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PSDM simulation in seismic survey design of fault plane

Sadegh Saffarzadeh[1], Abdolrahim Javaherian[1,2], Hossein Hasani[3], and Maryam Sadri[4]

[1] *Department of Petroleum Engineering, Amirkabir University of Technology, Tehran.*
[2] *Formerly Institute of Geophysics, University of Tehran, Tehran.*
[3] *Department of Mining and Metallurgical Engineering, Amirkabir University of Technology, Tehran.*
[4] *National Iranian Oil Company, Exploration Directorate, Tehran.*
Email: saffarzadeh@aut.ac.ir

ABSTRACT
Seismic modeling aids the geophysicists to have a better understanding of the subsurface image before the seismic acquisition, processing, and interpretation especially in complex structures. In this regard, seismic survey modeling is employed to build a model close to the real structure, and obtain very realistic synthetic seismic data. Therefore, a survey designer can consider the effects of various survey parameters on the resulting image by some illumination and resolution analyses. The primary objective of this study is to apply the seismic modeling on designing the seismic survey parameters such as wavelets, and their frequencies to analyze the resolution and illumination of the faulted target. A pre-stack depth migration simulator was used to evaluate the source wavelets with different frequencies on the resulting seismic image. Results verified that a geophysicist could improve the image of fault planes in a seismic section using the ray-based analyses, concerning illumination and resolution of fault image.

Keywords: seismic modeling, ray tracing, PSDM simulator, seismic resolution, illumination analysis, fault imaging

INTRODUCTION
Seismic survey modeling is increasingly significant to find the optimal acquisition and imaging solutions for specific geophysical objectives. It enables geophysicists to test various scenarios and consequently analyze the positive and adverse effects of each parameter on the quality of seismic images. Eventually, the geophysicists can improve the parameters regarding the objective of seismic survey designing such as amplitude-versus-offset studies, and 4D feasibility (Lecomte et al., 2003, Drottning and Branston, 2009).
Seismic illumination and resolution analyses provide a quantitative description of survey parameters that can distort the image during migration in the data processing. An appropriate illumination map can improve the imaging through reducing the cost of reshooting. Specifically, when the overburden geology is complex such as a trust fold or a salt dome body, it is of particular significance to try to simulate the target response for given survey geometries. Laurain et al. (2004) illustrated the importance of 3D illumination studies and compared various illumination-based analyses, followed by analyzing the conventional method with the model-based results used in the seismic survey designing. Stork (2013) presented various methods for illumination analyses to image the acquired data by using the reverse time migration (RTM). Saffarzadeh et al. (2017) used the illumination map by ray-tracing modeling to choose the optimum survey direction in a faulted horizon.
Lecomte et al. (2003) introduced a pre-stack depth migration (PSDM) simulator approach for handling 3D lateral resolution and illumination in PSDM images without the need to migrate synthetic data in the processing stage. This simulation process is a 3D spatial convolution technique working in the depth domain that models PSDM point scatter responses and also reflectors, with computational times close to 1D convolution and more available than finite-difference methods. The reasonable target illumination helps seismic processors during PSDM with an accurate velocity model in the processing stages.
In the present study, the seismic survey parameters were pre-designed using the conventional method by workflow of the 3D seismic survey. These parameters were used in the seismic modeling to investigate the effects of some parameters on the illumination of the fault system.

METHOD
The model-based approach often uses the background model and estimates the ray path by different survey settings. The aim of survey design studies is to propose how acquisition geometries can be optimized given the objectives of the acquisition. The most valuable input for seismic modeling is a reliable velocity and density model. In this case, one should try to make the depth interval velocity model using the pro-velocity obtained by 2D seismic and also well data (well logs, cores, etc.). The analyses based on illumination and resolution attributes can be useful to modify the seismic survey parameters determined by the conventional method. A comprehensive way to analyze the seismic resolution is based on ray tracing. This method incorporates the source wavelet, the overburden model, and the source/receiver position to examine the resolution on the target

of the horizon. The local target PSDM method used to analyze the resolution of the data on the target is explained in the next section.

Simulated PSDM image

The simulated PSDM image is a fast and robust approach to study the effects of geological structures on the resolution of the resulting seismic image. Ray-based modeling can estimate the 3D spatial pre-stack convolution operators called point spread functions (PSFs). Although ray modeling is similar in application and capability to 1D convolution, it provides the more robust and flexible results in the 3D spatial pre-stack domain. The 1D convolution is only able to simulate the post-stack time-migrated section while using the PSDM simulation works in the pre-stack domain it is possible to investigate the depth, resolution, and illumination of resulting image. The inputs to the PSDM simulator are an appropriate background model, survey geometry, and an incidence angle-dependent reflectivity obtained from the elastic properties, V_P, V_S, and density of the model. Rather than producing synthetic seismograms and processing these data to achieve the PSDM image (with the pretty high cost if a large volume of data must be modeled, processed, and imaged), this method applies the so-called PSDM filters on input reflectivity structure to produce PSDM look-alike image. The reflectivity cube, which is obtained from acoustic properties of the model (V_P, Vs, and density), can be converted to the wavenumber domain using fast Fourier transform (FFT). The PSDM filter is produced by ray-based modeling in the wavenumber domain. The reflectivity is then multiplied by the PSDM filter and by applying an inverse FFT on this product the simulated seismic image in the spatial domain is produced. Figure 1 shows the flowchart of generation of the simulated PSDM image.

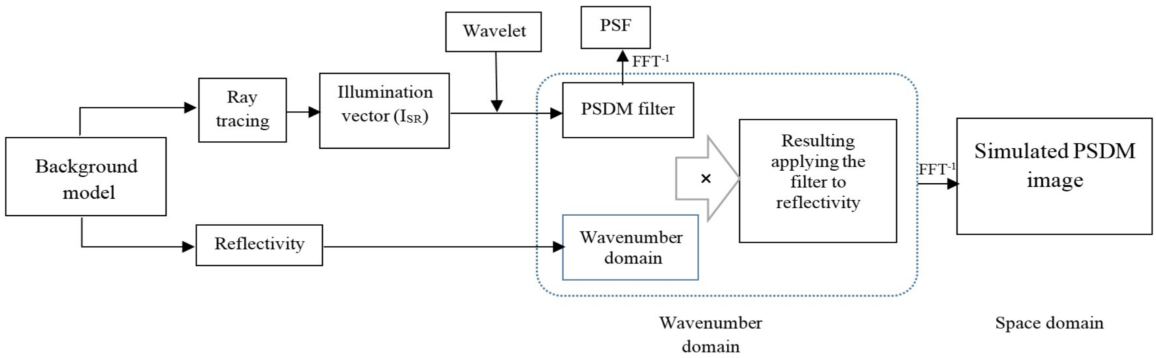
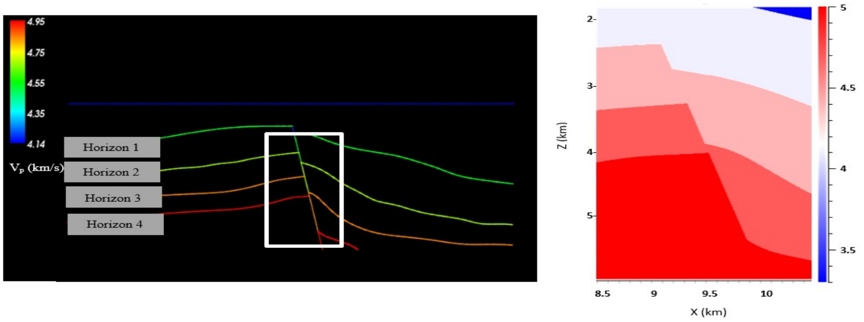


Figure 1. The flowchart of PSDM image generation. The simulated PSDM image is calculated by the inverse Fourier transform of multiplication of reflectivity and PSDM filter in the wavenumber domain.

For each shot-receiver pairs, illumination vector could be generated by the ray-based method. The full set of illumination vectors carries the information about all dips and azimuths regarding all possible shot and receiver pairs in the given model. The point-spread function (PSF) that is the response of scattered in the spatial domain can be obtained based on ray tracing. The size and sharpness of the PSF directly specify the imaging resolution of the target for different geometry parameters. To calculate the PSF at a point on the image, all scattering vectors in the wavenumber domain are mapped for a particular frequency band, and pulse, then an inverse Fourier transform is applied to gain the corresponding image. Briefly, the PSDM filter was generated by the illumination vectors in the wavenumber domain considering the proper source wavelet. On the other hand, the PSF was calculated by inverse Fourier to transform of the PSDM filter that is the spatial response of the PSDM. The simulated image constructed by combining a reflectivity model of the target with the PSDM filter in the wavenumber domain provides a direct prediction of the PSDM amplitude (Figure 1).

EXAMPLE

The study area is located in the southwest of Iran. Appropriate survey parameters were obtained using conventional processing techniques and the workflow of the 3D land seismic survey (Vermeer, 2012). The interval velocity function was obtained through a velocity analysis of the 2D seismic data and correlated with the data of the well. A proper model (velocity and density), survey geometry, and horizon information were used for ray-based analyses. For investigation of different parameters on the seismic resolution, a 2.5D homogeneous model (velocity and density) was built from the actual model information by considering the horizons and their related velocities between each other. The reflectivity of the model was generated in the area of study (Figure 2).



(a) (b)

Figure 2. (a) A 2D cross section of the model which shows the horizons and the fault plane. The white box is the area of the study for PSDM simulation. (b) The reflectivity of the model in the area of the investigation.

The effect of various pulses on the PSDM image was studied in detail through the resulting PSDM images. Figure 3 shows the effects of using source frequencies of 20, 60, and 80 Hz on the PSF and seismic sections. Results showed that the lateral and vertical resolutions of PSF for the 80 Hz frequency is better than other frequencies, but the frequency should be selected based on available instrument and different limitation consideration. The high frequency can improve the imaging; however, it is not always true since the role of illumination may not be seen for the parts that are not illuminated.

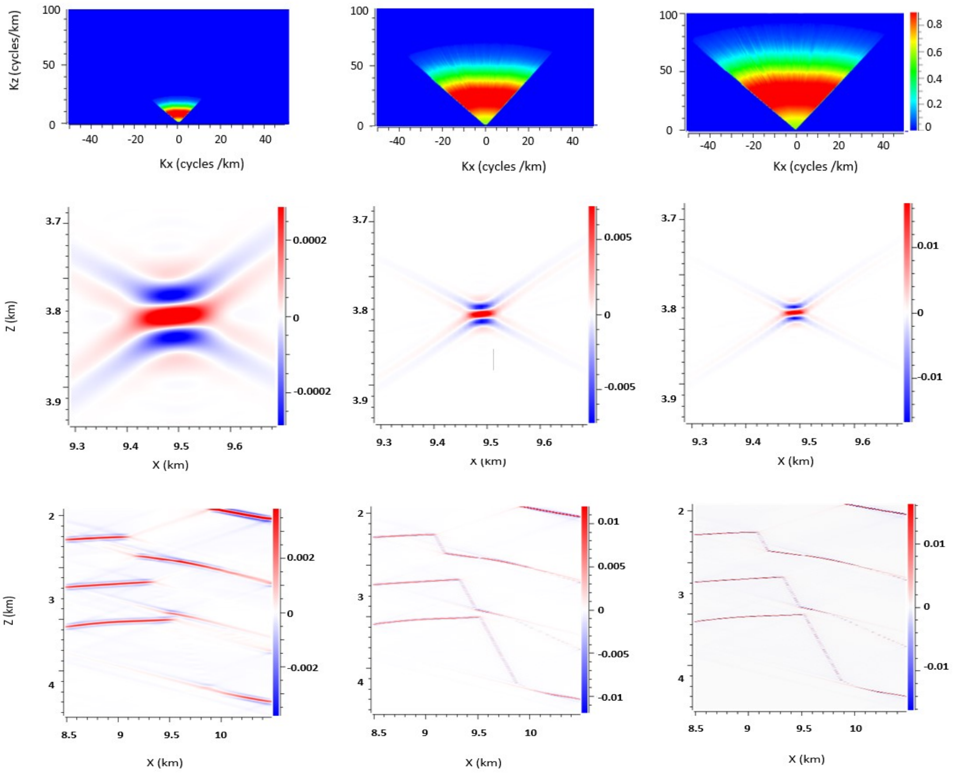


Figure 3. The PSDM filters (top row), PSF (middle row) and the PSDM images (bottom row) for Ricker zero-phase source wavelet 20 Hz (left column), 60 Hz (middle column), and 80 Hz (right column). The 20 Hz source wavelet has low resolution on the PSF, and the fault plane cannot illuminate on the PSDM image.

CONCLUSIONS

The model-based approach often uses the background ray tracing model and pre-designed survey parameters to estimate the ray path in complex structures. PSDM simulator was used in this work to investigate the effects of different source wavelet frequencies on the resulting seismic images. We concluded that 20 Hz source wavelet cannot image the target fault plane, but higher frequencies results show a higher resolution and better recognition of the fault plane. This paper proved that a survey designer could enhance the image of fault planes by better understanding the effects of different survey parameters such as source wavelet frequencies, on the resolution of the resulting image. The significant point is that when using a 20 Hz source frequency, it is not wise to anticipate imaging the fault plane.

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