Research and Application of Up-hole Constrained Tomographic Static Correction Technology

Introduction

The study area is located in Western China, where the surface structure is very complex, the terrain fluctuates violently, with steep mountains and deep gullies everywhere, the elevation drop reaches 800m, as shown in figure 1. There are high-velocity rock formation exposed and thick loess covered in the near-surface, the thickness of loess in the mountain area reaches 300m. The velocity and thickness of the low-velocity-zone change sharply, the refractive layer is unstable, and the fluctuation of the terrain causes different delay time between different receivers on the surface, which leads to serious static correction problems. Figure 2(a) shows a typical shot gather in the study area, the first break wave is very discontinuous, and the reflected wave cannot be identified. Static correction is the key and foundation of seismic data processing in complicated areas. The commonly used static correction method mainly includes elevation static correction, refraction static correction and tomographic static correction (Marsden D., 1993). Elevation static correction is a field measurement results, which has a strong dependence on the elevation accuracy of the shot and receiver; Refraction static correction requires a clear refraction layer; Tomographic static correction does not need to distinguish the type of first-arrival waves, direct wave, refracted wave and reflected wave can all be used as first-arrival information. The inversion model does not need the layered medium assumption and is not limited by the vertical and horizontal variation of surface, which is more in line with the actual structure of low-velocity-zone. Tomographic static correction has become the mainstream technology to solve the static correction problems(Zhu et al., 1992, Zhou et al., 2019).

Figure 1 Elevation map of the study survey

Figure 2 Comparison of typical shot records before and after the application of static correction. (a)Before using the static correction; (b)After using the up-hole constraint static correction.
The tomographic inversion depends on the first break information of different offsets and its accuracy. When the low-velocity-zone is thin, the near offsets first break information can reflect the velocity change of the near-surface; While when the low-velocity-zone is thick, more first break information of mid-to-far offsets is needed to participate in the inversion and calculation to break through the thickness of the low-velocity-zone. As a result, there will be more high-velocity rays pass through the shallow grid during the inversion process, resulting in higher velocity in the shallow model. Therefore, uphole constraint tomographic static method is proposed. This method makes full use of first break information of mid-to-far offsets, and applies uphole velocity information to constrain the near-surface model. The method ensures the accuracy of the shallow velocity model, and meets the thickness requirement of the low-velocity-zone.

Theory

Tomographic static correction is a method to calculate the near-surface velocity based on tomographic inversion. It includes a forward process and a inversion process, the forward process is to calculate the travel time of each source-receiver pair, and the inversion process is to update the velocity model according to the remaining time of the first break. The tomographic static correction uses the travel time of the first break wave to obtain the near-surface velocity through ray tracing, and then calculate the error between the forward first break time and actual first break time, the velocity model is modified through iterations until it reaches the set threshold. The travel time equation of ray path for tomographic inversion of near surface velocity is:

\[ T = \int \frac{dl}{V(x, z)} = \int S(x, z)dl \]  

(1)

Where \( V(x, z) \) is the near-surface velocity model, \( S(x, z) \) is the slowness mode, \( l \) is the ray path of first break wave, and \( T \) is the travel time along the ray path.

If a slight disturbance \( \Delta S(x, z) \) is given to the slowness model \( S(x, z) \), the corresponding travel time changes:

\[ \Delta T = \int \Delta S(x, z)dl \]  

(2)

Tomographic inversion uses equation (2) to invert the first break travel time of seismic records and construct near-surface slowness model, the discrete expression of equation (2) is:

\[ \Delta T = A \Delta S \]  

(3)

Where \( \Delta T \) is the difference between the actual first break travel time and theoretical first break travel time, matrix \( A \) is the ray path, and \( \Delta S \) is the changes of slowness model. The updated slowness model \( S + \Delta S \) can be obtained by solving the equation.

Up-hole constrained tomographic inversion uses up-hole velocity information to obtain the initial surface velocity(slowness)model, which is used to constrain the changes of slowness in the iterative process of tomographic inversion:

\[ S_{t+1} = S_t + (1 - \omega) \Delta S \]  

(4)

Where \( \omega \) is the constraint weight coefficient, the value range is between 0 and 1. The constrained power becomes stronger as \( \omega \) increases. When the value is 0, the shallow velocity is not constrained, and when the value is 1, the shallow velocity is completely constrained.

The constrain weight coefficient is calculated by adaptive algorithm in the process of constrained tomographic inversion. The near offset first break and up-hole velocity information are mainly used for the shallow velocity model, and the value of the constrain weight coefficient is large, its value becomes smaller with the increasing of inversion depth. When approaching the top of the high-velocity layer, the constrain weight coefficient becomes smaller and smaller, and more mid-to-far offset information participates in the inversion. The method not only makes up for the defects of nonuniform distribution and insufficient detection depth of the up-hole, but also ensures the accuracy of the middle velocity model, so as to obtain high precision statics and further improve the quality of stack sections.
Example
Tomographic static can construct near surface velocity model under complex surface conditions, the model reflects the changes of the velocity and thickness of the low-velocity zone. Figure 3 shows the near-surface velocity model before and after the uphole constrained inversion, and 12 uphole velocity are embedded into these two models. It can be seen that after the uphole constraint, the velocity of shallow surface layer tends to be slower, which is more consistent with the uphole velocity, and the high velocity information in the middle and deep layers is more prominent, and the layer boundary is more obvious. The velocities of inversion model at position A,B,C in figure 3 are extracted respectively and displayed superimposed with the uphole velocity at the same positions, as shown in figure 4. It can be seen that the surface velocity obtains by constrained tomography matches better with the uphole velocity than that without constrained tomography.

![Figure 3 Comparison of near-surface velocity models before and after uphole constrained tomographic inversion.](image)

Figure 3 Comparison of near-surface velocity models before and after uphole constrained tomographic inversion. (a)Velocity model before uphole constrained inversion; (b)Velocity model after uphole constrained inversion. 12 uphole velocity are embedded into the two models.

![Figure 4 Superposition picture of uphole velocity and near-surface velocity obtained by tomographic inversion.](image)

Figure 4 Superposition picture of uphole velocity and near-surface velocity obtained by tomographic inversion. The blue curve is the uphole velocity, the red and green curves are the near-surface velocity extracted before and after the uphole constrained tomographic inversion respectively.

Figure 2(b) shows the shot records after the application of uphole constrained tomographic static correction. It can be seen that the events of the first break wave is smoother and more continuous, and the effective signal is clearer comparing with figure 2(a). Figure 5 shows the comparison of stacking section before and after the application of the uphole constrained static correction. It can be seen that after the uphole constraint, the events continuity of the stacking section is enhanced, the shallow layer information is more abundant, the signal-to-noise ratio is increased, the structure and the characteristic of the reflected wave group are clearer, and the quality of the stacking section is significantly improved.
Figure 5 Comparison of stacking sections before and after the application of static correction. (a) Stacking section without application of static correction; (b) Stacking section using the tomographic static correction; (c) Stacking section using the uphole constrained tomographic static correction.

Conclusions
The uphole constrained tomographic static correction technology not only avoids the influence of high-velocity rays on the velocity of shallow layer during the inversion process, but also makes full use of the first break information of the mid-to-far offsets, to ensure the accuracy of the shallow and middle velocity model. The method provides a reasonable near-surface velocity model and high precision statics for complex surfaces, therefore it improves the imaging quality of the stacking section and supplies a good foundation for the subsequent data processing, and the method can be used for reference in solving static correction problems in complex areas.

Reference