Proc. of the 8th International Symposium on Geotechnical Safety and Risk (ISGSR)
Edited by Jinsong Huang, D.V. Griffiths, Shui-Hua Jiang, Anna Giacomini and Richard Kelly
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doi: 10.3850/978-981-18-5182-7_05-004-cd

ISGSR 2022

Uncertainty Estimation of P Wave Velocity and Layer Boundaries Using Seismic Refraction with Synthetic Horizontal Layered Geological Model

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Abstract: This paper conducts a series of studies on the uncertainty problems encountered in the role of personnel in the implementation processing of seismic refraction. In order to increase the reliability result of the seismic refraction method, evaluating the seismic refraction method is fundamental. The main paper's purpose is to evaluate seismic refraction and reduce uncertainty in seismic refraction considering human interpretation results. We analyze the uncertainty of seismic refraction separately in two-part: first arrival picking processing and grouping of data into a unified layer with identical wave velocity based on the time-distance curve (T-D curve). This study utilized forward modeling results of a synthetic geological model in which the boundaries of layers (gently dip straight line) and the P wave velocity (Vp) of each layer was given. The model is made up of five layers, with velocity increasing with depth (Vp = 700 m/s, 1100 m/s, 1500 m/s, 1800 m/s, and 2200 m/s from top to bottom). The uncertainty will consider based on the P wave velocity value and thickness layer. According to the first arrival picking results of seven operators, we discovered high uncertainty (11.2 %) in the first layer. On the grouping layer processing, high uncertainty of P wave velocity (11.8 %) and thickness layer (16.3%) in the first layer. Adding information on thickness data in processing seismic refraction effectively reduces uncertainty to 7.1 %, and P wave velocity data can reduce uncertainty to 1.7 %. Thickness data and velocity data effectively reduce uncertainty in grouping layer processing. However, uncertainty from first arrival picking still exists.

Keywords: Seismic refraction; time-distance curve; Synthetic case; Forward modeling.

1 Introduction

Seismic refraction is an active geophysical method that uses P wave velocity as the physical parameter, this method is widely used in geotechnical engineering investigation Stewart et al. (1997). The reliability of the seismic refraction method results has become an important issue related to site investigation in geotechnical engineering. The reliability calculation provides a way to evaluate the combined impacts of uncertainty Ducan (2000). Decreasing the uncertainty will affect increasing reliability and low risk. An effective way to reduce uncertainty is to evaluate the seismic refraction method. Interpretation of geological models is a 2D/3D geological profile with vertical as depth and horizontal as distance Artimo et al. (2003). The methods for constructing geological models can be divided into two ways: geo model-driven and data-driven. However, both ways contain uncertainties. This paper will focus on the uncertainty of the data-driven approach, especially on the seismic refraction method. The seismic refraction method uses P wave velocity (Vp) to identify the lithology of the layer. P wave velocity is the first wave recorded in the receiver due to the greater velocity energy of the elastic seismic wave Aziman et al. (2016). Three factors, such as acquisition, data processing, and interpretation in the field, are the main factors that lead to the uncertainty of the seismic refraction method. Each source will influence the other step by step. Processing data is an important part of the seismic refraction method due to the reliability of the result. A two-step can define processing data of seismic refraction, and there are first arrival picking and grouping layer. The first step is first arrival picking. This step is essential in the seismic refraction method because the way considers the first arrival time of each person will influence the result. Manual picking has some issues related to visual interpretation, visual estimation, and experience from the people Senkaya and Karsil (2011). The second step is the grouping layer. The data from the first arrival picking will process in the grouping layer step. The grouping layer is highly related to reliability velocity and boundary value.

2 Method

This paper does forward modeling using finite different calculation (TESSERAL software) on the basis of wave propagation in seismic principal from synthetic geological profile (see Figure 1) and processing with the seismic refraction method. The seismic refraction method uses the principle of Snell's law, with increasing P wave velocity value with depth. On the basis of Huygens' Principle, each point of the propagation wave will make the new source wave during the wave propagation in the boundary. Thus, the wave will go back to the surface and be recorded by geophones. This synthetic geological profile had 45 geophones with 2 shot points (see Figure 1).

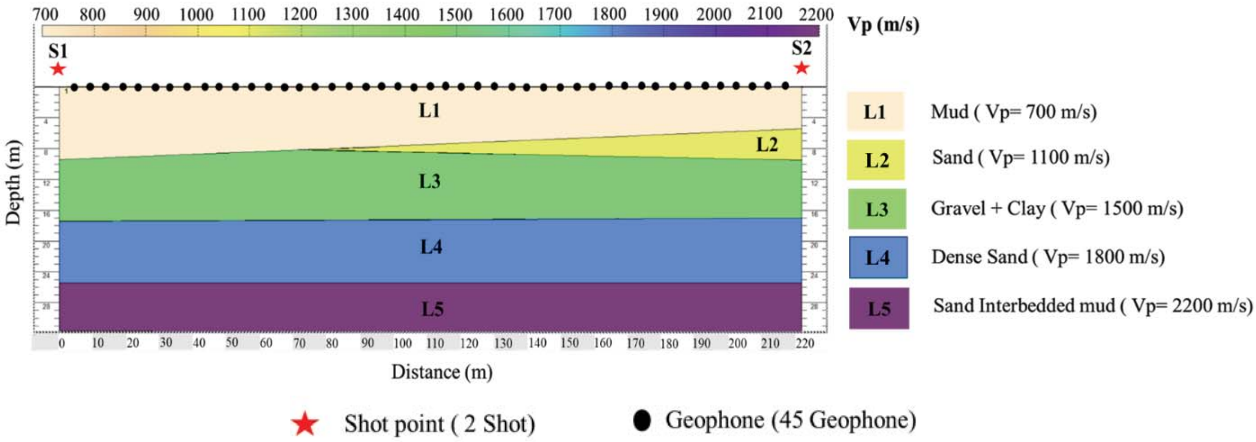

Figure 1. Synthetic Geological profile

Figure 2 shows the processing seismic refraction method. The processing of the seismic refraction method can be separated into two steps. There is first arrival picking and grouping layer. We use seven graduate students from the rock and soil mechanics laboratory as operators in the first arrival picking processing. The result from first arrival picking is the first arrival time, the first arrival time will plot in the time-distance curve. The time-distance curve will be involved in the analysis uncertainty of first arrival picking processing and grouping layer processing.

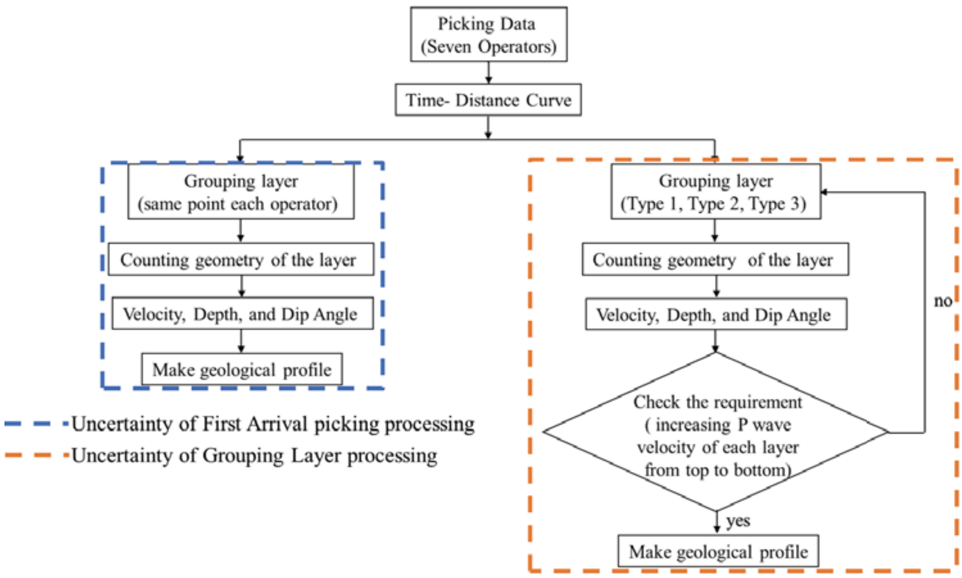

Figure 2. Research Flow chart

The processing to evaluate the seismic refraction method will separate into two parts (see Figure 2). The blue dotted line indicates the analysis of the uncertainty in first arrival picking processing and the orange dotted line indicates the analysis of uncertainty in grouping layer processing. The way grouping layer for first arrival picking processing and grouping layer processing was difference. In the analysis of uncertainty first arrival picking from seven operators, we grouped the same point in the time-distance curve from seven operators. The analysis of quantitative uncertainty in the first arrival picking from seven operators is interesting because the processing of first arrival picking is related to individual interpretations. However, in the analysis of the uncertainty of grouping layer processing, we grouped layers based on three types. The three types indicated the different grouping points in time-distance curves to consider the changing of the slope. The inverse slope represents velocity value and amount of layer (according to the gradient slope) Igboekwe and Ohaegbuchu (2011). This method requires increasing the value of velocity (Snell's law). Figure 3 is grouping layer processing. There are three types, the number of points considers the type classification divided by the probability grouping layer, with a= layer 1, b= layer 2, c= layer 3, and d= layer 4 (the numbering layer from top to bottom). Type 1 shows probability grouping layer with layer1, layer 2, and layer 3 having the same number of points. However, Type 2 represents the probability of layer 2 having more points than layer 1 and layer 3. The last types in Type 3, in these types, indicated that probability layer 3 has several points more than layer 1 and layer 2. In all types, the amount of points in layer 4 is more than in layer 1, layer 2, and layer 3. The processing of Type 1, Type 2, and Type 3 will be looped until getting the relevant result as the theory of seismic refraction method (increasing the value of velocity with depth).

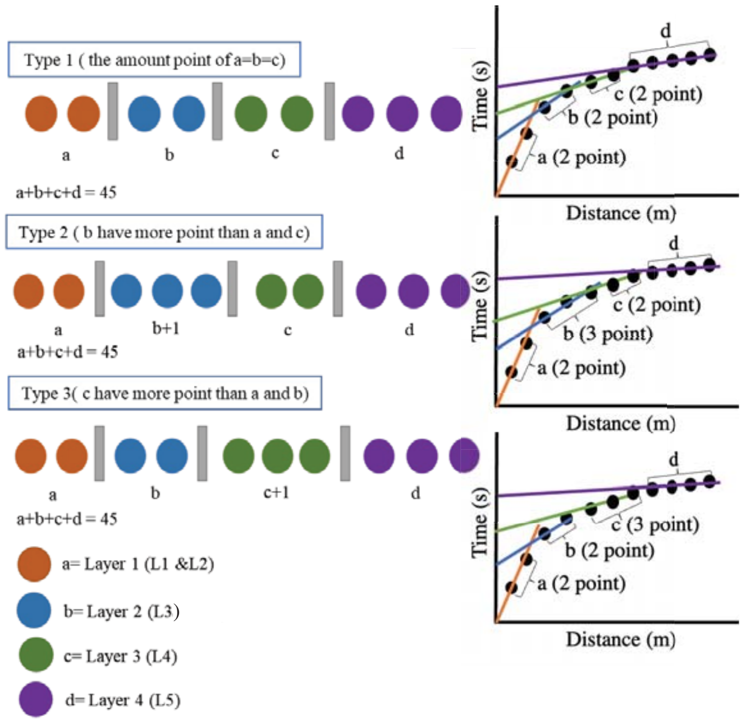

Figure 3. Grouping Layer Flow Chart

3 Result and Discussion

3.1 Quantitative Analysis of First Arrival Picking from Seven Operators

Analysis of uncertainty from first arrival picking will separately focus on P wave velocity and thickness layer.

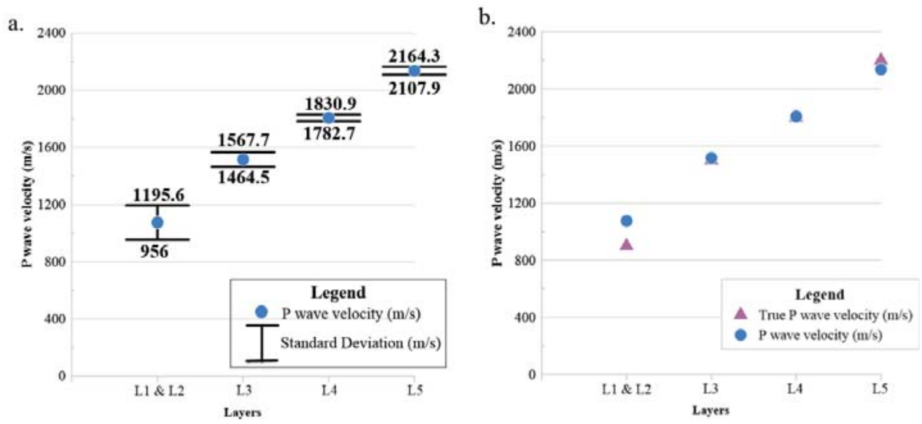

Figure 4. P wave velocity analysis from seven operators (a= Quantitative analysis, b= Comparison mean value with true velocity value from synthetic geological profiling)

Figure 4 shows a quantitative analysis of P wave velocity from seven operators. The value of uncertainty in this paper is indicated by the standard deviation. The more significant standard deviations indicated the larger variation effect of P wave velocity value from first arrival picking by 7 operators. This paper assumes Layer 1 combined with Layer 2 because of the limitation of detecting a thin layer in the seismic refraction method. On the basis of calculation mean and standard deviation on first arrival picking from seven operators, found that the first layer (L1 &L2) had a high standard deviation (119.8 m/s). The high standard deviation represents the variation of the first arrival picking on the geophone near with shot point. The variation was due to the direction of waves influencing the result in the seismic trace, and each operator difficult to consider the first arrival time. The comparison of true P wave velocity values from synthetic geological profiles shows that the first layer (L1 & L2) has a low accuracy value compared with L3, L3, L4, and L5. Different viewpoints to pick first arrival time will influence with increasing uncertainty on P wave velocity value and low accuracy of P wave velocity.

Figure 5 shows the quantitative analysis of thickness layer from 7 operators. The influence of the first arrival picking on L1 & L2 (0.3 m) is small compared with L3 (0.8 m) and L4 (1.3 m). The comparison of mean in thickness layer with the true thickness layer from synthetic geological model shows the first arrival picking from 7 operators has high accuracy. The accuracy value of P wave velocity and thickness layer is essential to get a high-reliability value in seismic refraction results. On the basis of Figure 4b and Figure 5b different viewpoints to pick the first arrival time from 7 operators will influence the accuracy of P wave velocity, especially on the first layer (L1 & L2).

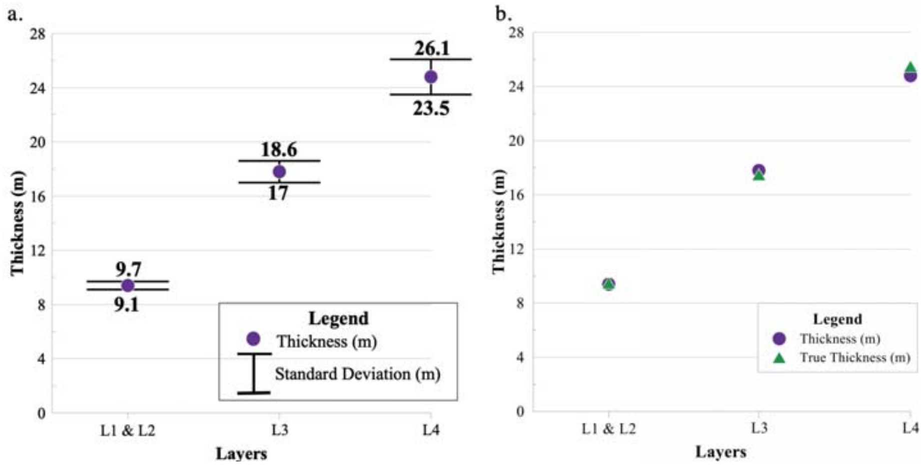

Figure 5. Thickness layer analysis from seven operators (a= Quantitative analysis, b= Comparison mean value with true thickness layer value from synthetic geological profiling)

3.2 Quantitative Analysis of Grouping Layer Processing

Grouping layer processing is continuity from first arrival picking processing. After seven operators do first arrival picking, plotting the time-distance curve to choose the change slope. This process needs to find the slope change (gradient) in the time distance curve to consider the velocity and thickness value. Usually, researchers use subjectivity to consider the changing gradient slope in the time-distance curve. The high-velocity contrast makes the slope change significantly, so it is easy to distinguish the amount of layer from the time-distance curve. Nevertheless, in this case, the contrast velocity is not large enough. So, we need to predict the change of the slope. The grouping layer processing probably contains uncertainty.

Figure 6 shows the quantitative analysis of P wave velocity and comparison of mean results from seven operators with the true P wave velocity value on the synthetic geological model. The quantitative analysis shows high uncertainty on the first layer (L1&L2) with a value is 135.1 m/s. On another hand, the accuracy value of P wave velocity on the first layer (L1&L2) is low. The true P wave velocity value represents the P wave velocity from the synthetic geological model. Based on the result, the grouping layer processing has a high influence on the uncertainty of P wave velocity and the accuracy of the P wave velocity value in the first layer (L1 & L2). The high uncertainty and low accuracy value on the first layer are due to the slope point. The choosing point in the slope will influence the high changing of P wave velocity value and low accuracy P wave velocity in the first layer.

Figure 7 shows a quantitative analysis of thickness layer from 7 operators based on grouping layer processing. High uncertainty founded in all-layer. The high uncertainty influences the low accuracy value of the thickness layer. On the basis of analysis P wave velocity and thickness layer, the choosing point to consider changing of slope in the grouping layer processing influence with high uncertainty and low accuracy of thickness layer value. Consideration of uncertainty was based on the standard deviation value by 7 operators. The accuracy value represents the mean from 7 operators compared with the thickness data of the synthetic geological model.

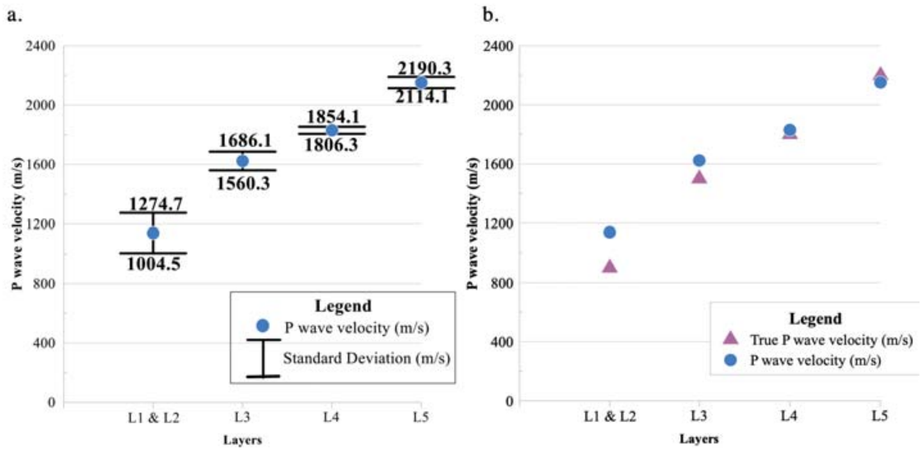

Figure 6. P wave velocity analysis from seven operators on the grouping layer processing (a= Quantitative analysis, b= Comparison mean value with true velocity value from synthetic geological profiling)

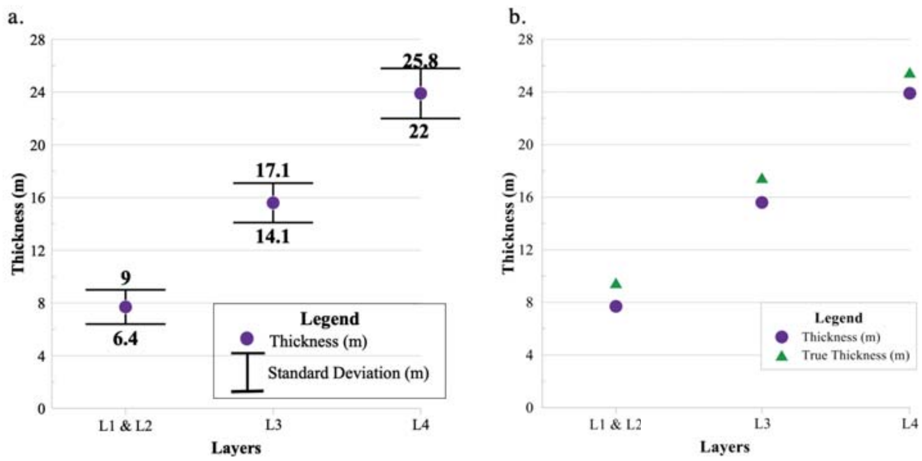

Figure 7. Thickness layer analysis from seven operators on the grouping layer processing (a= Quantitative analysis, b= Comparison mean value with true thickness layer value from synthetic geological profiling)

3.3 Reducing uncertainty in grouping layer processing with P wave velocity data and thickness layer data

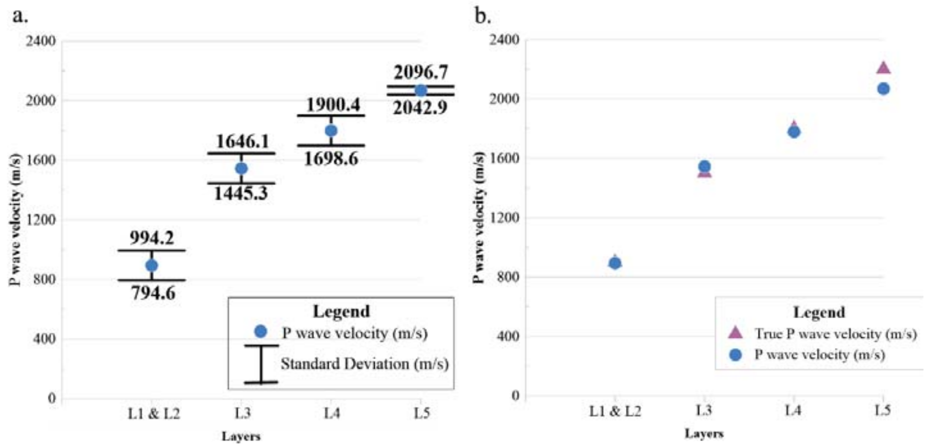

Figure 8. Quantitative analysis of P wave velocity with the influence of P wave velocity data from boreholes data (a= Quantitative analysis, b= Comparison mean value with true P wave value from boreholes data)

Reducing uncertainty in the seismic refraction method will reduce the risk. After evaluating this method, this paper tries to reduce uncertainty on grouping layer processing with P wave velocity data and thickness layer data. The synthetic geological model in this paper had two shots point in the near with the first geophone and the last geophone. In this section, we assume the boreholes are located in the same shot points location.

Figure 8 and Figure 9 are the quantitative analysis of P wave velocity and thickness layer from 7 operators influenced by P wave velocity data and boreholes data. Comparing the results in Figure 6 and Figure 8, it can be seen that the accuracy of the P-wave data processed by the grouping layer is improved by 26 %, and its uncertainty is reduced to 1.7%. On another hand, the analysis of thickness layer data (see Figure 7 and Figure 9) can reduce uncertainty to 7.1 % and increase the accuracy (5.9 %) of thickness layer results from grouping layer processing. On the basis of the result, the P wave velocity data and thickness layer data can reduce uncertainty on grouping layer processing due to an increase in the uncertainty value of P wave velocity and thickness layer from 7 operators' comparison with Figure 6 and Figure 7. Moreover, adding P wave velocity data dan thickness layer data improve the accuracy value.

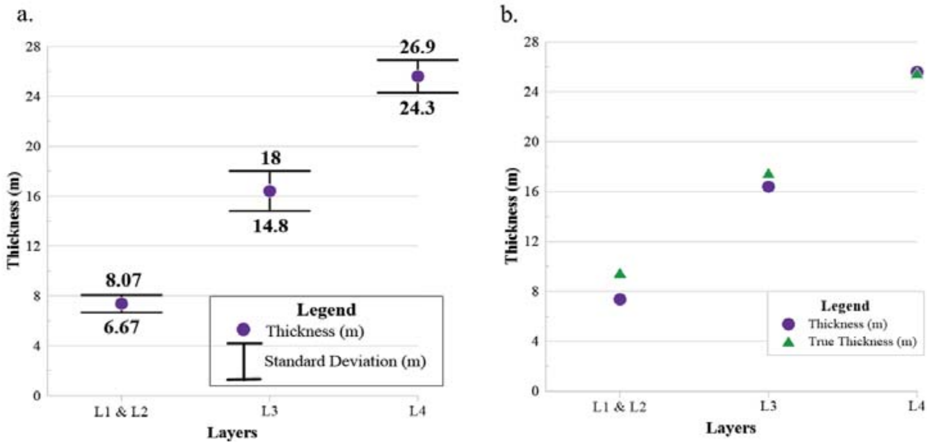

Figure 9. Quantitative analysis of thickness layer with the influence of thickness layer data from boreholes data (a= Quantitative analysis, b= Comparison mean value with true P wave value from boreholes data)

4 Conclusion

This paper found considerable uncertainty and low accuracy value of P wave velocity on the first layer in first arrival picking processing (11.2 %). On another hand, the grouping layer found consideration uncertainty and low accuracy value on P wave velocity (11.8 %) and thickness layer (16.3 %). P wave velocity data can reduce uncertainty on grouping layer processing to 1.7 % and thickness layer data can reduce uncertainty to 7.1 %. However, the uncertainty of first arrival picking still exists.

Acknowledgments

This research was funded by the Minister of Science and Technology (MOST) of Taiwan under the project number MOST 108-2638-E-008-001-MY2.

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