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Near-surface solutions in seismic data processing

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Summary

Near-surface variations associated with a rugged terrain and lateral velocity anomalies create not only a statics problem in seismic data processing, but a subsurface imaging problem with the uncertainty of the near-surface structures. In this paper, we use synthetic models to demonstrate the pros and cons of various near-surface methods.

***Keywords**: Waveform Tomography, Traveltime Tomography, GLI, Delay-Time, Statics*

Introduction

Near-surface variations cause a statics problem in seismic data processing. Elevation statics correction is a traditional way to remove the topography effect, but it is not a solution to correct for the near-surface anomalies. The delay-time method (Hagedoorn, 1959) was widely used in refraction interpretation and the statics calculation. We demonstrate in this paper using the synthetic model that the delay-time method is not a solution for complex near-surface structures because of its assumption of the flat layers. The GLI method (Hampson and Russell, 1984) can create a good near-surface model if the near-surface structures are layer-based, but it fails when there is a velocity gradient in depth. Traveltime tomography (Zhang and Toksoz, 1998) is better than GLI in this situation. However, because the refraction-based traveltime tomography requires the first-arrival picks, it cannot handle the low velocity anomalies below a high velocity layer. The waveform tomography (Tarantola, 1984) is the best in our model studies, but we point out under what circumstances it may fail in processing real data.

Delay-Time

We design a simple model as shown in Figure 1.

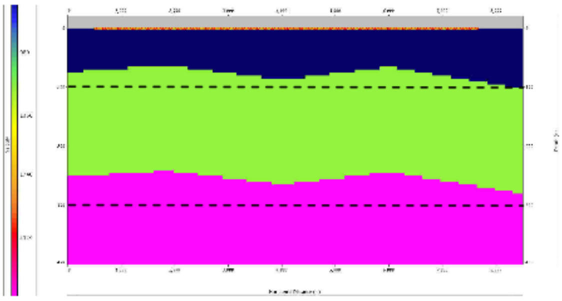

Figure 1: Simple velocity model. Shots are marked in red on the top of the model.

Synthetic first-arrival travel times are generated using ray tracing for the model. The delay-time result is shown in Figure 2.

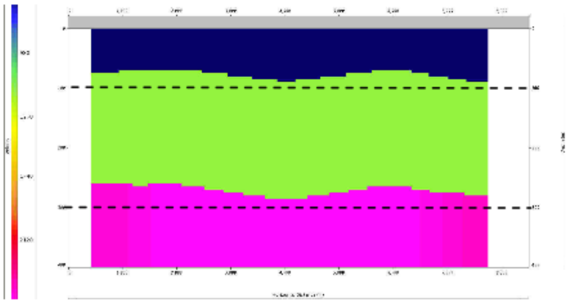

Figure 2: Delay-time result. Dashed lines denote the depth at 100 m and 300 m.

As the first layer is nearly flat, the delay-time accurately estimates the thickness of the first layer and the velocity of the second layer. Because the first layer is not completely

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flat, the estimated thickness for the second layer suffers from the flat layer assumption of the delay-time method. Comparing with the true model in Figure 1, we can see the deepest point of the second layer is more closer to the dashed line at 300 m than that in the true model.

GLI

We apply the GLI method for the same input as above. Figure 3 shows the GLI result.

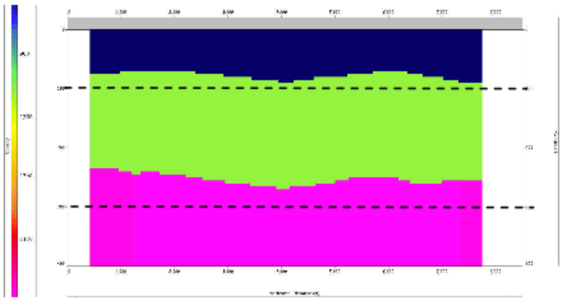

Figure 3: GLI result. The thickness of the second layer is more accurately imaged than that in the delay- time.

The GLI method is based on a layer-based ray tracing. Except for the boundary area where the layers are less illuminated, GLI produces a more accurate estimation for this simple model than that using the delay-time method.

In our second model study, we create a complex model by adding a velocity gradient to the second layer (Figure 4).

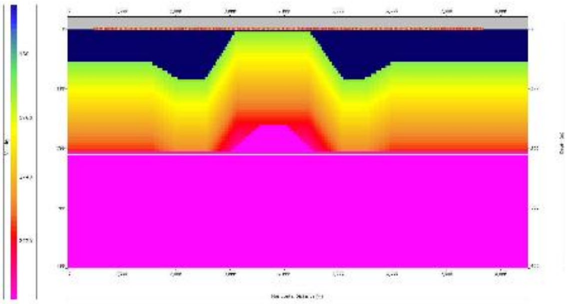

Figure 4: Complex velocity model with the velocity gradient in the second layer.

We generate the synthetic traveltimes using an eikonal equation solver and then apply GLI. The estimated model is shown in Figure 5. Since the GLI method is a layer based inversion, it cannot handle the velocity gradient in the second layer so the top of the bottom layer is totally wrong comparing with the true model.

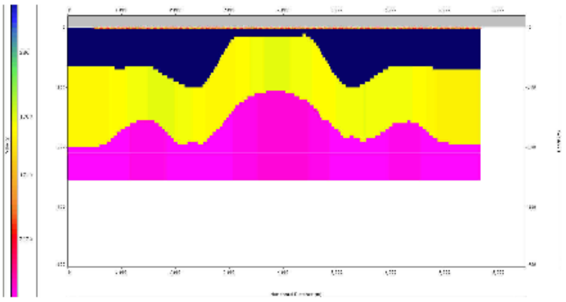

Figure 5: GLI solution of the complex model.

Traveltime Tomography

Traveltime tomography determines the near-surface velocities by examining the discrepancy between observed first-arrival traveltimes and modeled traveltimes associated with an initial velocity-depth model. It perturbs the initial model parameters until the difference between the modeled and the picked traveltimes is minimized in the least-squares sense. We use the nonlinear traveltime tomography (Zhang and Toksoz, 1998) that accounts for the changes in the traveltime gradient to avoid the ill-posed inverse problem in solving the least-square equations. Iterate until the discrepancy between the modeled and the picked traveltimes, measured as the RMS errors in the inversion, has been reduced to a sufficiently small value comparable to the picking errors. The output is the final velocity-depth model for the near-surface, calculated model traveltimes, and the ray density associated with the final model.

Applying the nonlinear traveltime tomography for the complex model, we obtain a new result shown in Figure 6.

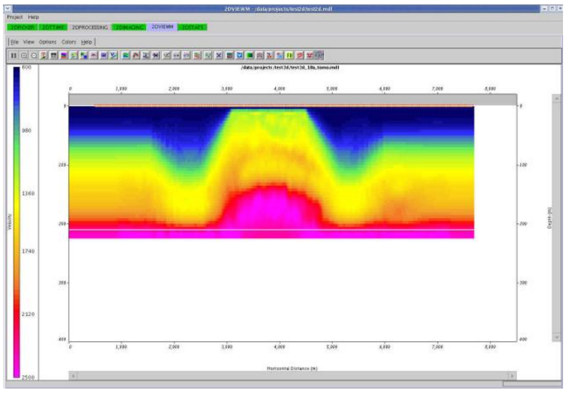

Figure 6: Traveltime tomography solution of the complex model.

Generally speaking, the traveltime tomography can be applied for the complex structures with the rough topography variations. However, the first-arrival traveltime tomography may fail to image a low velocity layer below a high velocity top where there may not be any rays refracted back from the low velocity hidden layer with the minimum traveltime. Figure 7 shows a model with a hidden layer. Figure 8 is its traveltime tomography result.

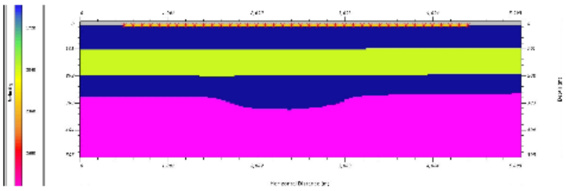

Figure 7: Model with a hidden layer.

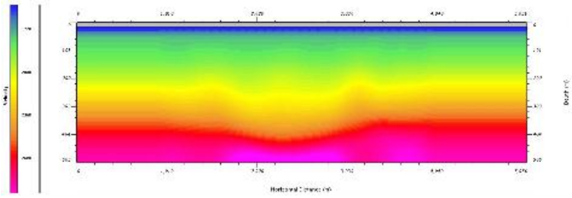

Figure 8: Traveltime solution of the model with the hidden layer.

Waveform Tomography

Waveform tomography (Tarantola, 1984; Pratt, 1999) provides a more accurate solution than the traveltime tomography as it measures the discrepancy between observed and modeled seismic waveforms that have both amplitude and phase variations comparing with only single arrival traveltimes in the traveltime tomography. Figure 9 and Figure 10 show respectively the waveform tomography result for the complex model (Figure 4) and the hidden layer model (Figure 7). They are clearly the best among all the methods.

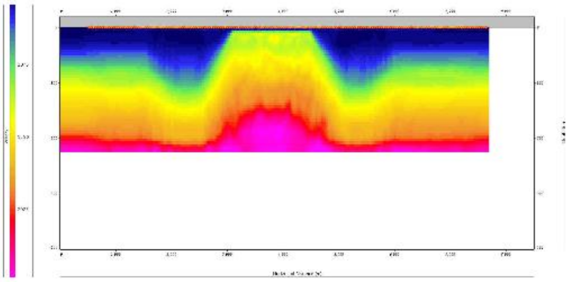

Figure 9: Waveform tomography result of the complex model (Figure 4).

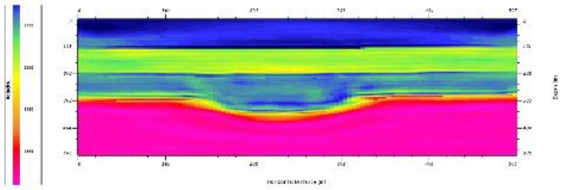

Figure 10: Waveform tomography result of the hidden layer model (Figure 7).

However, to reduce the cost of waveform tomography, we normally solve its nonlinear problem with an iterative conjugate-gradient method, in which the minimization of the least-square misfits may suffer from the local minima. Using the complex model as an example, we purposely shift all the shot records up by 80 ms to simulate a real problem like the vibroseis data. Figure 11 shows a single shot record.

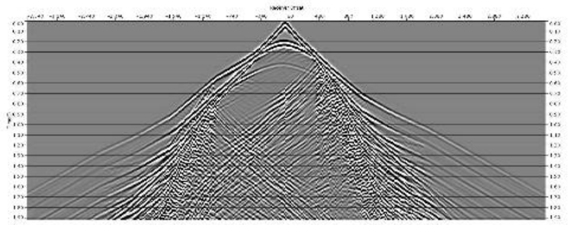

Figure 11: Shot record of the complex model, shifted up in time by 80 ms.

If we apply the waveform tomography without any phase matching, Figure 12 is the new result

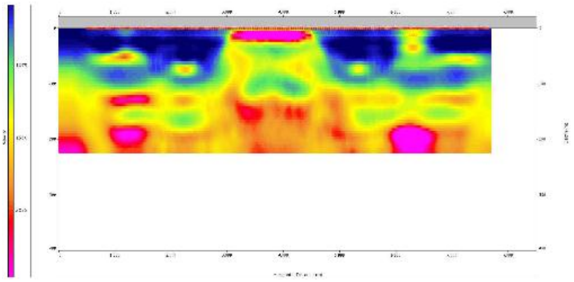

Figure 12: Waveform tomography result of the complex model (Figure 4) with the input that has a time shift.

Conclusions

We compare delay-time, GLI, traveltime tomography, and waveform tomography with synthetic models. The delay-time method is not a solution for the complex near-surface model. GLI can produce a good layer model if there is no velocity gradient in the layers. Traveltime tomography can handle the complex near-surface variations but it fails to image the hidden layer. Waveform tomography is the best in the model studies, but careful processing and QC are required for real data.

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