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Forward modelling study of 2D finite difference reverse-time migration for downhole seismic data

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Summary

The application of seismic data acquired with receiver located in borehole is not limited in assisting surface seismic analysis nowadays. Various acquisition methods (i.e. from near to far offset, cross-well, multi-component receiver) have been developed for borehole seismic survey, which enables multiple technology for imaging of borehole seismic data. Few limitations of pre-stack reverse-time depth migration on reflector dipping angle or source-receiver geometry make itself a suitable tool for migration of borehole seismic data. This study tests reverse-time migration based on finite difference (FD) solution of 2D wave equation for applying on synthetic borehole seismic data generated by different geologic models. Forward modelling of generating synthetic borehole seismic data was done by solving 2D elastic wave equation, so the synthetic seismogram is a full-waveform modelling with presence of both P and S waves and surface waves. Acoustic wave equation is used for extrapolate the recorded wavefield backwards, and different behavior of events other than primary P-wave is examined in the discussion of results.

Introduction

McMechan (1983) and Baysal (1983) introduced a migration process by extrapolate the recorded wavefield backwards with time using finite difference solution of 2D acoustic wave equation for synthetic surface zero-offset seismic data. This process is known as reverse-time migration (RTM). Because of including paraxial terms that have been approximated during conventional FD migration algorithms, it is able to accurately locate even 90° dipping reflector. The full-waveform character of RTM enables preservation of real amplitude of multiple components (i.e. P-P, P-S wave etc.) during migration process of pre-stack common shot gather, if appropriate imaging condition and elastic wave equation are implemented.

Borehole seismic record (i.e. VSP) has a form of shot gather, and 3-component VSP survey is common nowadays. Conventional imaging of VSP record involves VSP-CDP conversion, which is not suitable for dipping reflector and lateral velocity variation. Keho (1984) and Wiggins (1984) introduced Kirchhoff migration into VSP data imaging process, which has become a commonly used VSP migration technique. However, Kirchhoff migration is not suitable to be implemented in the area with complex subsurface geology because it is sensitive to large lateral velocity variation. Using the time-coincidence imaging condition, which is described by Claerbout (1971) and the same as that used in Kirchhoff VSP migration by Wiggins (1984), Sun and McMechan (1986) and Chang and McMechan (1986) tested pre-stack reverse-time migration of synthetic offset VSP data by FD solution of 2D elastic wave equation. The results imply a different resolvability of vertical and horizontal receiver components on horizontal and vertical geologic features. Sun and McMechan (1986) denoted a potential limitation of FD algorithm on randomly spaced VSP data, so Chen (1987) studied both surface and VSP reverse-time migration by finite element scheme of 2D acoustic wave equation. Chen and McMechan (1992) applied acoustic reverse-time migration for both synthetic and real 3D VSP data, bringing the technique into 3D area. Hokstad (1998) implemented 2D elastic reverse-time migration on a real marine walkaway VSP data acquired offshore Norway.

This study is focusing on testing of RTM based on FD solution of 2D wave equation for borehole seismic data. Arbitrary source-receiver geometry can occur in borehole seismic survey, for instance, receivers locate in a vertical or horizontal (or even inclined) well with either near or far offset. Three models with receiver located in both vertical and horizontal well are used to generate the synthetic seismic data in the forward problem. The study is focusing on response of different source-receiver geometry and geologic models for a single-shot test with extrapolate recorded wavefield back to starting time instead of considering specific pre-stack migration imaging condition. The results can be used either in the field of exploration seismology or source locating of microseismic events.

Theory and Method

The forward modelling for generating synthetic borehole seismic data is done by SOFI2D (Bohlen, 2002). Three geologic models created are shown in figure 1. For each of the model, seismic wavefield is recorded by two types of receiver geometries shown by figure 2 a). The non-reflecting absorbing boundary condition used in SOFI2D is described by Cerjan (1985), and free surface condition is used in the forward modelling yielding a result with presence of surface waves. A snapshot at 350ms of acoustic wavefield in the forward modelling is given in figure 2 b), where 100 grids wide absorbing boundary was added on the edge of the model. Both Vertical and horizontal component of forward modeling recorded wavefield are outputted into MATLAB (©Mathworks Inc., 2013) for reverse time migration.

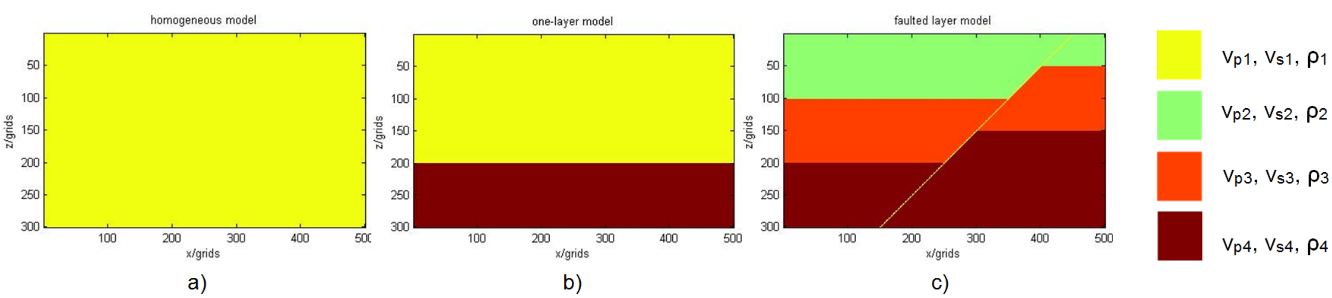

Figure 1. Three models created for generating synthetic seismogram in forward modeling. a) Homogeneous model b) One-layer model with a horizontal reflector c) Three layer model cut by a normal fault.

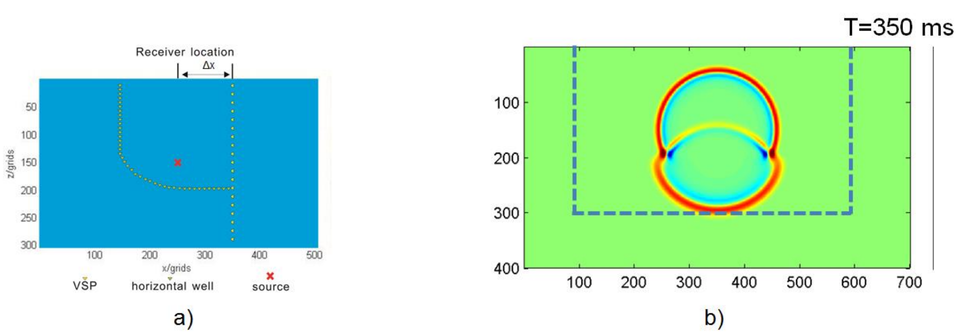

Figure 2. a) Two types of borehole receiver location used to record the wavefield in the forward modeling. Δx represents the minimum source-receiver offset for VSP geometry. b) Snapshot of the acoustic wavefield at 350 ms.

Examples

FD solution of 2D acoustic wavefield is given by McMechan (1983), which only predict the behavior of P-wave propagation. Figure 3 shows examples of synthetic seismograms by acoustic forward modelling. Figure 4 shows an RTM example for synthetic VSP data using the one-layer-model.

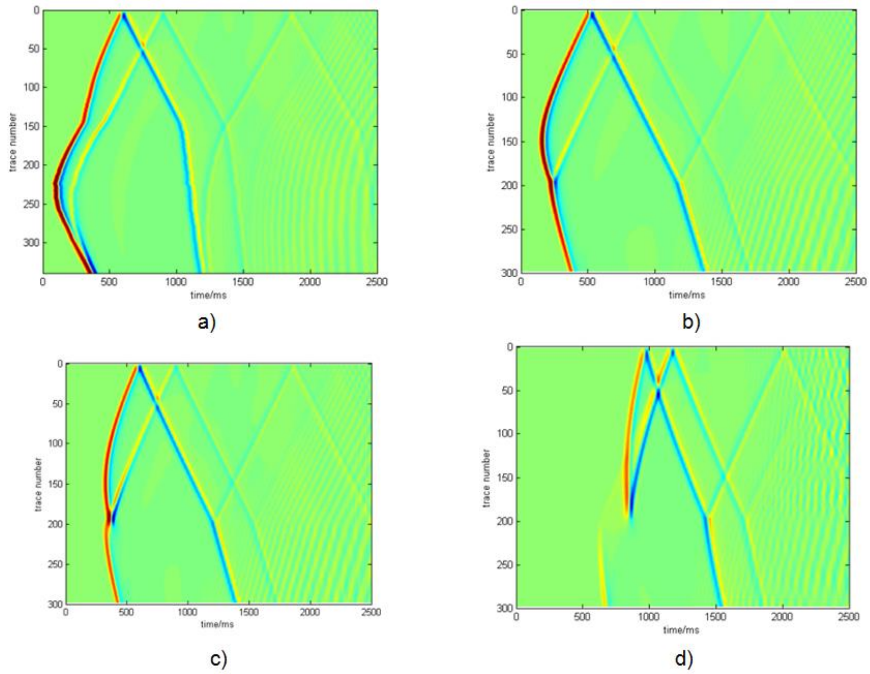

Figure 3. Acoustic example of synthetic seismogram for multiple source-receiver geometry. a) Record with receiver located in horizontal well b) VSP with minimum offset Δx=500m. c) VSP with minimum offset Δx=1000m d) VSP with minimum offset Δx=2500m.

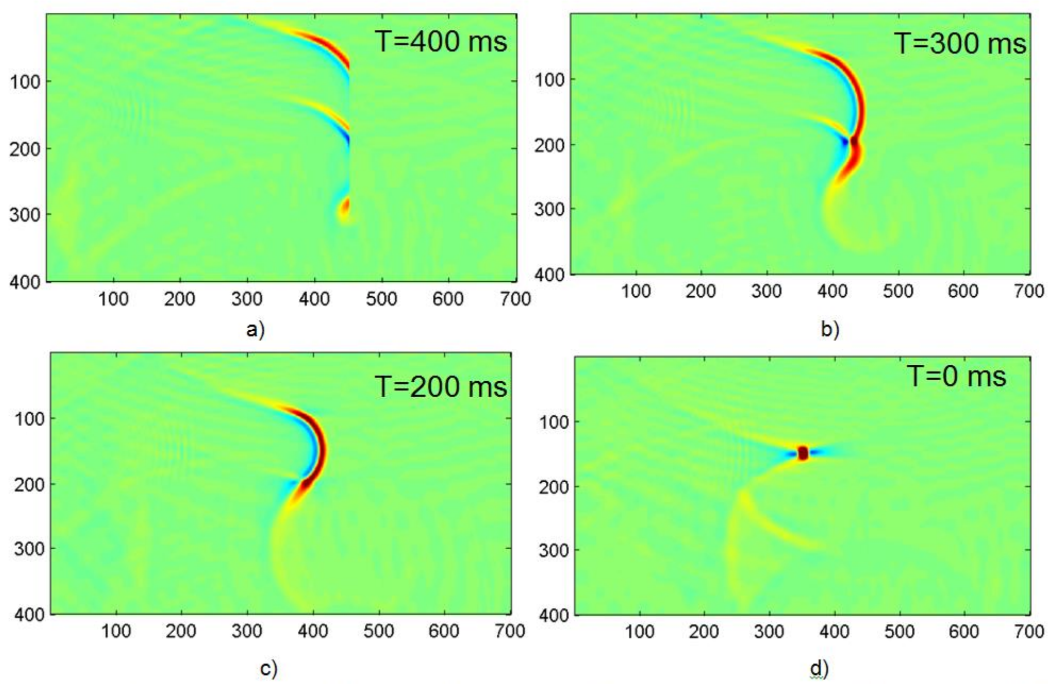

Figure 4. RTM example of the one-layer model with VSP source-receiver geometry based on FD solution of 2D acoustic wave equation. a) Snapshot of reversed wavefield at 400 ms away from the end of reverse calculation. b) 300ms c) 200 ms d) Reversed wavefield to time=0.

Conclusions

In a single-shot 2D FD acoustic RTM for borehole seismic data, recorded wavefield can be correctly reversed to the original position; and the migration process is not limited by the source-receiver geometry or presence of dipping feature (i.e. fault). Vertical resolution is better than horizontal resolution if VSP source-receiver geometry is applied, but this effect can be reduced by placing receivers in a horizontal well. The presence of correctly revered surface reflection is the major advantage of the borehole seismic survey geometry when applying reverse-time migration. However, reverse time calculation appear to be sensitive to noise, in addition, can generate noise by effect such as dispersion at the edge of receiver line.

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