

Model Development Relating Electrical Resistivity to Mechanical Elasticity of Hydrothermal Aquifer at Geothermal Area of Panggo-Kaloling, Sinjai Regency, Indonesia

Lantu^{1*}, D.A. Suriamihardja², A.M. Imran³, T. Harianto⁴

¹Student of Graduate Program of Civil Engineering, Hasanuddin University

²Department of Physics, Faculty of Science, Hasanuddin University

³Department of Geological Engineering, Faculty of Engineering, Hasanuddin University

⁴Department of Civil Engineering, Faculty of Engineering Hasanuddin University

*email: geolantu@gmail.com

ABSTRACT

A mathematical model has been developed to obtain the relationship between two parameters of electrical resistivity and mechanical elasticity of subsurface rocks of the hydrothermal area of Panggo-Kaloling in Sinjai Regency. The model was developed using data exploration concerning of both methods from the area under consideration. Constructed model is able to relate a time travel of seismic waves propagation that stands for mechanical elasticity to electrical resistivity in the area. The characteristic properties of the relation show a close connection to the parameter of porosity of the subsurface rocks. Comparing the results derived from the modeling with that of obtained from measurement gives suitable approximation with error level of less than 20%. The study concludes that the model is able to predict mechanical elasticity by using geo-electric method, or electric resistivity by using seismic refraction method.

Keywords: porosity, electrical resistivity, mechanical elasticity, and travel time of waves propagation

Article history: Received 20 April 2015, last received in revised 10 October 2015

1. INTRODUCTION

The increasing consumption of energy and demand of natural resources in the subsurface of the Earth lead to the increasing role of exploration. At the same time, scientific engineering for design and construction of infrastructures need more comprehensive information concerning the structure of bedrock. It is due to the facts that many buildings and roads have been damaged caused by the lack of information of soil properties where structures and building are constructed.

The exploration as well as exploitation of natural resources and structural mapping of subsurface rock is really required while environmental sustainability must remain guaranteed from the impacts. The Geophysical explorations are reasonably less priced and non-destructive method, and are the very potential for the exploration and mapping of the bed rock structure comprehensively. Nevertheless, geophysical explorations are of no absence of fundamental flaws. Consequently, careful

activities during exploration conducted need to obey precautionary principle.

Geophysical explorations are the common methods conducting in: (1) indirect measurement; (2) using limited number of parameters; (3) using more than one methods to obtain accurate results. The lesser methods we use the more effective and efficient works we conduct. Owing to this premise, we construct a transformation model that can link electrical resistivity to mechanical elasticity parameters in exploring subsurface rocks as was previously developed by [1],[2],[3],[4]. Meju et al. [1] utilize the electromagnetic and seismic refraction methods for determine the correlation of electrical resistivity and seismic to adapted to near surface of the earth [5]. In this study their developed the relation of electrical resistivity and p wave velocity in linear relation. Ayolaby et al. [2] have been carried out of Igbogbo to determine the structure setting of the subsurface material and ground water potential without study the relationship between electrical and elasticity properties.. Ursin and Carcione [3] studied the cross properties relation between electrical conductivity and seismic velocity to determine the stiffness module and density expressing the porosity in terms of those properties. Jones and Eaton [4] studied the relationships of velocity – conductivity for mantle mineral assemblages. In this case he developed the relationship between the transversal velocity v_s and conductivity. In this construct, mechanical elasticity will be

represented by travel time of seismic waves propagation, and electrical resistivity represented from geo-electric measurement. Physical parameter which has connection to both parameters of electrical resistivity and mechanical elasticity will be selected to be porosity of the subsurface rocks as was developed by Hossain and Cohen (2012). The analysis will take benefit from the development of technology and information processing to help the process of interpretation. It is assumed that the porosity used in electrical and mechanical properties remains the same for both purposes. Based on this assumption, the transformation model will be develop .

The study aims: (1) to explore electrical and mechanical properties of the sub-surface rocks in the hydrothermal area; (2) to relate mathematically parameter of electrical resistivity to parameter of mechanical elasticity.

2. MATERIALS AND METHODS

Data were collected at the hydrothermal area of Panggo-Kaloling, Sinjai Regency, Province of South Sulawesi, and performed by the method of electrical resistivity by using geo-electric method together with mechanical elasticity by using the method of seismic refraction. The focus of study cover the stretching of ranges from is 90 m to 100 m lengths. Other important parameter to find is the porosity of the subsurface rocks under studied. The Schlumberger and Wenner configurations are used to set up the pattern of probes to figure

out the vertical profiles of electrical resistivity of the subsurface rocks. The Schlumberger configuration is set up at four corners to determine the condition of resistivity, while the Wenner configuration is set up on four sides to determine the nature of resistivity in 2-dimensional profiles of vertical layers. It is believed that from the facts reported by Hossain and Cohen (2012) that the porosity (ϕ) will be an important parameter that linked the electrical resistivity to the mechanical elasticity of the rock under studied. If it is assumed that the time travel (t_p) of seismic waves propagation is a function of porosity ϕ_r that can be written as:

$$t_p = f(\phi_r) \quad (1)$$

Similar to that of (1), the resistivity (R) is a function of porosity ϕ_e that takes the form as:

$$R = g(\phi_e) \quad (2)$$

If the both explorations involve geoelectric and seismic methods at the same area then we have:

$$\phi_r = \phi_e = \phi \quad (3)$$

The travel time of propagation per unit length can be written as:

$$t_p = f\{g^{-1}(\phi)\} \quad (4)$$

It has been proven that the relation between porosity ϕ_e and electrical resistivity takes the form as:

$$\phi_e = \left(\frac{R_f}{R_o}\right)^{1/m} \left(\frac{R_M - R_o}{R_M - R_f}\right) \quad (5)$$

Equation (5) shows that R_o , R_f , and R_M respectively stand for measured resistivity, fluid resistivity that filled the rocks and resistivity of rock matrix, m is cementation factor. While from seismic exploration method, we can find the relation between porosity ϕ_r with the time of wave propagation per unit length which is given by:

$$\phi_r = \frac{(t_p - t_M)}{(t_f - t_M)} \quad (6.a)$$

In other formulation, we will have also the form of:

$$t_p = \phi_r t_f + (1 - \phi_r) t_M \quad (6.b)$$

Equation (6.b) shows that t_p , t_f , and t_M respectively are the measured travel time of propagation, travel time of propagation in fluid, and travel time of propagation of rocks matrix per unit length. The important way to find out the standard model for subsurface rocks is to measure the resistivity at the same area in time and equal conditions for both exploration methods of electrical resistivity and mechanical elasticity. For both methods, the porosity of subsurface rocks is of importance to have equal values whether for the measurement of electrical resistivity as well as for mechanical elasticity. Substitute the equation (5) into the equation (6.b) we will have:

$$t_p = AR^{\frac{1}{m}} + B R^{\frac{m-1}{m}} C \quad (7)$$

Constants in equation (7) are written as follows:

$$A = \frac{R_f^{\frac{1}{m}} R_M}{R_M - R_f} (t_f - t_M) \quad (8.a)$$

$$B = \frac{R_f^{1/m}}{R_M - R_f} (t_M - t_f) \quad (8.b)$$

$$C = t_M \quad (8.c)$$

The relationship between t_p and R can be obtained by calculating the constants of A , B and C of equations (8.a, 8.b, and 8.c) using the method of least square as performed by Petras and Bednarova (2010).

3. RESULTS AND DISCUSSION

A. Geo-electrical Resistivity Measurement

Measurement using Schlumberger's configuration: covering 4 sounding points successfully has identified 4 (four) layers which is reduced into 3 (three) layers of subsurface rocks. In each figure 1.a to 1.d, the vertical axis is resistivity, horizontal axis is electrode space; where... = resistivity, h = thickness, d = depth, Alt = altitude; Color form bottom to upper layers indicates as apparent resistivity.

Sounding 1.

The first sounding depicted in Figure 1.a discovers layer (1) having 23.2 m of resistivity with 0.864 m of thickness is identified as overburden; layer (2) having 142 m of resistivity with 1.14 m of thickness. is interpreted as volcanic tuff; and layer (3) having 6.84 m with 14.5 m of thickness which is identified as an aquifer of hydrothermal zone.

Sounding 2

The second sounding depicted in Figure 1.b discovers layer (1) having 12.8 m of resistivity with 0.26 m of thickness is identified as overburden layer; layer (2) having 628 m of resistivity with 1.14 m is identified as volcanic tuff, the aquifer of hydrothermal zone is found in the fourth layer

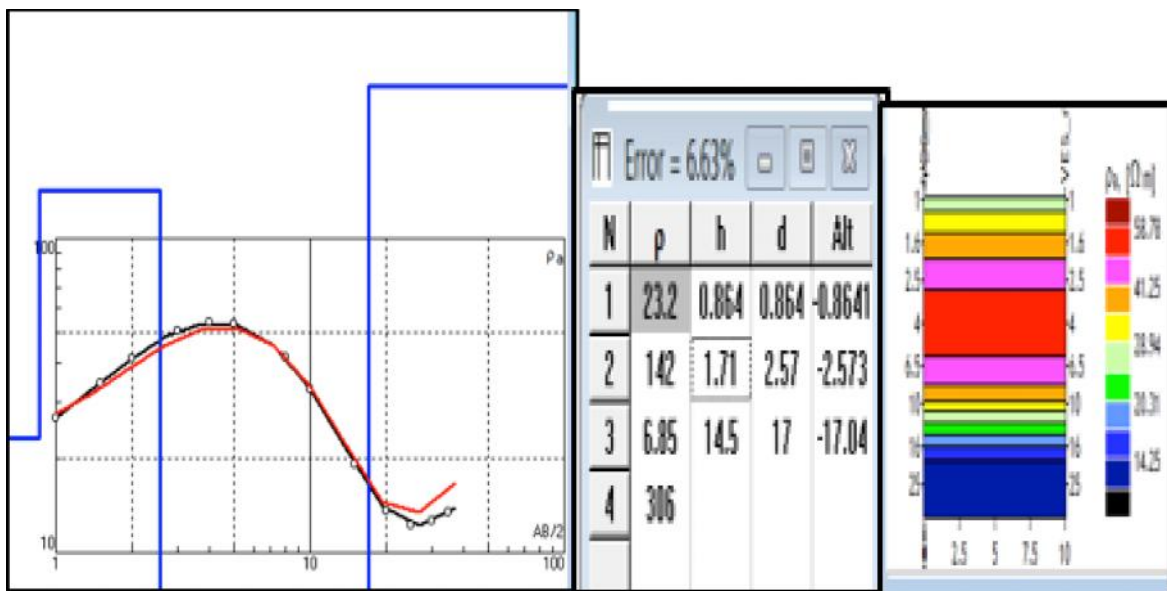


Figure 1.a The first sounding of Schlumberger configuration with its sounding Profile

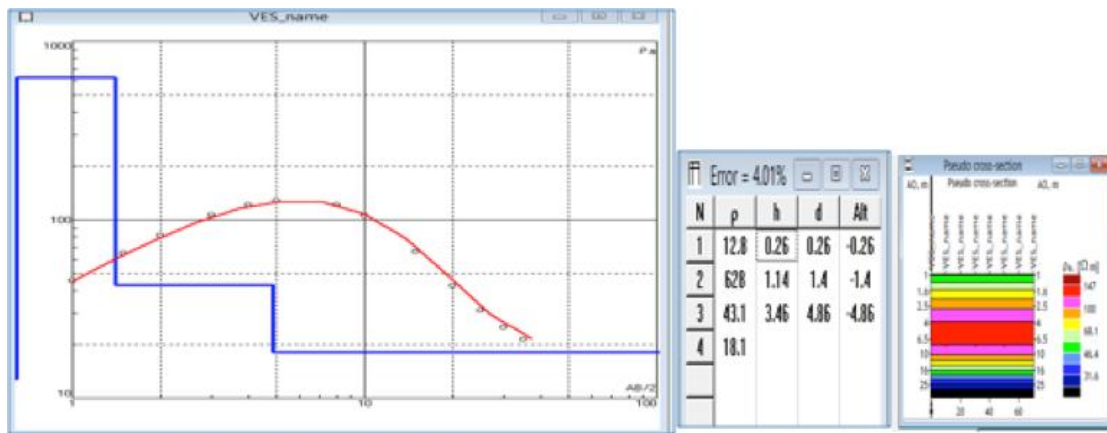


Figure 1.b The second sounding of Schlumberger configuration with its sounding profile

The third sounding depicted in Figure 1.c discovers layer (1) having 5.8 m of resistivity with 0.585 m of thickness identified as overburden layer; layer (2) having 482 m with 0.59 m of thickness identified as the volcanic tuff ; and layer (3) having 5.034 m with 1.01 m of thickness which is identified as an aquifer of hydrothermal zone.

Sounding 3

The third sounding depicted in Figure 1.c discovers layer (1) having 5.8 m of resistivity with 0.585 m of thickness identified as overburden layer; layer (2) having 482 m with 0.59 m of thickness identified as the volcanic tuff ; and layer (3) having 5.034 m with 1.01 m of thickness which is identified as an aquifer of hydrothermal zone

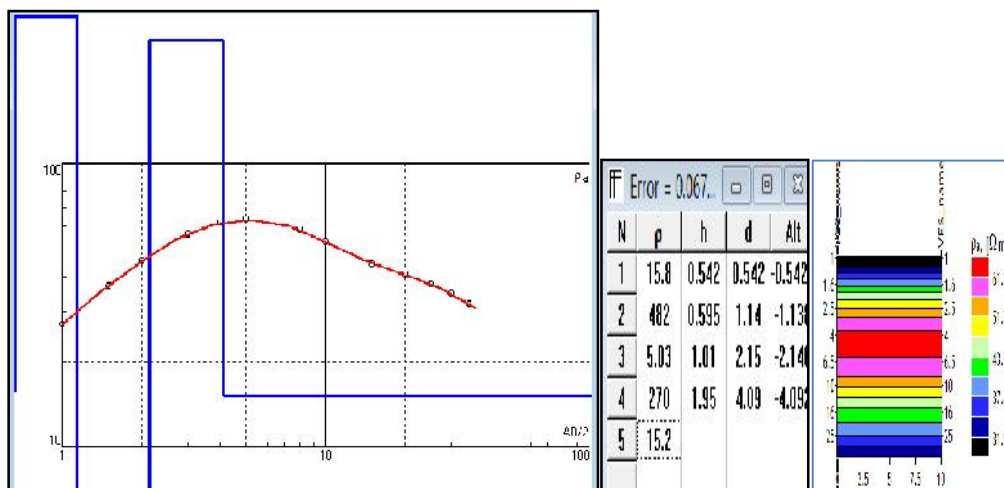


Figure 1.c The second sounding of Schlumberger configuration with its sounding profile

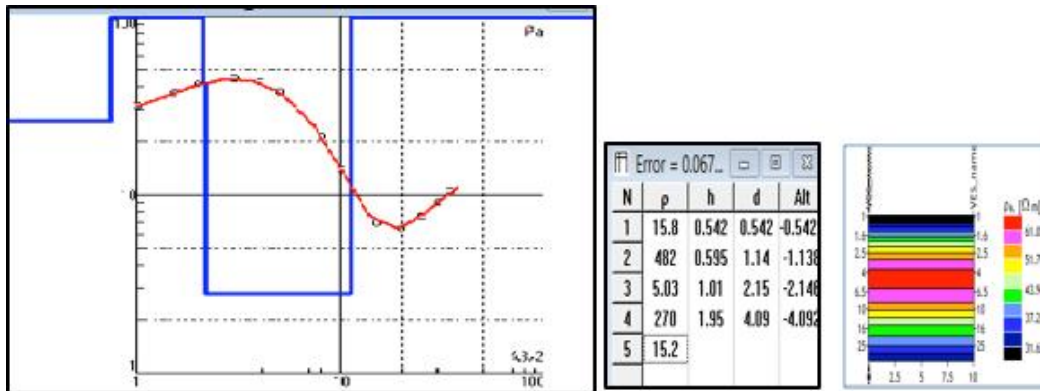


Figure 1.d The third sounding of Schlumberger configuration

Sounding 4

The fourth sounding depicted in Figure 1.d discovers layer (1) having 25.8 m with 0.4 m of thickness identified as overburf=den layer identifiwe as overburden layer; layer (2) having 103 m with 1.72 m of thickness identified as volcanic tuff; and layer (3) having 42.7 m of resistivity with 0.82 m of thickness asthe aquifer of the fourth sounding.

profile of vertical layers which are generally also showing 3 (three) types of rocks resistivity. Those are layer (1) with 15 m of resistivity, layer (2) with resistivity greater than 100 m, and layer (3) as an aquifer zone with resistivity small than 10 m. In these measurement is identified three types of subsurface as overburden layers (green), the volcanic tuff (yellow and red) and the hydrothermal zone (blue).

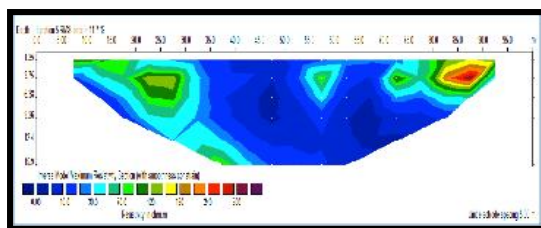


Figure 2.a The first line of Wenner configuration discovered from all soundings show high resistivity with the thickness of about 0.8 m to 1.5 which can be identified as the rocks of volcanic tuff.

B. Measurements using Wenner's configuration

The results of this configuration are depicted in Figure 2.a, Figure 2.b, Figure 2.c, Figure 2.d, and Figure 2.e and give the

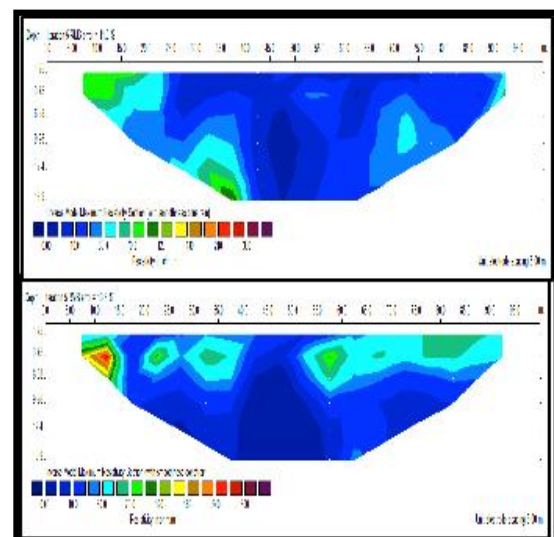


Figure 2.b and 2.c The second line and the third line of Wenner configuration

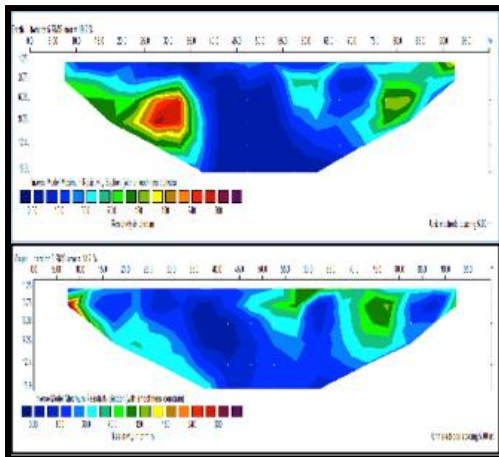


Figure 2d and 2.e The fourth line and the fifth line of Wenner configuration.

C. Seismic Interpretation

The relationship between electrical resistivity with mechanical elasticity which is represented by travel time of wave propagation of subsurface rocks has been completed by using both exploration methods of geo-electric and seismic measurements. Seismic data acquisition is done and

performed in the same location and condition that of the geo-electric measurement. The results give us with six trajectories of exploration which are carried out on each side of the hydrothermal area. The analysis and interpretation of seismic data are conducted using tomography of seismic method by which the results depicted in more detail profiles. Velocity profiles in the four trajectory measurements are described in Figure 3.a-Figure 3.f below

The results have identified three layers of propagating velocity of P-waves. Those are layer (1) having velocity of 200 m/s, layer (2) having velocity of 400 m/s, and layer (3) having velocity of 600 m/s. There six trajectory measurement seismic realized in this study. At all of trajectory there are the shallow depths of hydrothermal zone (green) color. In to six the such easurement identified the fault zone. These faulting are estimated as a source of the emergence of geothermal systems.

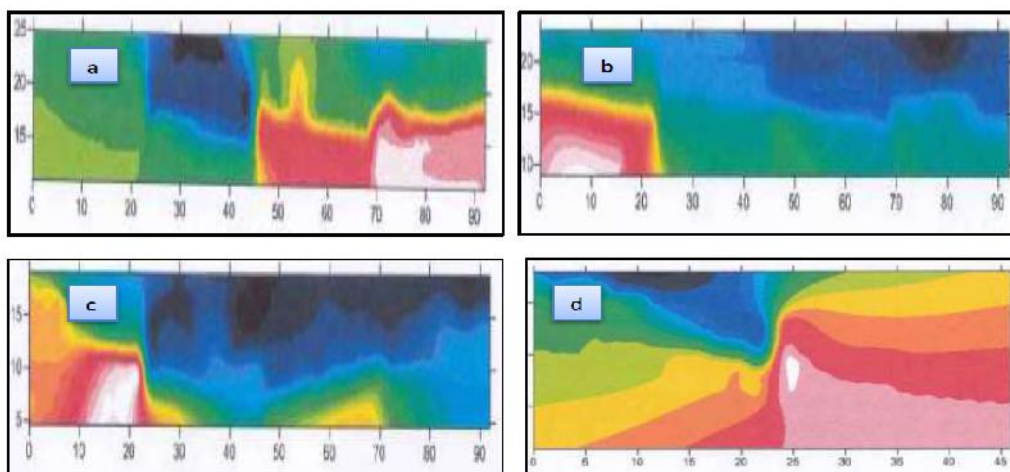


Figure 3a. velocity profile in a,b,c and d trajectories seismic

D. The Relationship of Electrical Resistivity to Mechanical Elasticity

Solving equation (7) using the method of least squares numerically approximated by finite differences as was performed by least square method resulted in four curves that describe the relationship between mechanical elasticity with electrical properties as depicted in Figure 4.a, Figure 4.b, Figure 4.c, Figure 4.d Figure 4.e, Figure 4.f below. The fourth of these relation are:

1. Relation of velocity of wave propagation with conductivity as
2. Relation of velocity of wave propagation with resistivity.
3. Relation of time propagation/unit length with conductivity
4. Relation of time propagation/unit length with resistivity

4. CONCLUSIONS

The analysis and interpretation of the data measurement confirm the mathematical models being developed. The velocity of waves propagation as a function of conductivity or resistivity. Therefore when one of the both physical parameters of the rock is obtained, then the other parameter can be calculated using the model.

5. ACKNOWLEDGEMENTS

Data were collected at the hydrothermal area under the support of Hasanuddin University funding. The analysis was done at the Geophysical Laboratory, Department of Physics, Faculty of Science, Hasanuddin University. We are really indebted to personals and institution being involved in the survey and laboratory works, to whom we express our deep appreciations.

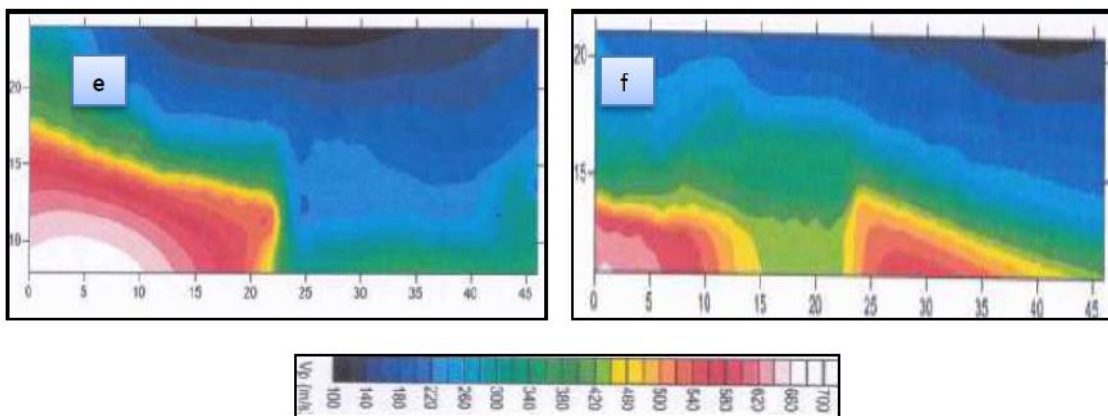


Figure 3b velocity profile in e and d trajectories seismic

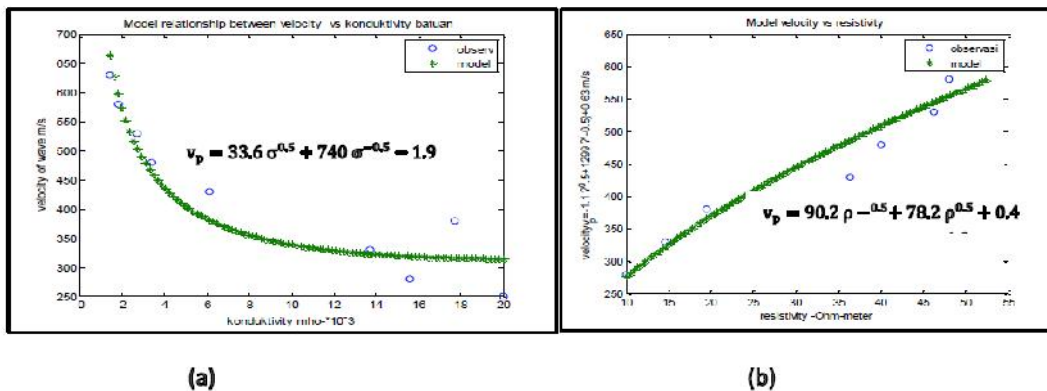


Figure 4 (a) Relation of velocity of wave propagation with conductivity, 4(b) Relation of velocity of wave propagation with resistivity

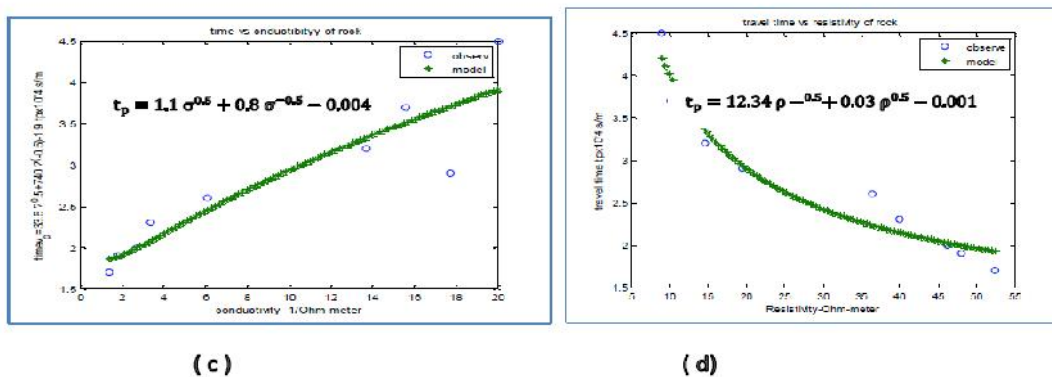


Figure 4 (c) Relation of time propagation/unit length with conductivity, 4 (d) Relation of time propagation/unit length with resistivity

6. REFERENCES

- [1] Meju, M.A., L. A. Gallardo, and Mohamed, A. K., (2003). Evidence Correlation of electrical resistivity and seismic velocity in the heterogeneous medium near surface Material. Geophysical Research Letter, Vol.30, No.7.
- [2] Ayolaby, E.A. and Adeosun, L.O. et al., (2009). Seismic refraction and Resistivity study of part Igbogbo Township, South-West Nigeria. Journal of Applied Science, Res, Dev, Vol. 11,42-61.
- [3] Ursin, B. and Carsione, J.M., (2007). Seismic Velocity Electrical Conductivity Relation. International Workshop Innovation in EM, Gravity and Magnetic Methods, New Prospective for Exploration, Capri Italy, April 15-18.
- [4] Alan, G. J., Evans, R. L., (2009). Velocity-conductivity relationship for mantle assemblages in Archen Cratonic Lithospher based on a review of laboratory data. Elsevier lithos 109, 131-143.
- [5] Hossain, Z., and Cohen, A. J., (2012). Relationship among porosity, permeability, electrical and elastic properties. SEG, Las Vegas.
- [6] Petras, I. and Bednarov, D., (2010). Total Least square Approach Modeling. Acta Montanistica Slovaca Roenik 15, Cislo 2, 158-17.

