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From Seismic Tomography to Channel Wave Tomography

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Abstract During the development of coal fields, small-scale structures, anomalous bodies and changing of coal thickness in the mine working face are important factors which can affect mining safety. Hence these key issues need to be addressed. Researches show that channel wave tomography is very useful in solving these issues. It has an important theoretical and practical significance for reducing exploration risk, ensuring coal mine safety during production and saving exploration cost. This article aims to introduce the origin and development of channel wave tomography.
Keywords seismic tomography, inversion, channel wave, small-scale structures

Introduction

Tomography is a kind of geophysical inversion and interpretation method used to reconstruct rock mass distribution of geophysical parameters so as to delineate geological anomalies. Due to above advantages, tomography technology develops rapidly in the academic field and is widely used in geophysical exploration. According to the different geophysical field, tomography technology can be divided into seismic tomography, electromagnetic tomography, geological radar tomography, resistivity tomography, density tomography and magnetic tomography, etc.

Seismic tomography is a technology by using the various kinematics (travel time and the ray path) and dynamics (waveform, amplitude, phase and frequency, etc) of seismic wave data to inverse the geologic structure of the Earth's interior. Its main purpose is to determine the fine structure and the local inhomogeneity in the Earth's interior.

Safety problems caused by small structures in working face become more and more serious. The important factors affecting the safety of coal mining are small faults, small folds, subsided columns, changing of coal thickness, magmatite intrusions, etc. Channel wave is one kind of seismic waves generated in a certain rock and coal seam combination. In coal-bearing strata, compared with the surrounding rock, coal seam's velocity is low and its density is small. In geological section, as shown in figure 1, interfaces between coal seam and roof or floor strata are high wave impedance interfaces. The coal seam is a typical low velocity interlayer. It constitutes a "waveguide". When part of body wave's energy (including *P* wave and *S* wave) excited in the coal seam is imprisoned in the coal seam and its adjacent rocks, because of multiple reflections by top and bottom interface, not radiating towards the surroundings, superposing and interfering constructively, it forms a strong interference perturbation, called channel wave.

Channel wave exploration (fig.1) is a kind of geophysical exploration method which is usually carried out underground, and it has many advantages such as high resolution, large detection range, etc. Besides, Channel wave exploration is very effective for small structure detection.

Studying on channel wave inversion tomography technology based on full wave can greatly improve interpretation precision of the small structures in the working face and guide the rationality of the working face layout. So it has a great theoretical and practical significance to reduce the risk of exploration and ensure safety mining as well as save exploration cost.

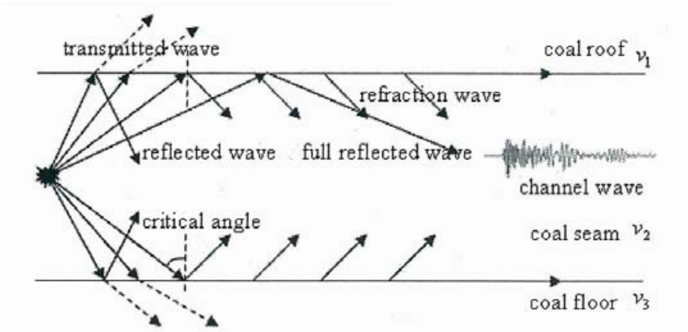

Fig. 1 *Schematic diagram for forming channel wave*

Channel wave tomography technology

Channel wave tomography can be mainly divided into two parts, the forward numerical modeling and inversion numerical modeling.

The forward numerical simulation for the channel wave

The forward modeling plays an important role in tomography. The precision in the forward calculation and speed of the forward calculation directly determine the resolution and reliability of imaging. According to the theoretical basis, numerical simulation generally is divided into numerical simulation for ray-tracing by calculating travel-time via integral equation and numerical simulation for wave field.

Numerical simulation for wave equation is a process of solving the partial differential equation with variable coefficients. In recent years, researchers have made much research on wave equation forward modeling using different methods such as finite difference method, finite element method and boundary element method and so on.

Using finite difference method, we can obtain the channel wavefield response. For example, equation (1) represents the equation satisfied by Love channel wave:

$$\frac{\partial^2 u}{\partial t^2} - {v_s}^2 \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial z^2}\right) = -4\pi\delta f(t) \qquad (1)$$

Where u represents the theoretical wavefield record, v_s represents shear wave velocity and δ represents delta function and $f(t)$ represents the seismic source function.

Inversion method

Inversion is to solve a nonlinear least square optimization problem (Tarantola, 1987), as shown in equation (2).

$$F(m) = \left\| u_{obs} - u_{cal}(m) \right\| \qquad (2)$$

Where F represents the objective function constructed for geophysical inversion problem, u_{obs} represents the observed wavefield data and u_{cal} represents the theoretical wavefield record u .

Geophysical problems are mostly highly nonlinear and seismic tomography is a typical nonlinear inverse problem. Seismic inversion method can be divided into two categories. The first category is the linear or quasi linear inversion method.The second is the fully nonlinear inversion method. In recent years, nonlinear inversion has obtained more and more attentions. In tomography, the nonlinear inversion methods mainly include genetic algorithm, wavelet multi-scale genetic algorithm, simulated annealing algorithm, artificial neural network algorithm, chaos algorithm and swarm intelligence algorithm, etc.

Classification of channel wave tomography

Channel wave tomography develops and improves daily with tomography technology.

Appling the treatment means of CT into the channel wave exploration, it can improve the accuracy of channel wave exploration. Channel wave technology mainly uses the transmission or reflection channel wave data. Using propagation time can study the velocity non-uniformity of exploration area, using the amplitude attenuation can study the absorption coefficient of medium and using channel wave based on full wave can study the physical properties of coal seam and some small structures.

Channel wave tomography based on travel time

In channel wave exploration, after direct P wave follows channel wave, and which is directly related to the structure of the coal seam. In channel wave's train, there is a special phase, named airy phase. Its high frequency and strong energy can be seen in the extreme point in the group velocity curve. Because channel wave's dispersion is high, there is noise interference and channel wave contains more than one phase with different phase velocity, which is difficult to pick up the arrival time than a single phase velocity. Airy phase is a set of wave trains in the wave group's envelope. Its velocity is the lowest, its energy is the highest and it decays slowly. So the airy phase information is especially suitable for travel time inversion.

Channel wave's travel time tomography is to extract the airy phase's (of Love wave or Rayleigh wave) arrival time of the fundamental mode curve and compute inversely to obtain the velocity disturbance information of the coal seam.

Channel wave tomography based on amplitude attenuation

Since the non complete elastic property of the earth medium, seismic wave's energy will be loss and be absorbed in the medium and its amplitude will attenuate. This kind of attenuation is different from the attenuation caused by wavefront diffusion and interface loss, known as medium absorption attenuation. Generally a dimensionless Q value is used to describe the elastic properties of the medium. The Q value is the inherent characteristic of the medium and can reflect the physical and mechanical properties of the medium itself. The Q value tomography can provide more abundant information for understanding the medium's structures and physical properties.

There are several kinds of imaging method using seismic wave attenuation. Because the most obvious change of seismic wave attenuation is the amplitude change, Study on amplitude attenuation imaging firstly was taken into account. In recent years, researchers both at home and abroad have made a lot of attenuation imaging by using the seismic wave amplitude change as the observation data. While the amplitude attenuation method has a poor stability, because stratum structure is complex and factors affecting the seismic wave attenuation are very complex. The seismic wave amplitude is vulnerable to various factors (geometric diffusion, instrumental response, source, geophone's coupling characteristics, reflection, transmission and so on) and it is difficult to eliminate the factors in this method. These factors cause the amplitude data observed to be instability or inaccurate. So far, people do not fully understand the problem of attenuation characteristics, mechanism, frequency correlation, etc. Even after several decades of development, it is still facing many problems and subjects which need new theory and calculating method to resolve.

Channel wave tomography based on full waveform

Channel wave inversion tomography based on full waveform (Pratt 1999) is to compute the difference between the record observed and synthetic record calculated according to the initial model by solving wave equation. If the difference does not meet the requirement, it needs to modify the velocity parameters of the model, calculate the synthetic record again based on the new model, compare it with the record observed again, and so on, until the difference is reduced to a given error value. Then the last model can be approximately thought as the final result and can reflect the actual velocity distribution.

This requires firstly establishing a correct channel wave seismic-geological model according to the rock physical properties of coal seam (velocity, density and other elastic parameters). The most widely used forward modeling method for channel wave is the finite difference numerical modeling method.

It's still a new research topic to apply a complete nonlinear inversion method for channel wave tomography. Because of importance of channel wave exploration, channel waveform tomography based on full wave will have a good application prospect.

Conclusions

The channel wave exploration is one of the front topics of geophysical technology, and channel wave tomography based on full wave equation is a new technology which is still in its initial stage. It needs to be perfected in many technical aspects.

(1)The first problem is modeling small complex morphological structures. In practical application, further research on the forward modeling method in the inversion method is essential;

(2) Channel wave tomography is of a nonlinear inverse problem, yet the non uniqueness is an inherent problem of nonlinear system;

(3) In 3D channel wave tomography problem, the number of the parameters to be inversed is large, which will result in instability and non uniqueness;

(4) The stability and speed of the nonlinear inversion algorithm directly affects the development of the imaging technology.

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