Seismic Acquisition Techniques in Complex Areas

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Summary

Aiming to overcome the difficulties in surface seismic surveys, BGP has devoted itself to research and development of new techniques for seismic acquisition in complex areas over recent years. This includes wave equation forward modeling, geometry optimization based on illumination analysis and noise elimination, database visualization for multi – geophysical information, and the technique for suppressing ambient noise. These techniques have greatly improved the acquisition quality in complex areas.

Key words: Wave equation forward modeling, Illumination analysis, Noise suppressing, Visualization, Environmental noise

Introduction

Complex seismic survey areas mainly include desert, hills, and oil production areas in various terrains. These complex surface zones result in noises and the subsurface structures varying greatly with steep thrust structures, low –amplitude structures and lithologic traps. These adverse conditions all lead to technical problems in geometry design, shooting and receiving, noise attenuation, and static corrections. To overcome these difficulties, BGP has carried out a major R&D program on the acquisition techniques in complex areas. All achievements from the R&D program, such as noise elimination and overthrust imaging, have greatly enhanced BGP´s acquisition capability in complex areas. Both our field capability and resulting data quality in such areas have improved dramatically. The difficulties in seismic data acquisition in complex areas belong to one of the following three categories: (1) acquisition geometry, (2) severe noise, and (3) complex statics. Our effort has focused on all three aspects and the resulting technology is effective in addressing these difficulties to a large extent. Consequently, the quality of acquired seismic sections has improved greatly. We discuss our techniques in the following sections.

Geometry Design Techniques

The analysis of acquisition geometries based on forward modeling

The impact of topographic undulation in rugged terrain on near–surface seismic wave propagation is complicated and often produces various interferences. Therefore, in order to ensure that the geometry design meets requirement of imaging the geological target, we must carry out numerical simulation for seismic waves, analyze all propagation patterns, and understand the formation of different surface interferences. The basis for solving these problems is the wave equation forward modeling in the rugged surface area. The simulation can simulate shot records of various geometries as well as secondary noise caused by the topography. Based on these considerations, we choose an optimal survey geometry suitable for generating good stack images. This is usually accomplished by comparing a set of practically feasible of geometry designs.

Geometry analysis based on illumination

The main process of illumination analysis is to find the most suitable geometry in a complex area by examining the illumination intensity in different positions of the target layer. Again, we compare all

geometries we can use in the area. Such a geometry that provides a uniform illumination ensures the image quality of complex areas. The illumination module adopts an analysis method based on generalized screen propagator (GSP) and local plane wave illumination analysis. We use a wave equation based on the propagation function to express the seismic wave energy that propagates from shot points and receiving points to the target area. We then perform the local plane wave analysis and obtain energy flows in all directions. By sorting the energy flows in the target area, we can find the total illumination, directional illumination, total aperture response, and directional aperture response. The illumination analysis technique is mainly applied to:

(1) Analyze the illumination intensity of various geometries and select the optimal geometry in accordance with the expected target layer;

(2) Help identify the causes from the shadow zone and provide guidance for data processing and interpretation;

(3) Optimize the shot distribution and improve the shooting efficiency in weakly illuminated areas.

Geometry analysis based on noise attenuation

1) <u>Geometry analysis based on stack response</u>

The main purpose of this technique is to analyze the noise suppressing ability of various geometries in the stacking process. The analysis procedures are as follows. We first choose typical CMP gathers or forward modeling CMP gathers in the work area as references. It is required that the offset for selected reference traces be evenly distributed; that the selected reference traces cover a large enough range of offsets; and that each reference trace be energy balanced and NMO-stretch muted. We then pick the amplitude values in the simulated traces corresponding to different offsets within each CMP bin of the geometry, and perform weighted stack on them to produce the final output for the bin. Because the CMP gather of each bin is extracted from the same reference, there should not be much information about the geological structure and other similar geological information in the final dataset. This means that the foot-print in the time slice generated in this manner is independent of underground structures and only related to geometrical attributes. It also reflects the variations] in offset distribution in adjacent bins and the energy variation in different offset gathers. We use the criterion that the smaller the variation is and the more even the energy of each bin stack is, the weaker the acquisition ‘foot-print’ is. As a result, the stack response can reflect whether the geometry itself is good or not.

2) <u>Geometry analysis based on DMO impulse response</u>

This technique performs 3D DMO processing on synthetic data simulated for a real geometry. The characteristics of DMO stack can be seen from the DMO operator that performs amplitude mapping along its impulse response track. DMO fold analysis is the process that first calculates the distance from the midpoint of a source-receiver pair to the next adjacent bin along the source-receiver vector, and then calculates the weighted fold after DMO according to the chosen target layer (The time, velocity, and dominant frequency are suitable for Fresnel zone calculation). The weighted fold can reflect DMO response well.

The technique produces an event of a dip formation

at a given reflection time in each CMP bin, and evaluates the geometry according to the DMO impulse of each CMP bin based on the event. For a particular pair of source and receiver (offset=2h), we assume that we know the dip angle of the target layer below the bin pierced by the source-receiver line and the two way time event at the zero offset, and then calculate DMO imaging time that is the image location of this reflector corresponding to the CMP. We set a seismic wavelet to the travel time positions of all source/receiver pairs which make contributions, and then stack all wavelets to get the final DMO response output. A good zero-phase response shows that this bin can be well imaged after DMO processing.

3) Geometry analysis based on PSTM response

This technique mainly performs pre-stack time migration based on the impulse travel times from the shot point to the diffraction point and from the diffraction point to the shot point, respectively. A diffraction impulse can be considered as any point on the PSTM ellipsoid that has the receiver and the shot points as its focal points. Thus, the data trace formed by PSTM is the summation of all PSTM ellipsoids passing through the given output point. Therefore, the layout of sources and receivers in a 3D geometry has a direct impact on PSTM outputs. More precisely, the geometry analysis technique based on PSTM response consists of performing migration for a certain diffraction surface based on corresponding input traces first and then analyzing and evaluating the imaging result. Thus we calculate the PSTM responses of all candidate geometries using the point PSTM response formula. The optimal geometry is chosen whose PSTM impulse response gives rise to the smallest side lobe and narrowest main peak, and produces the best continuity of main peaks between adjacent bins.

Static Corrections Techniques

Lateral varying time-depth curve

The time-depth (T-D) curve shows the relationship between the weathering thickness and vertical travel time. The weathering correction (static corrections from surface to the base of LVL) can be calculated directly using this curve after the LVL thickness is obtained through the near-surface survey. The datum static corrections can be achieved by adding the elevation corrections (static corrections from base of LVL to the final datum). It is suitable for continuous media such as desert, loess plateau, and mountains with a Quaternary gravel cover. The traditional time-depth curve method uses only one T-D curve in the entire work area. For complex near-surface areas with large spatial variation in time vs. depth, one T-D curve is insufficient for the residual static correction. We have proposed the method using laterally varying T-D curve and developed a set of procedures for establishing these curves.

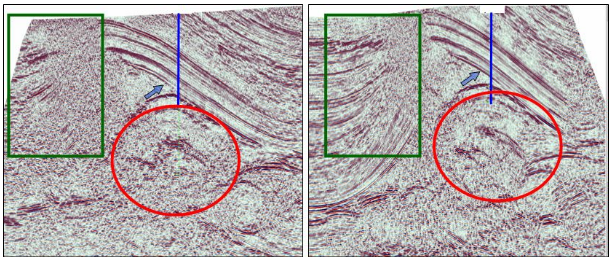
Deformable layer tomography

In recent years, the method deformable layer tomography (DLT) has been developed. DLT can determine both the velocity and geometry of each velocity layer. The inverted model takes on the feature of a layered medium. For the areas with a thin weathering layer with clear strata within, the solution of DLT is better than that of the conventional method. DLT depicts a more accurate surface and velocity interfaces than the conventional method. From the comparison we can see both long and short wavelength statics are well solved with DLT.

Joint statics

In most cases, a variety of near-surface conditions coexist in one project. Due to different near-surface features and adaptability of different statics methods, one statics method cannot adequately solve the statics problem. The joint statics is a more effective way to solve this problem.

The joint statics can be divided into two types: joint model building and joint application of statics. The former includes both lateral and vertical model building. Lateral model building uses an appropriate method to get different near-surface models for different regions and then combine them into a final model to calculate statics. Vertical model building uses different methods to get the near-surface model or obtain some specific parameters for different strata features, and then calculate the final statics. Joint application of statics selects two more than static methods based on the near-surface conditions and apply them in combination to achieve the best static corrections.



Previous 3D migration section New 3D migration section

Figure 1. The comparison of a section from 3D project in a mountain area in Western China. The two panels show respectively the results from an conventional and new surveys. The section runs from south to north.

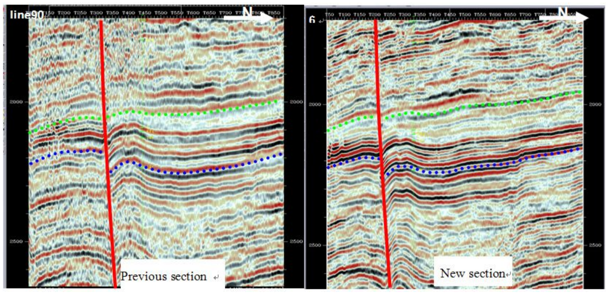


Figure 2. Comparison of acquisition results in a desert area.

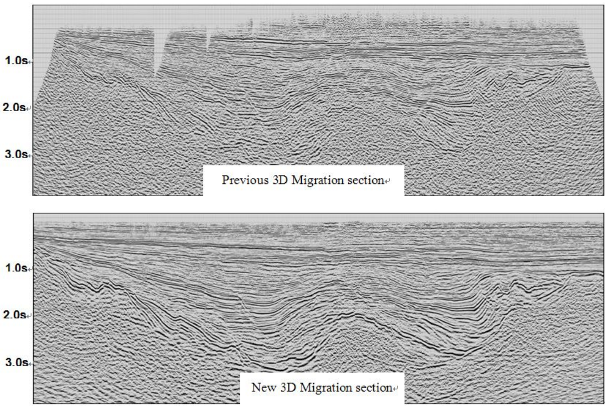


Figure 3. Comparison of 3D acquisition results in an urban area.

Field Examples

Using the methods discussed above, BGP has been able to significantly improve the data quality in surface seismic surveys in complex areas. As illustrations, we present examples from three differentregions with vastly different conditions. The first example is a 3D survey in a mountainous region in Western China. Figure 1 shows the comparison of data from a conventional survey and our new survey. We can see that the new 3D acquisition procedure has produced a much clearer structural image. The difference is especially pronounced in the south limb of the structure. Figure 2 shows an example from a desert in Western China. We again compared the old

section with the new one. We can observe that S/N ratio and resolution are clearly increased in the new section. It also shows clearly the pinchouts, which are favorable locations for stratigraphic traps and warrant for further detailed interpretation. Figure 3 presents the comparison of two 3D seismic surveys in an urban area. The new 3D data filled the gaps in the shallow layer that were in the old section. The S/N ratio and data resolution have been increased dramatically. As a result, the formations at the intermediate depth are better defined and structures at large depths are imaged in the new section. There is no doubt that the new data set would greatly improve the result of subsequent interpretation.

Conclusion

BGP has developed a set of procedures for seismic data acquisition in complex areas with both severe surface topography and highly variable near-surface velocity structures. The procedures emphasize the optimization of acquisition geometry, attenuation of noise, and effective static corrections. As a result, we can acquire data with much high quality in a variety of complex environments such as mountains, deserts, and urban areas. The data from the new acquisition procedures provide a higher S/N ratio, better structural definition, and deeper information.

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