NUMERICAL SIMULATION OF SEISMIC WAVE PROPAGATION NEAR A FLUID-SOLID INTERFACE*

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INTRODUCTION

Seismic wave propagation near fluid-solid interface problems is found in many scientific and engineering applications such as:

- Seismic exploration in marine environment
- Interaction seismic wave with reservoir dam
- Earthquake induced tsunami

Until now, these problems are still open research area. Many researchers have investigated these problems experimentally or numerically.

Person (1999) using physical modeling has been successfully investigation of the seismic wave along liquid-solid interfaces. The drawbacks of the experimental approach are the measurement and data processing are so complicated, the measurement accuracy depends on the operator skill and the physical models are not easy to be built and expensive.

Van Vossen et al. (2002) used this method to model seismic wave propagation in fluid-solid configuration using finite difference method (FDM). Diaz and Joly (2005) use nonconforming finite element method using staggered mesh which pressure-velocity formulation is used in fluid medium and velocity-stress formulation is used in solid medium. Komatitsch et al. (2000, 2011) and Madec et al. (2009) developed a high order spectral element method (SEM) for simulating seismic wave propagation near a fluid-solid interface. Wilcox et al. (2010) developed a high order discontinuous galerkin method (DGM) for modeling seismic wave through coupled three dimensional elastic-acoustic media. The DG methods allow unstructured mesh configuration and inter-element continuity is not required. The basis function is discontinuous across mesh boundaries and only requires communication between mesh that have common faces. No global matrix inverting is required and the problem can be solved locally in each mesh. In their approach, they divided the spatial domain into hexahedral elements. Higher order accuracy can be achieved easily by increasing the order of basis function polynomials.

In this paper we develop a high order discontinuous galerkin method (DGM) for simulating two dimensional seismic waves near fluid-solid interface. The wave motion in both fluid and solid media is governed by elastodynamics equations in the form of velocity-stress formulation. The spatial domain is divided into unstructured triangular elements. Perfectly matched layer (PML) is used as absorbing boundary condition. We are using NUDG framework from Hesthaven (2002).

GOVERNING EQUATIONS

We use the velocity-stress formulation as the governing equations.

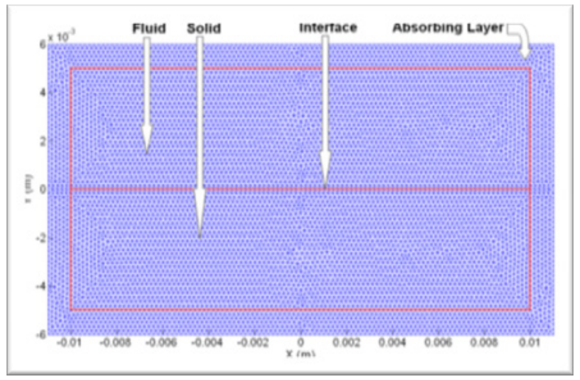
$$\frac{\partial v_x}{\partial t} - \frac{1}{\rho}\left(\frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y}\right) = f_x \qquad \frac{\partial v_y}{\partial t} - \frac{1}{\rho}\left(\frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y}\right) = f_y$$

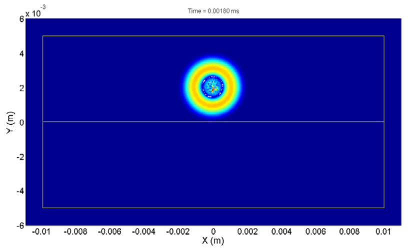
$$\frac{\partial \tau_{xx}}{\partial t} - (\lambda + 2\mu)\frac{\partial v_x}{\partial x} - \lambda\frac{\partial v_y}{\partial y} = 0 \qquad \frac{\partial \tau_{yy}}{\partial t} - \lambda\frac{\partial v_x}{\partial x} - (\lambda + 2\mu)\frac{\partial v_y}{\partial y} = 0 \qquad \frac{\partial \tau_{xy}}{\partial t} - \mu\left(\frac{\partial v_x}{\partial y} + \frac{\partial v_y}{\partial x}\right) = 0$$

RESULT AND DISCUSSION

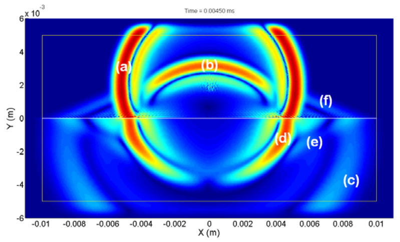
Numerical Example I

The first example has a simple configuration: two half-planes separated by a straight interface, one constitutes the fluid medium and the second one constitutes solid medium. The material properties for the fluid are c_p = 1500 ms^{-1}, c_s = 0 ms^{-1} and ρ = 1000 kgm^{-3} and the material properties for the solid are c_p = 4000 ms^{-1}, c_s = 1800 ms^{-1} and ρ = 1850 kgm^{-3}. The size of each medium is 20 mm x 5 mm. Absorbing layer surrounding the domain with the thickness of the layer equals 1 mm and total number of triangular elements is 15060. The polynomial degree is N = 3 and the time step Δt = 10^{-8}s. The source function is a point source located in the fluid at 2 mm above the interface, the time variation of the source is given as Gaussian with dominating frequency is 1 MHz.



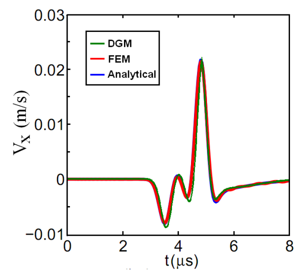


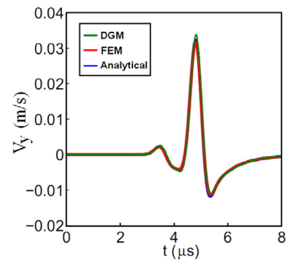
Velocity fields of 1st example at 0.18 s



Velocity fields of 1st example at 0.45 s

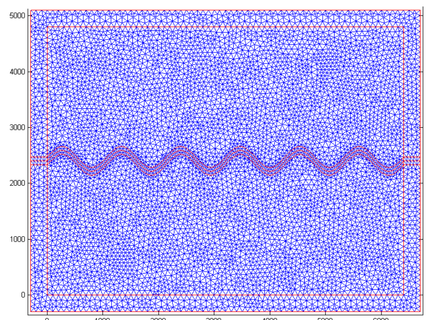
To validate the DG method, we compare the numerical DGM (the green curve) solution to the FEM solution (the red curve) and analytical solution (the blue curve). The curves are perfectly superimposed, showing the good accuracy of DGM.

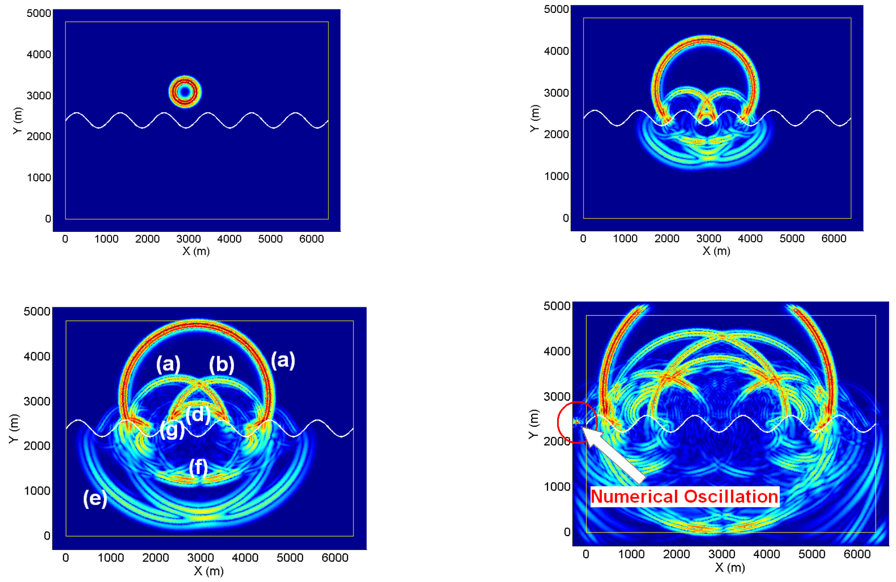




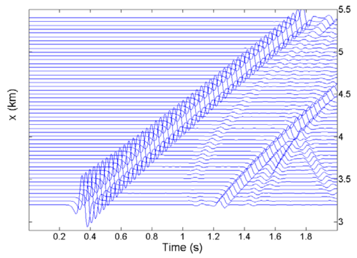
Numerical Example II

This example is taken from Komatitsch et al. (2000). The domain of the second example consists of two homogenous half-spaces in contact at a sinusoidal interface, as shown in figure below. The lower part of the model is elastic, while the upper part is acoustic, a water layer. The material properties for the water are c_p = 1500 m^{-s}, c_s = 0 ms^{-1} and ρ = 1020 kgm^{-3} and the material properties for the solid are cp = 3400 ms^{-1}, cs = 1963 ms^{-1} and ρ = 2500 kgm^{-3}. Total number of triangular elements is 13876. The polynomial degree is N = 5 and the time step Δt = 10^{-2}s. The source function is a point source located in the fluid at x = 2900 m and y = 3098 m, the time variation of the source is given as Ricker (i.e., the first derivative of a Gaussian) with dominating frequency is 7 Hz.

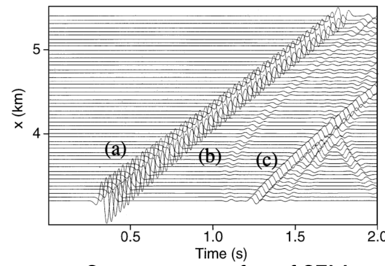




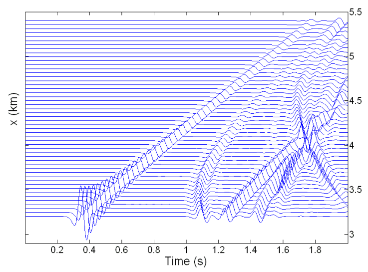
Mode conversions of wave reflected at the interface are clearly visible. The entire wave fields are composed of various waves i.e: (a) the direct P-wave, (b) the strongly curved reflected P-wave on the first anticline on the right, (c) the P-wave reflected off the first anticline on the left [symmetric of phase (b)], (d) the P-wave reflected off the central syncline, which undergoes a time delay and therefore a triplication, (e) various transmitted P-waves, (f) various P-to-S converted waves, and (h) a slow phase traveling along the interface, which is interpreted to be a Stoneley wave. Although the numerical calculations show excellent results, the modeling of fluid medium by using velocity-stress formulation has a drawback. It will generate a small parasitic S-waves near the interface. This parasitic S-wave will be accumulated for long time simulation and can destroy the stability of the numerical scheme.



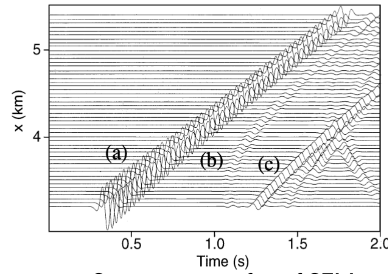
Seismogram of v_x of DGM



Seismogram of v_x of SEM



Seismogram of v_y of DGM



Seismogram of v_y of SEM

Comparisons of seismograms between DGM and SEM results are shown in above figure. Those figures show a good agreement.

CONCLUSIONS AND FUTURE WORKS

We have introduced that the use of high-order discontinuous galerkin methods allows one to model seismic wave propagation across a fluid – solid interface. The numerical scheme provides stable and accurate methods for simulating seismic wave, the comparisons with finite element method and analytical solutions show a good agreement. Numerical results have shown that the use of velocity-stress formulation will generate very small parasitic S-waves near the interfaces. Therefore in the future we will use velocity strain formulation instead velocity-stress formulation for modeling seismic wave near fluid-solid interface.

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