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Extended Abstract

Time domain modeling of seismic waves in visco-acoustic media with variable density and topography

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Abstract

Accurately simulation of seismic wave propagation in media with irregular topography is a crucial step in geophysical imaging and inversion of land data. The recently proposed time domain finite difference (TDFD) method for visco-acoustic wave propagation is used to be extended to media with irregular topography, including the free surface boundary condition. The proposed method implemented accurately and effectively in terms of computational cost by the immersed boundary method.

1. Introduction

Two of the most accurate seismic imaging methods based on non-destructive surface acquisition are full waveform inversion (FWI) and least squares reverse time migration (LSRTM). Since the general approach of these methods to recover geomechanical properties is based on minimization of the data residuals, an accurate forward modeling operator ensures that the residual only depends on the model error. Seismic modeling is based on the numerical solution of the partial differential equation of wave propagation using methods such as finite difference or finite element. In the simplest case, this equation is solved under conditions of constant density for an acoustic medium. Different methods have been conducted to develop modeling methods by considering real conditions. One of these considerations, which has significant impact in onshore geomechanical studies, concerns the effects of irregular topography. In this study, we use the immersed boundary method to model the propagation of visco-acoustic waves in an environment with irregular topography and variable density. We also validate the method's performance using a realistic example model.

2. Methodology

In finite-difference (FD) modelling with rectangular mesh, the immersed boundary method induces the effect of free surface boundary conditions which is zero vertical stress at the boundary, without increasing grid points around the complex irregular topography. This ability lets discreting the model space using grids with larger node spacing, therefore speeds up the modelling process and reduces the computational cost and memory requirements .

In this method, the free surface boundary condition is implemented by assigning the virtual wavefield to extra grid nodes above the surface topography. These nodes, which are called "ghost points," are given a wavefield equal and opposite sign of the wavefield at corresponding mirror points with respect to the topography surface. Therefore, the vertical stresses become zero at the middle points on the boundary. The main challenge is that these mirror points are not located on the FD grid points necessarily, so to determine the value of the wavefield at them,

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interpolation is required. A more accurate interpolation method induces the free surface boundary condition more precisely. In the following, Using the immersed boundary method, we describe the interpolation technique used in this paper. The proposed interpolation includes the following steps: 1) the wavefield at all ghost points is set to zero. 2) The wavefield at the mirror point is interpolated by the barycentric Lagrange interpolation method [1] using four FD nodes surrounding each mirror point. Generally, some of these four nodes could be ghost points as well, with the zero initial wavefield. 3) Repeat the interpolation process multiple times by the iterative symmetric method [2]. In every iteration, the opposite values of the interpolated wavefield at mirror points are assigned to their corresponding ghost points. Tests demonstrate that after 20 iterations, the value of the interpolated wavefield converges to the exact values at the mirror points. 4) Each ghost point that has the opposite value of the exact wavefield at the corresponding mirror point, contributes to the next FD time step to induce free surface boundary conditions.

In visco-acoustic modelling, the wave equation has complex-valued velocity. Visco-acoustic wave propagation is primarily modelled in the frequency domain. Yang and Zhu [3] proposed a method by transforming the visco-acoustic wave equation from the frequency domain to the time domain. In this paper we used the method in order to apply topography in visco-acoustic media.

3. Results and Conclusions

The velocity and density models inspired by a realistic region in Iran, with the complex irregular topography, shown in figures1 (a) and (b), respectively, were used to investigate the performance of the proposed algorithm.

We utilized the immersed boundary method to model acoustic and visco-acoustic wave propagation when the free surface boundary conditions were induced in the complex and irregular topography of the model .

In this example, we used a constant quality factor (Q=20) for visco-acoustic media. However, the proposed method is general and accepts variable attenuation models. Figures2 (a) and (b) depict the acoustic, and visco-acoustic wavefield propagated in the model with Q=20 after 3 second propagation time.

Comparing these two propagations, the value of the amplitude being reduced in Q=20 at an equal time as a result of attenuation can be seen quite clearly. In addition, as can be seen in the figures, the modelled wavefield at the surface topography has a value of zero.

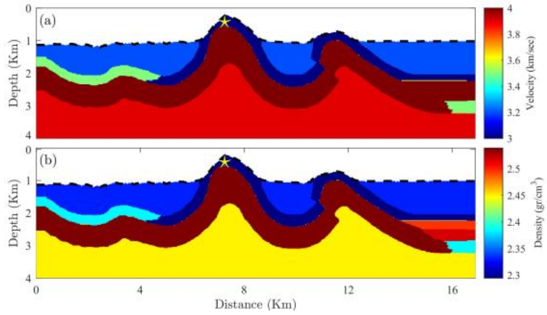

Fig. 1. (a) velocity model, (b) density model of the region. The yellow star indicates the source location. The dashed black line indicates the surface of the model.

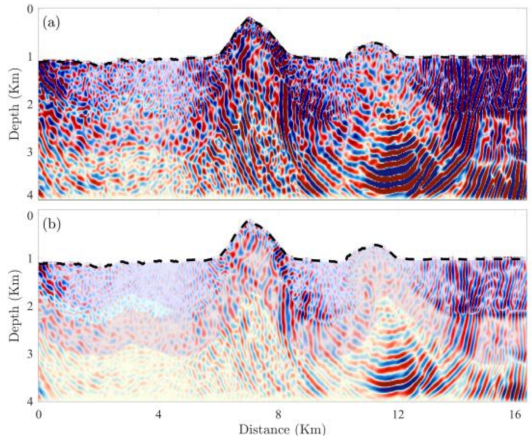

Fig. 2. (a) The acoustic wavefield after three second of wave propagation, (b) The visco-acoustic wavefield with Q=20 at the same time.

4. References

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