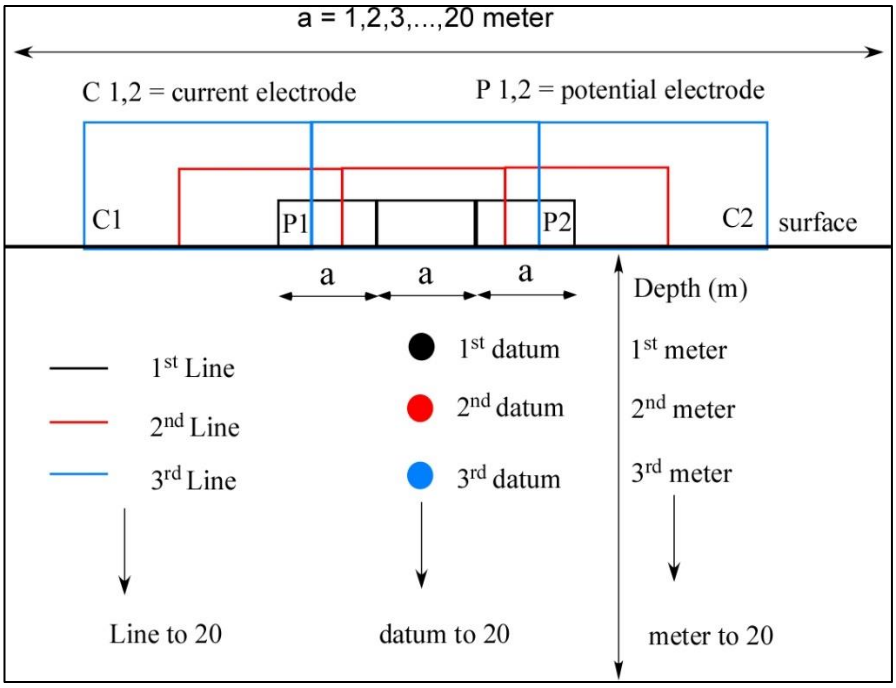

Figure 2. The design survey of field resistivity measurement (GL 01-06).

In this observation, the depth of the target was set up to 20 m. Based on the design survey, the total length was 60 m to reach the 20 m target depth. In practice, the electrodes space must be with the shortest distance of 1 m for a total line to be 3 m. The other lines were placed to the nearby electrode spacing to 20 m so that a total was about 60 m. Thus, the resistivity profiles obtained from a depth of 1-20 m.

Lowrie (2007) arranged the relationship between electrode spacing and resistivity. The electrode spacing (r_{AC}, r_{CB}, and r_{DB}) is thesame as given the name previously. Therefore, point A is the input current electrode, so the potential at point C;

$$U_C = \frac{\rho I}{2\pi}\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) \text{.........(2)}$$

The same thing also apply to the potential at point D;

$$U_D = \frac{\rho I}{2\pi}\left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right) \text{.........(3)}$$

Thus, the potential difference between points C and D is;

$$V = \frac{\rho I}{2\pi}\left\{\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) - \left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right)\right\} \text{......(4)}$$

From equation (4), then the resistivity ρ can be obtained;

$$\rho = 2\pi\frac{V}{I}\left\{\left(\frac{1}{r_{AC}} - \frac{1}{r_{CB}}\right) - \left(\frac{1}{r_{AD}} - \frac{1}{r_{DB}}\right)\right\}^{-1} \text{.........(5)}$$

The Schlumberger electrode configuration (ρ_a) over an earth model consisting of homogeneous and isotropic layers is related to the kernel function through the Hankel integral as follows (Koefoed, 1970);

$$\rho_a = S^2 \int_0^{\infty} T(\lambda) J_1(\lambda S)\lambda d\lambda \text{.........(6)}$$

and the resistivity transform function, T(λ), as follows;

$$T_i(\lambda) = \frac{T_{i+1}(\lambda) + \rho_i tanh(\lambda h_i)}{[1 + T_{i+1}(\lambda) tanh(\lambda h_i)/\rho_i]}.$$

$$i = n-1, \ldots, 1 \text{.........(7)}$$

$S = half\ the\ current\ electrode\ spacing$

$J_1 = first\ order\ Bessel\ function$

$\lambda = integral\ variable$

$n = the\ number\ of\ layers$

$\rho = the\ resistivity$

$h = thickness\ of\ the\ ith\ layer$

E-ISSN : 2579 – 3136

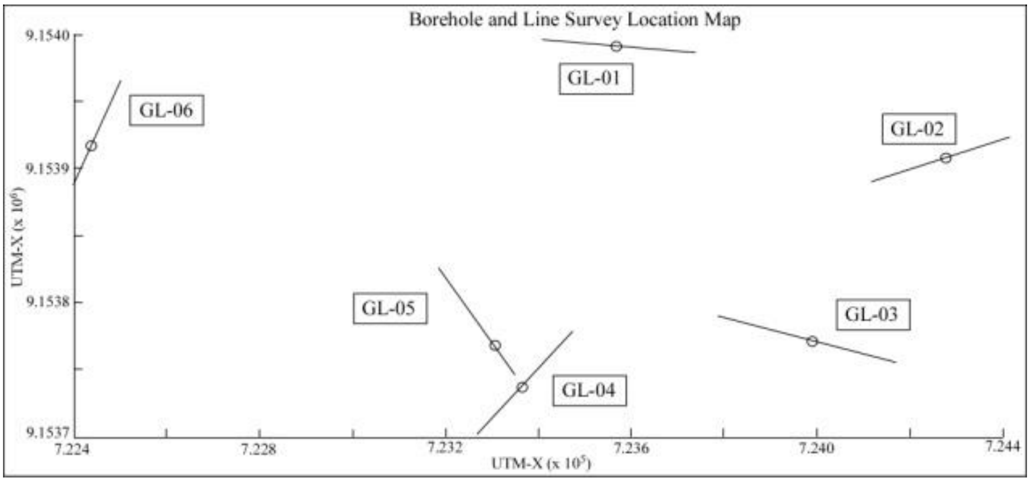

Figure 3. Borehole and line survey map.

The equation 6 denotes the most common phenomena in geophysical process. In this case,the phenomena are related to resistivity distribution in the subsurface with (ρ_a) as a measured data. Equation 7 denotes a forward model to compute the number of layer thickness and resistivity.
A parameter driven from the forward function is then calculated recursively using the damped least-squares inversion method. Such an inversion method has been well defined by Levenberg (1944) and Marquardt (1963). The observation designed crossing the borehole to validate the resistivity measurement. The current electrodes were separated up to 60 m (AB/2 = 30 m) in each spacing interval 20 m (Figure 3).

The figure above is situated along the Pasuruan coastline. The line azimuth is set to be in the Northeast-Southwest and Northwest-Southeast and perpendicular relative to the shoreline. The data distribution then plotted in a logarithmic curve to figure out electrode spacing-resistivity relationship. The value of resistivity decreases with the addition of the width of the electrode spacing as the following in equation 1.

RESULT AND DISCUSSION

Based on the measurement on GL-01 section, there is a rapid change in resistivity within 4 m and 12 m of the spacing electrode (a). This is such an anomaly that must be less resistive then underlying and overlying layer. Furthermore, the figure 4 to figure 9 represent the resistivity distribution data (ρ_a) over electrode spacing (a). These figures below indicated that the soil model in the research area has multiple layers or more than two layers.

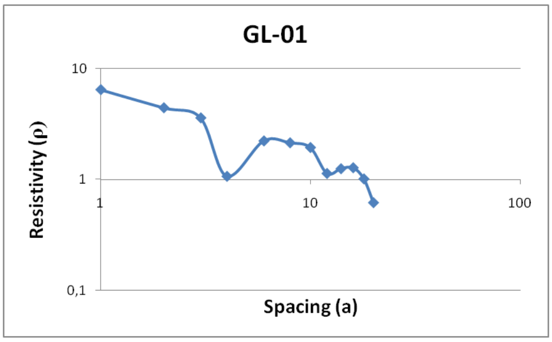

Figure 4. Resistivity distribution along electrode spacing in GL-01.

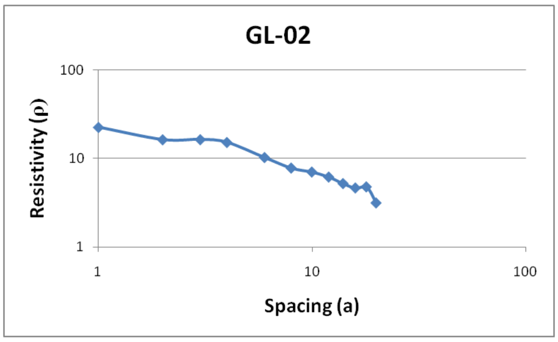

Figure 5. Resistivity distribution along electrode spacing in GL-02.

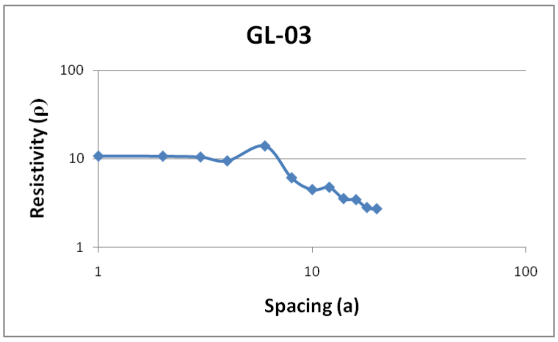

Figure 6. Resistivity distribution along electrode spacing in GL-03.

E-ISSN : 2579 – 3136

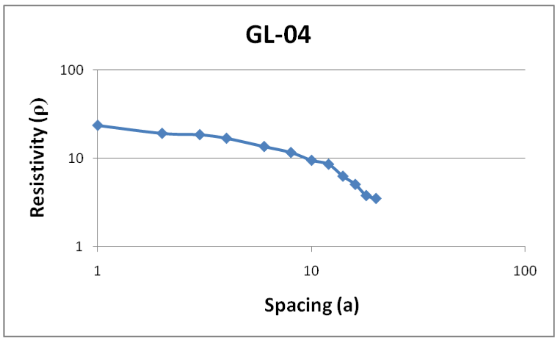

Figure 7. Resistivity distribution along electrode spacing in GL-04.

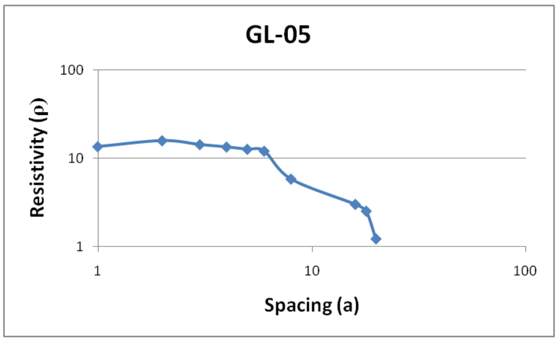

Figure 8. Resistivity distribution along electrode spacing in GL-05.

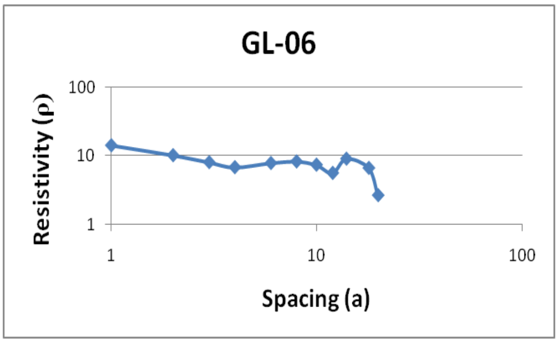

Figure 9. Resistivity distribution along electrode spacing in GL-06.

The resistivities data distribution change gradually based on the previous log plot curve. In order to figure out the number of layer thickness and resistivities, the inversion method was set up. The Marquardt-Levenberg inversion technique basically involved the traditional method of least squares (Marinho et al., 2016). A number of layer thickness and resistivities were taken from borehole data as a forward model in the inversion scheme.

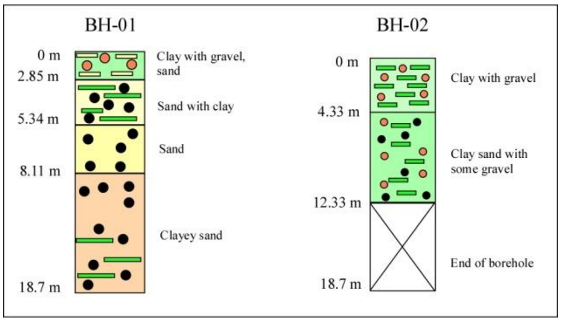

Figure 10. Stratified soil description of borehole data (BH-01 and BH-02).

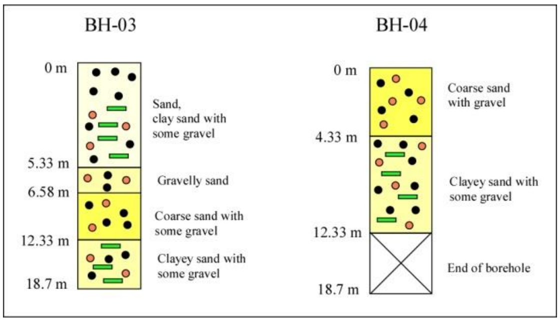

Figure 11. Stratified soil description of borehole data (BH-03 and BH-04).

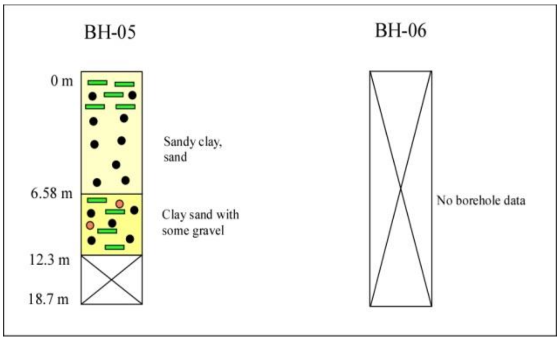

Figure 12. Stratified soil description of borehole data (BH-05 and BH-06).

The borehole location was set up in line with resistivity line survey, BH-01 was in line with GL-01, BH-02 was in line with GL-02, BH-03 was in line with GL-03, BH-04 was in line with GL-04, BH-05 was in line with GL-05, and BH-06 was in line with GL-06. In BH-01, four soil layers were described with clayey sand as the thickest layer. In BH-02, almost the soil layers were clayey layers. In BH-03, BH-04,and BH-05, sandy layers were common features founded on those borehole data. There is no borehole data of BH-06 causes the inversion method plays a significant role over the borehole to predict a number of layer thickness.

E-ISSN : 2579 – 3136

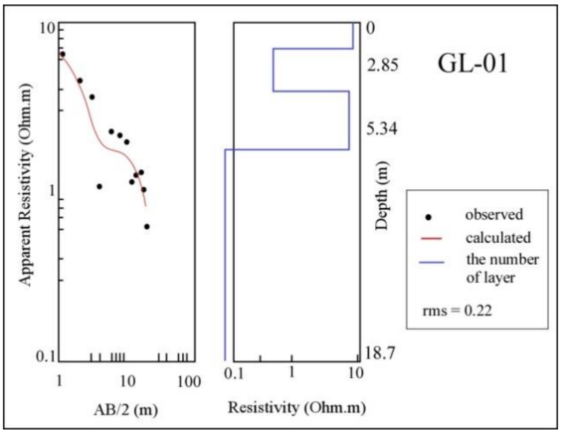

Figure 13. GL-01 inversion result indicating four soil resistivity layers at BH-01.

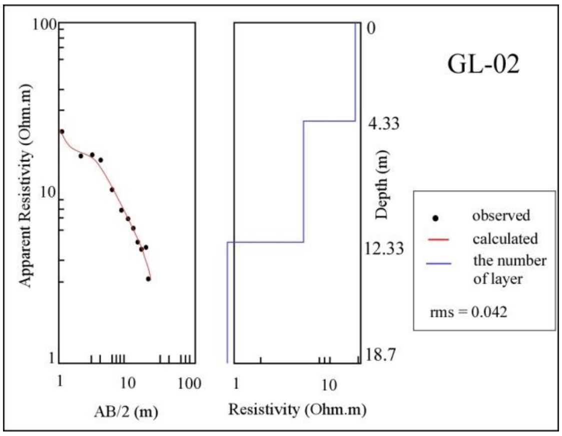

Figure 14. GL-02 inversion result indicating three soil resistivity layers at BH-02.

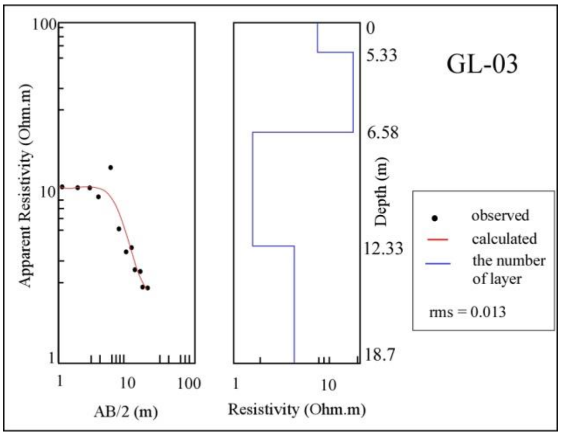

Figure 15. GL-03 inversion result indicating four soil resistivity layer at BH-03.

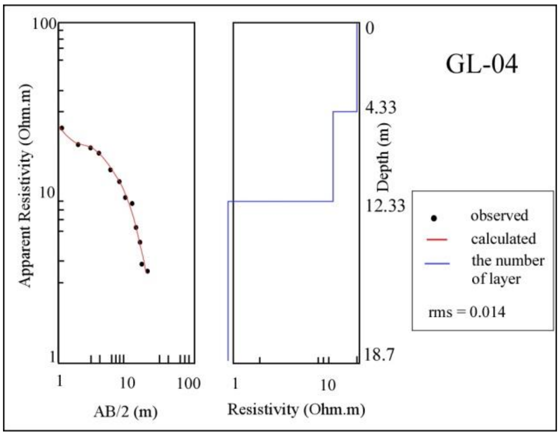

Figure 16. GL-04 inversion result indicating three soil resistivity layers at BH-04.

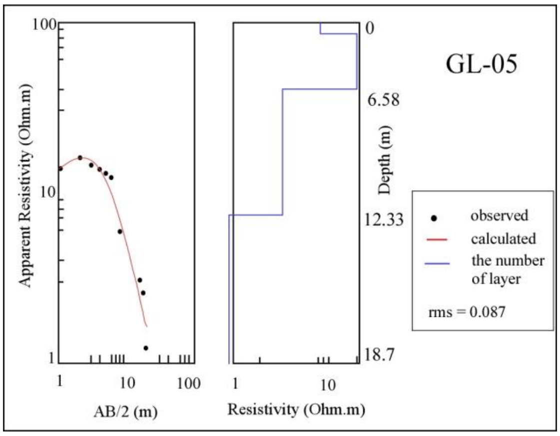

Figure 17. GL-05 inversion result indicating four soil resistivity layers at BH-05.

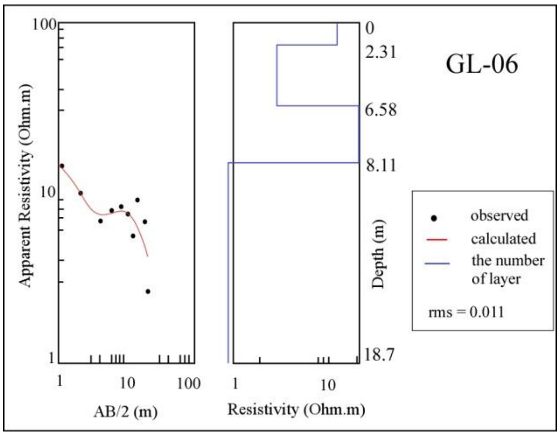

Figure 18. GL-06 inversion result indicating four soil resistivity layers at BH-06.

None of the rootmeans square (rms) error is more than 0.5. The maximum rms error is 0.22 in GL-01 and others are below 0.1 rms error, indicating good inversion result. The direct interpretation, or inversion, of the sounding curve (VES), curves into layer thickness and resistivities have attracted the attention of geophysicists for the past 40 years (Zohdy, 1975).

E-ISSN : 2579 – 3136

The misfit between the observed (black point) and calculated (red line) are shown in figure 13 until figure 18. The sounding curve (GL-01 to GL-06) represent generally decreasing resistivity with depthvariety of layer thickness. The surface electrical resistivity method is a useful tool in determining seawater intrusion in coastal areas for its capability to discriminate the large resistivity contrast between the presence of seawater that strongly reduces the resistivity values and saturated freshwater layers (Mogren, 2015). The large contrast and also rapid change of resistivity values within layer appear in GL-01, GL-03,and GL-06.

CONCLUSION

The 1D inversion of resistivity data using the damped least-squares method has been performed well in this study. This inversion scheme shows a good result by its minimum misfit. The model derived from data inversion indicated an identical property (the number of the layer) to the reality of the number of soil layer (from borehole data). The stratified soil layer has been well identified in this study (Tabel 2).

Table 2. Summary of predicted model

Resistivity (Ohm.m)	Soil layer Prediction
33.6 – 7.45	Gravely
7.45 – 3.98	Sandy
3.98 – 0.016	Clayey

The Pasuruan coastline has a variety of soil properties. This coastline must have been experiencing an interaction with seawater through time. In the normal condition, the relationship between resistivity value through depth might be increased due to the overburden process. The corrosive soil is ought to have lower resistive than underlying and overlying strata. The seawater interaction or intrusion probably one of a factor that decreasing value of resistivity through depth in this study area.

ACKNOWLEDGEMENT

The author would like to thank PT. Geosindo Utama for supporting data and facilities during field and desk studies.

REFERENCES

KOEFOED, O., 1970. A FAST METHOD FOR DETERMINING THE LAYER DISTRIBUTION FROM THE RAISED KERNEL FUNCTION IN GEOELEGTRICAL SOUNDING. Geophys. Prospect.

Levenberg, K., 1944. A method for the solution of certain non-linear problems in least squares. Q. Appl. Math.

Lowrie, W., 2007. Fundamentals of geophysics, Eos, Transactions American Geophysical Union.

Marinho, J., Lima, O., Vasconcelos, S., 2016. Inversion of electrical resistivity soundings for the investigation of aquifers in the acaraú-itarema region, ceará, Brazil, Revista Brasileira de Geofísica.

Marquardt, D.W., 1963. An Algorithm for Least-Squares Estimation of Nonlinear Parameters. J. Soc. Ind. Appl. Math.

Mogren, S., 2015. Saltwater Intrusion in Jizan Coastal Zone , Southwest Saudi Arabia , Inferred from Geoelectric Resistivity Survey. Int. J. Geosci.

Nyman, D, C., Mark, L., 1977. VES DIPOLE DIPOLE FILTER COEFFICIENTS. GEOPHYSICS 42, 1037–1044.

Telford, W.M., Geldart, L.P., Sheriff, R.E., 1990. Telford - Applied Geophysics, Cambridge University Press, Cambridge.

Zohdy, A.A.R., 1975. Automatic Interpretation of Schlumberger Sounding Curves , Using Modified Dar Zarrouk Functions. Geol. Surv. Bull. 1313-E.

E-ISSN : 2579 – 3136