First-Arrival Traveltime Inversion in the CMP Domain: Method and Application

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Summary

A new approach of first-arrival traveltime inversion was developed to estimate a near-surface velocity model for statics corrections in areas with complex geology. A 2D seismic dataset in a foothills area with severe topography was investigated to test this new method in the common midpoint (CMP) domain and a robust near-surface velocity model was obtained. The statics values calculated from this model have improved the quality of the stacked section.

Introduction

A crucial step in seismic processing is to solve for the near-surface effects. There are two major classes for the computation of statics values using velocity inversion from first-arrival traveltimes. The first approach is a tomographic method (e.g. Hampson and Russell, 1984; Stefani, 1995, and Zhu et al., 2000) which derives the near-surface velocity model based on traveltime reconstruction. The other approach is to map apparent velocities to depth by converting horizontal apparent velocities or slowness to depth (e.g. Rhül et al., 1990; Osypov, 1999; Lau et al.,1999). Traveltime reconstruction is not necessary for this case. A fast and comparable approach based on the second class was investigated using the first-arrival traveltimes in CMP domain from the 2D seismic data.

Method

First-Arrival Traveltime Description

The first-arrival can be considered as a refracted wave arrival or turning wave arrival. Here, the assumption of turning wave was used to transform time-offset first-arrival into velocity-depth model. Figure 1 shows the relationship between them. In the case of a linear increase in velocity with depth, the turning ray turns at the point of maximum depth, and the slope of the traveltime curve measures the apparent velocity experienced at the turning point. The intercept on the time axis is known as 'tau' which is associated with depth of turning point. If the turning wave propagates in a simple *V(z)* medium, then the turning point lies halfway between the source and receiver.

CMP Geometry of the First-Arrival

Diebold et al. (1981) extended the concept of CMP from reflected waves to turning waves. In the case of CMP geometry, where sources and receivers progress in equal steps in opposite directions, the natural choice of reference for them is the midpoint. The first-arrival traveltime can be described as:

$$t_{cmp} = x(P_s + P_r)/2 + (tau_s + tau_r)/2 \quad \text{or} \quad t_{cmp} = x(1/v_{as} + 1/v_{ar})/2 + (tau_s + tau_r)/2$$

Where, s and r denote the location of sources and receivers respectively, and the other parameters have been described in Figure 1. In this case, the observed traveltime slope and intercept time are the average of the slowness and intercept time of the upward source and upward receiver rays at the surface. This midpoint of the first-arrival is considered to be the position corresponding to turning point.

Conversion to Depth

The tau-velocity-midpoint data and offset-velocity-midpoint data obtained from the time-offset traveltimes are then converted to depth. There are four algorithms discussed in the literature for this process, namely: Tau-sum inversion (Diebold et al., 1981), maximum depth methods (Rhül et al., 1990, and Giese,1976), and the Herglotz-Wiechert (H-W) equation (Osypov,1999). These were tested and evaluated using 1D synthetic data and the H-W inversion was found to be the most suitable algorithm that generates the best velocity-depth function.

Field Data Example

Data Description

The method described above was applied to a 2D seismic line from the thrust-belt region of the Rocky Mountains. This line is about 20 km in length and was shot with a split-spread array using dynamite as source. The topographic range is about 1400 meters. The receiver interval is 10 meters, the nominal fold is 60 and offset ranged from 40 to 4030 meters. Figure 2 illustrates the picked first-arrivals in the shot domain incorporated with the elevation profile along this line.

Inversion Scenarios

The practical inversion started with first-arrival picking on shot gathers. First-arrival traveltime picks was then sorted into the CMP domain. Preprocessing including piecewise smoothing and interpolation applied to the CMP traveltimes to reduce the effect of picking errors and to regularize the offset-traveltime distribution. The long offsets (> 3000 m) were omitted in order to mitigate the severe topographic effects which can cause unstable velocity estimations. Then the apparent velocity corresponding to each offset was calculated by a second degree polynomial (Giese, 1976). The offset-velocity pairs were input into the H-W inversion to derive the thickness of each layer. The weathering layer velocity (v_0), derived from uphole times, was used for the first layer thickness estimation because of absence of very near offsets associated with the shallowest weathering layer. The velocity-depth pairs of each CMP were smoothed using a 2D smoothing filter and interpolated with a constant depth interval.

Near-Surface Velocity Model and Statics Correction

Figure 3a shows the near-surface velocity model computed using the method discussed above and Figure 3b is the near-surface velocity model generated by GLI3D tomographic inversion using the same first-arrival data. Based on the two models, independent statics values were calculated and applied on the seismic data and the resulting stacked sections are displayed in Figure 4. Figure 4a is a brute stack (with only elevation statics correction applied); Figure 4b is the stacked section after application of the tomographic statics correction using model in Figure 3b and Figure 4c shows the result after statics correction applied using the direct first-arrival traveltime inversion on the CMP data. Both Figure 4b and 4c show the improvement in the coherency and continuity of reflection events compared to Figure 4a. Slight differences can be observed on some parts of stacked sections between Figure 4b and 4c. These differences are caused by the statics values computed based on the different near-surface velocity models that were generated by the two different algorithms.

Conclusion

The first-arrival traveltime inversion in the CMP domain based on H-W equation is a robust and fast method for producing a near-surface velocity model for the purpose of determining statics corrections. The velocity model itself also can be used as the initial point for depth imaging, forward modeling and other inversion for further analysis.

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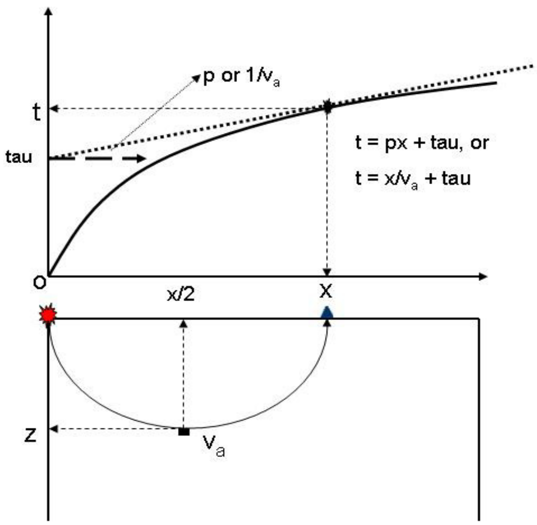

Figure 1: Schematic model showing the relationship between turning rays on the time-offset plot in a V(z) medium. t is the turning wave traveltime, the slope of the curve is p (slowness) or Va (apparent velocity in horizontal direction), x is offset between source and receiver and tau is the intercept time.

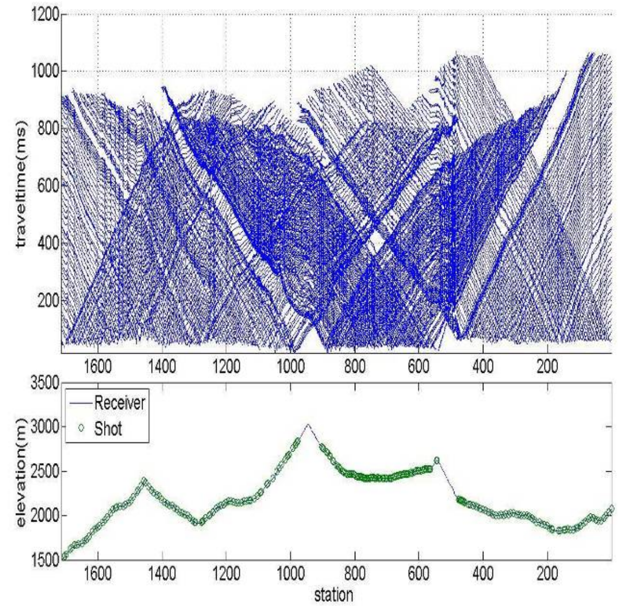

Figure 2: First-arrival traveltime picks in the shot domain. The upper part is the first-arrival traveltime curve for each shot and the lower part is the topography along the seismic line.

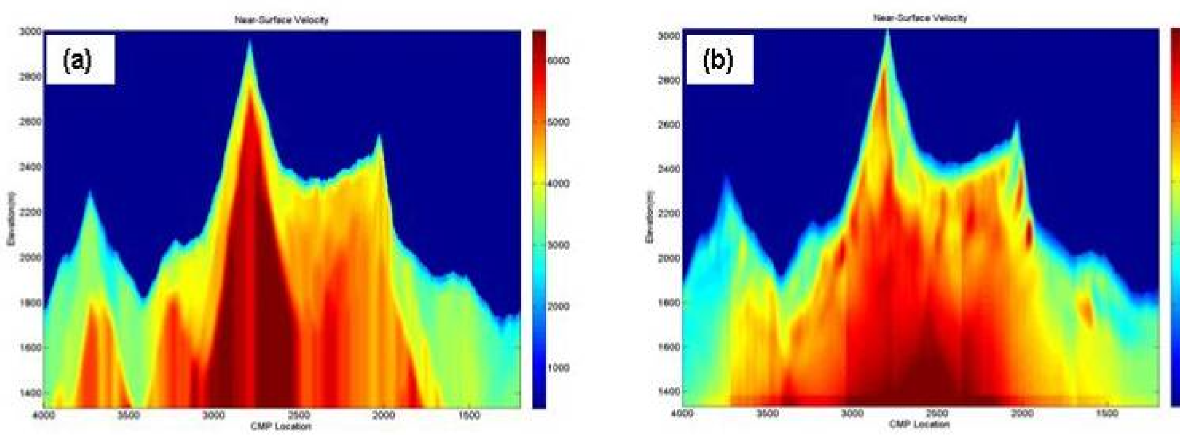

Figure 3: Near-surface velocity model: (a) Near-surface velocity model derived by first-arrival inversion in the CMP domain (b) Near-surface velocity model created by tomographic inversion based on raytracing.

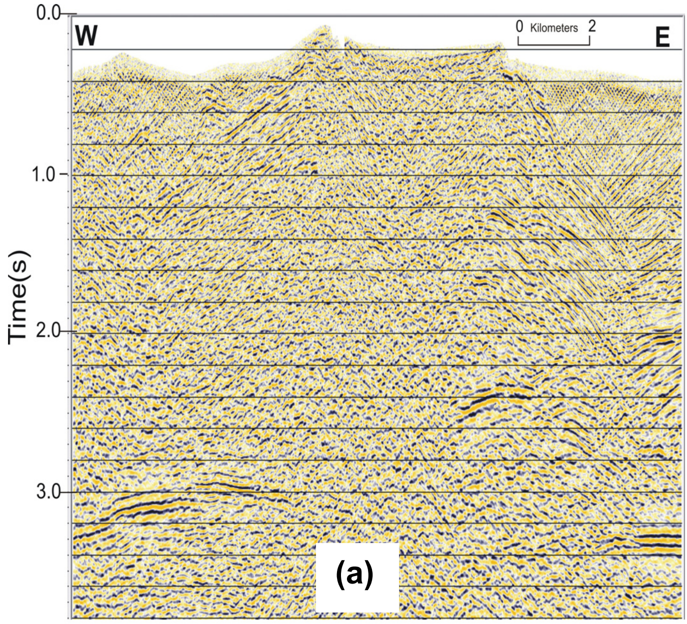

Figure 4: Stacked sections from the 2D data: (a) brute stack after only elevation statics; (b) stacked section after elevation statics and tomographic statics; (c) stacked section after elevation statics and weathering statics using the approach presented in this paper.