

3D Seismic Survey Technique in Less Explored Region

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Abstract: By summarizing the experiences of routine acquisition geometry designs, and using the 3D seismic survey data of a less explored region for instance, this paper put forward an acquisition geometry design method for less explored region plus the geological stratum calibration by reflection wave and time-depth conversion method. After drilling data and roadway data verification, the re-argumentation of acquisition geometry parameters for parameter determination and the forward modeling technique for geological stratum calibration and the stacking velocity time-depth conversion were proved to be very effective in improving the accuracy of seismic survey.

Keywords: Acquisition geometry, forward modeling, geological stratum calibration, less explored region.

1. INTRODUCTION

3D seismic survey is an effective method for prospecting geological structure such as fold, fault, collapsed column, goaf and coal seam erosion zone. But in the west part of China, due to the complicated geological condition, borehole data are rarely found and the prospecting level is very low. In the hope of speeding up the coalmine construction, a survey region started 3D seismic survey just after the stage of pre-survey, or merely in the stage of theoretical analysis of small coal mine mining situation. The lack of survey data brings difficulties for 3D seismic acquisition geometry design, reflection wave geological stratum calibration and time-depth conversion, and affects the accuracy of the prospecting result [1].

2. THE DETERMINATION OF 3D SEISMIC SURVEY PARAMETERS

3D seismic survey parameters include spatial sample interval, maximum offset, and maximum vertical distance, fold times and so on [2, 3].

2.1. Binning Size

In data acquisition system, only the binning size that satisfies the formula can have complete spatial sample frequency [4].

$$b \leq \frac{V_{int}}{4F_{max} \sin\theta} \quad (1)$$

Where b denotes the binning size, V_{int} denotes the upper layer velocity, F_{max} is the highest non aliasing frequency and θ is the dip angle [4].

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2.2. Determination of Maximum Offset

The proper maximum offset depends on these factors: NMO distortion rate, accuracy error of velocity analysis and reflection coefficient stability.

NMO procedure can distort waveform, especially for large offset. So when designing spread length, the NMO distortion of effective reflection waves from shallow and medium layer should be taken into account; the distortion should be restricted to a certain range. The relation between NMO distortion rate and spread length is:

$$k = \sqrt{1 + \frac{x^2}{t_0 v^2}} - 1 \quad (2)$$

Where k denotes the distortion rate, x denotes the offset, t₀ is the two-way travel time and v is the stacking velocity.

When designing spread length, this distortion effect should be taken into consideration and be restricted in less than 10%, so that the signal frequency is less damaged.

The RMS velocity and stacking velocity are computed based on the normal moveout, since the normal moveout increases along with the offset; the maximum offset must be large enough to guarantee high velocity accuracy [5]. The maximum offset should meet the accuracy requirement of the velocity analysis.

$$x \geq \sqrt{\frac{2t_0}{f(v-\Delta v)^2 - v^2}} \quad (3)$$

Here Δv is the velocity error, x is the spread length, v is the stacking velocity, f is the main frequency of reflection wave and t₀ is the two-way travel time of target stratum [6].

When the incidence angle approaches the critical angle, the reflection coefficient changes drastically, therefore to keep a relatively stable reflection coefficient, the incidence angle should be smaller than the critical angle (generally, less than 40°, in high dip angle area, less than 30°), so maximum offset limitation can be calculated as:

$$x \leq 2 * \sum_{i=1}^n h_i \tan \theta_{i0} \quad (4)$$

Where h_i is the thickness of layer i , θ_{i0} is the critical angle of layer i and x is the maximum offset.

2.3. Determination of Max Vertical Distance

Max vertical distance is the maximum vertical offset between survey line and shot point in an active acquisition geometry [6].

$$y_{\max} \leq \frac{v}{\sin \psi} \sqrt{2t_0 \delta t} \quad (5)$$

Here, ψ denotes the maximum dip angle (degree), δt is the maximum time difference (s) within one gathered CMP, often being a quarter of the apparent period of effective reflection wave. V is the average velocity (m/s), t_0 is the two-way travel time (s) of target stratum. (AUTHOR: The variables are missing here)

2.4. Fold Times

Fold times is determined by experience or experiment [7].

All the acquisition parameters above are determined by drilling data or mining data, so in a survey region which lacks these data, these parameters must be estimated by some other method.

3. 3D SEISMIC SURVEY EXAMPLE IN JIXIN COALMINE

Jixin coalmine is located in Jimusar, Xinjiang province, and is composed of three local small coalmines: Hongshanwa coalmine, Anxin coalmine, Shichanggoujixin coalmine. Before this 3D seismic survey, no drilling data has been found, nor geological survey data about this region and the geology structure are unknown. The outcrop and mining data show that the strata of this survey region are composed of lower sub-formation of Badaowan Formation of lower Jurassic and the Quaternary system. The coal seams are in Badaowan Formation of lower Jurassic, and among them, enable seams are mainly 7, 6, 4, 3 coal seams. 7 coal seam is about 3~6 m thick, 6 coal seam is about 10~18 m, 4 coal seam is about 1.5~5 m and the 3 coal seam is about 1.9~3 m. The distance between floor of seam 7 and roof of seam 6 is about 10~25 m, and the distance between floor of seam 6 and roof of seam 4 is about 25 m, floor of seam 4 and roof of seam 3 are about 1 m. The bury depth of coal seam varies between 100~450 m, and the dip angle is about 25°.

3.1. Preliminary Design of Acquisition Parameters

Based on the 3D seismic survey experience of adjacent area and acquisition parameter argument [8], 8-line-8-shot geometry is chosen, in which inline interval is 40m, trace interval is 10m, CDP binning is 5m×10m, active trace number in a single survey line is 48, fold times is 24, shooting off end, the maximum offset is 514m, the maximum vertical distance is 210m, and the minimum offset for shallow part is 175m, while for deeper part it is 194m.

3.2. 2D Experiment

Using the explosive parameters of single point experiment, a 2D survey line experiment was carried out

using preliminary designed acquisition parameters. Survey line is designed along the direction of dip, and active receivers are 48, trace interval is 10m, shooting off end with zero offset and fold time is 24. The experiment data is processed and the result section is shown in Fig. (1).

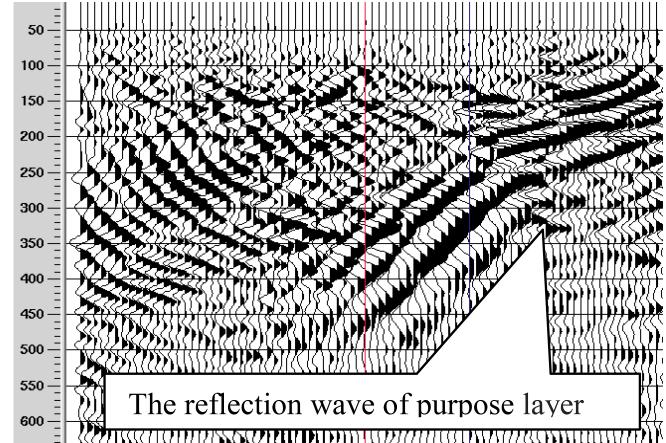


Fig. (1). Data of experimental survey line after stack.

From Fig. (1), it can be seen that data with fold times of 24 has a good S/N ratio, and meets the prospection need. The travel time of reflection wave from target layer varies between 0.2s~0.5s, the stack velocity of target layer at the shallow part is 3100m/s, and that of at the deep part is 3300m/s, with the highest valid frequency being 120Hz. The dip angle of shallow part is 15°, and that of the deep part is 45°.

3.3. Re-argument of Acquisition Parameters

Putting RMS velocity, highest valid frequency of reflection wave and dip angle of target layer into equation (1), it can be computed that the CDP binning size should be smaller than 9.724m×9.724m to ensure that space aliasing does not occur. Putting RMS velocity, two-way travel time of reflection wave and dip angle of target layer into equation (2), it can be seen that the maximum offset should be less than 720m. Putting the depth and dip angle of target layer into equation (3), it can be seen that the maximum offset should be less than 600m. Taking these two results into consideration, 650m is chosen as the maximum offset. From equation (5), it can be computed that the maximum vertical distance should be less than 250m. Compared with the preliminary design, it can be seen that the CDP binning size does not meet the requirement of eliminating space aliasing, and the CDP binning size should be adjusted to 5m×5m. The maximum offset and maximum vertical distance of preliminary design meet the requirement, but the minimum offset of shallow part is too large, which can cause blank in shallow seismic data, while the minimum offset of deep part is too small, which can cause blank in deep seismic data, and both lead to sharp shrinkage of effective control area.

The final acquisition parameters are adjusted to: 8-line-5-shot acquisition geometry with inline interval of 20m, trace interval of 10m, and CDP binning size is 5m×5m. Active receive traces in a single line are 48, fold times is 24, shooting off end, maximum offset is 502m, maximum

vertical distance is 150m. The minimum offset in shallow part is 60m, the minimum offset in deep part is 620m.

3.4. Data processing Quality Evaluation

After data process of the whole survey area, the S/N ratio is relatively high, the energy of reflection wave from target layer is very strong, and is easy to be recognized and traced. The geology structure is quite clear (Fig. 2).

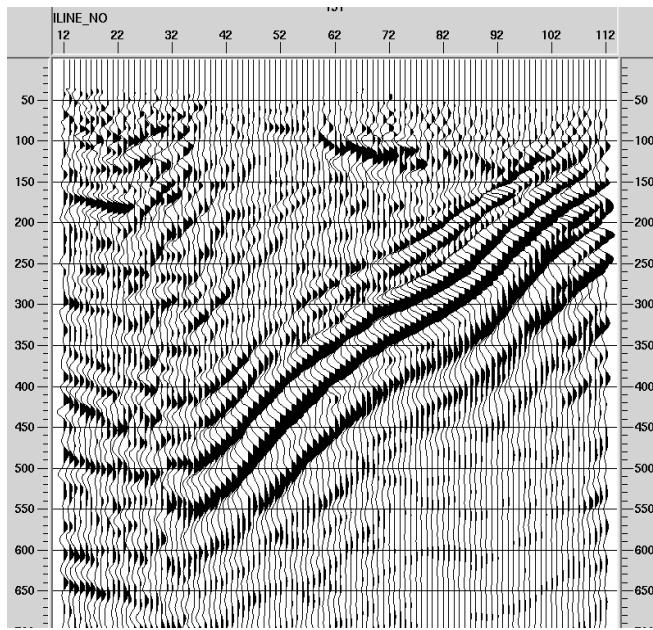


Fig. (2). Final migration sections.

3.5. Seismic Data Fine Interpretation

There are three steps in 3D seismic data interpretation: geological stratum calibration by reflection wave, geology structure interpretation and time-depth conversion.

3.5.1. Geological Stratum Calibration

Common stratum calibration methods include VSP bridge connection, adjacent pilot stratum, forward modeling and time-depth conversion. But due to lack of borehole data, the above four methods cannot work. So a new method must be found. Constructing a geological model (Fig. 3) by outcropping data and mining data, forward modeling is conducted, and the result (Fig. 4) can be used to calibrate the reflection wave to a certain stratum. Fig. (5) is the standard time profile of survey area, and by comparing Fig. (4) with Fig (5), it is found that the calibration is reasonable. By considering the similarity of waveform, phase continuity, amplitude and frequency characteristic, and by comparing the relation between multi wave groups, the reflection wave is traced. For some reflection wave that cannot be traced in the whole survey area, it is traced and compared locally.

3.5.2. Preliminary Time-depth Conversion

The conventional time-depth conversion equation is $H=1/2 \times V \times T_0$; this method needs borehole data or mining data to calibrate seismic velocities to establish seismic velocity field of the whole survey area (requiring an evenly

distributed velocity samples). By using this method, time-depth conversion was carried out and the result is shown in Table 1.

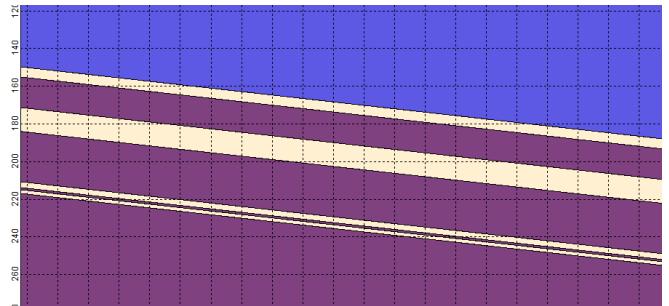


Fig. (3). A simple geology model of survey area.

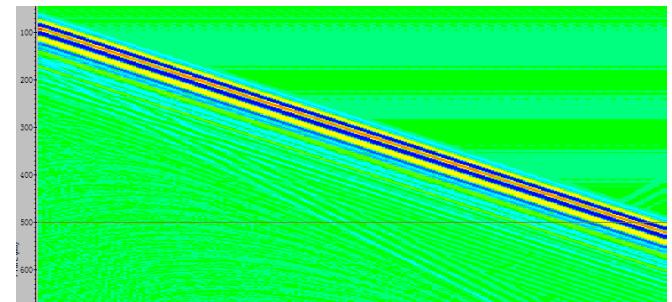


Fig. (4). Synthetic data of geology model.

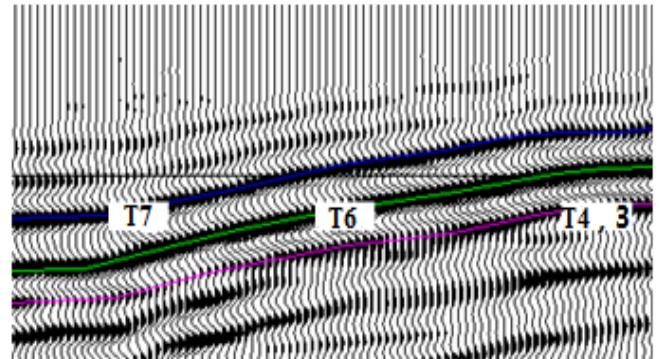


Fig. (5). Standard time section of survey area.

In data processing, velocity analysis was carried out using $100m \times 100m$ grid, which equals to a drilling network of $100m \times 100m$. Based on this assumption, stack velocity was converted into interval velocity, and the velocity field was constructed along the target coal seam layer. Then the interval velocity and average velocity were obtained from outcrops in coal seam roadway. Dividing average velocity by interval velocity, a velocity coefficient k can be obtained, and the contour map of k can be drawn. Multiplying k contour map with the interval velocity contour, an average velocity contour can be obtained, and the travel time of reflection wave can be used from coal seam in the stack section, computing a coal seam floor contour map. Using this coal seam floor contour map, it can be observed that the coal seam floor elevation of 6th coal seam was well predicted in the 4 explorations (Table 1).

Table 1. Predicted elevation of 6th coal mine floor.

Type	Borehole A1	Borehole A2	Borehole A3	Borehole A4
Conventional convert method	385	390	420	370
Stack velocity conversion method	410	444	470	400
Actual elevation by borehole data	415	425		410

Two months later after the structural concept, borehole A1, A2 and A4 were completed. From Table 1, it can be seen that the coal seam floor elevation predictions of two methods are different, and the stack velocity conversion method is more accurate.

3.5.3. Final Time-depth Conversion

Adding drilling data of borehole A1, A2, A4 to stack velocity time-depth conversion, and after adjusting k value contour, a new velocity contour can be obtained. Conducting stack velocity time-depth conversion again, it can be predicted that the depth of A3 borehole is 485m.

3.6. Verification of Survey Result

Drilling data of borehole A3 show that the elevation of floor of 6th coal seam is 489m, and the roadway mining data shows that the elevation errors of coal seam floor are below 1.5%. Two faults of both 7m fault throw are verified by roadway mining, and the horizontal error of fault position is no more than 10m.

CONCLUSION

CDP binning size is the fundamental parameter in data acquisition geometry design as it decides the shot interval and receiver interval and affects the total cost. The size of CDP binning should meet the need of eliminating space aliasing. The re-argument of data acquisition parameters can ensure obtaining good quality seismic data. In a survey area lacking borehole data, forward modeling technique can be used to determine which stratum the reflection wave comes from. Time-depth conversion using stack velocity can improve the accuracy of coal seam floor elevation determination.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

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