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Numerical Studies of Realistic Single Well Monitoring and Walkaway VSP Configurations

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ABSTRACT

A finite-difference seismic modeling method based on non-equidistantly spaced grids is presented. The modeling has been applied for the computation of synthetic borehole seismic data of a walk-away VSP configuration at a saltdome. The algorithm uses a staggered grid representation of the structure. This leads to difficulties in the representation of fluid-solid interfaces. Parameter smoothing operations must be considered for such models.

INTRODUCTION

Low frequency borehole seismics become more and more interesting for high resolution data of hydro-carbons reservoirs. The technical development of modern borehole tools like borehole based seismic sources requires the numerical verification of wave propagation phenomena in complex borehole environments. The numerical modeling must consider complex subsurface structure and rheology as well as the tools in the borehole. The applicability of numerical methods for studying seismic wave propagation is always limited by the complexity of the subsurface structure. Generally full wavefield solutions by grid methods (e.g., pseudo spectral, finite-differences) can handle more complex structures than ray-based or analytical solutions. This advantage shell be used to incorporate borehole related effects to the modeling results. In the case of low frequency borehole seismics, grid methods based on equidistantly spaced grids encounter the problem of dealing with different scales of the order of several magnitudes between seismic wavelength (e.g., $\lambda = 10$ m) and borehole size (e.g., R= 10 cm). Grid spacing is adjusted to the wavelength which does not allow the definition of small scale structures in the numerical mesh. (Falk and Tessmer, 1996) suggested a grid refinement technique to overcome these difficulties. The technique bridges the gap between different lengths of scale and allows the representation of fluid filled boreholes, casing or logging tools in the model. This enables a realistic simulation of borehole seismics for any frequency range and any complexity of the subsurface structure. Furthermore we incorporated relaxation mechanisms by the application of memory variables to model intrinsic wave attenuation.

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A second topic within this paper deals with the accurate representation of fluid-solid interfaces (e.g., boreholes) on staggered grids. Boundary conditions for internal interfaces are normally regarded to be solved in an implicit way just by the distribution of the material properties (Lamé constants and densities). This implicit condition is not satisfied for fluid-solid interfaces defined on staggered grids. Furthermore one can observe dependencies between the orientation of the interface in relation to the staggering-direction of the material parameters and stress components within a grid cell. Conventional smoothing by slowness averaging is a more or less practical approximation. However if the shear modulus in the fluid is zero averaging must be applied very carefully. This works accurately only if the interface is aligned with the grid.

EXAMPLE: SINGLE WELL MONITORING (SWM)

Surface seismic methods often fail to image sub-salt structures because of the strong reflectivity of the salt-top. SWM can be a very useful method to get better images from the flank of a salt structure by illuminating it from the side. Source and receivers are located in the same borehole. The modeling method allows the computation of a full wavefield solution including all borehole related events like tube waves generated by the borehole-source. Figure 1 (right) shows a snapshot of the horizontal displacement for a

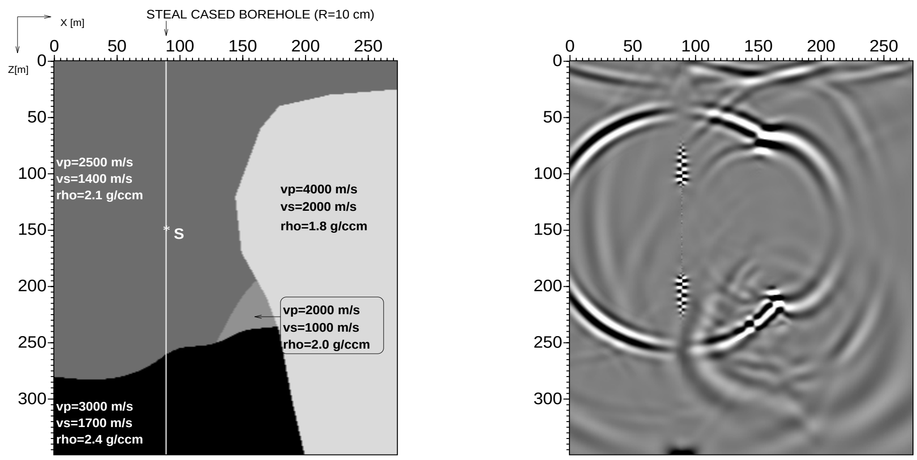

Figure 1: SWM configuration. The steal cased borehole is water filled. The snapshot shows the horizontal displacement at t=0.0901 s. Center frequency f=100 Hz

2D salt-structure in a SWM configuration. Snapshots as well as synthetic seismograms can be helpful for the interpretation of undefined events in real data and for case studies.

FLUID-SOLID INTERFACES ON STAGGERED GRIDS

The accuracy of the implicit fulfillment of the interface condition depends on the orientation of the interface in relation to the staggering direction. We define that the shear mod-

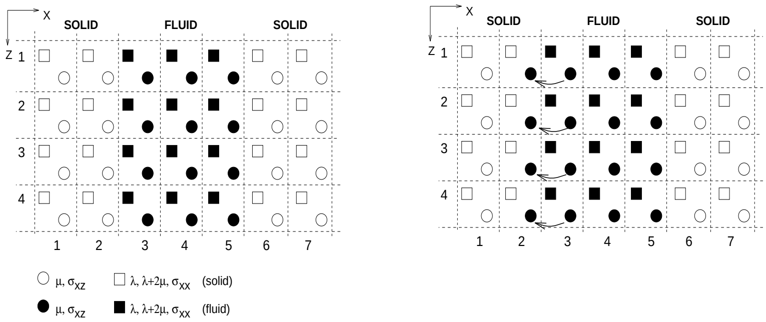

Figure 2: a) Asymmetrical fluid layer (upper sketch) and b) Modified interface condition by harmonic averaging of the shear modulus (equivalent to copying shear modulus in this model, where the interface is aligned with the grid).

ulus is located at a grid point shifted half a gridspacing forward in every dimension from the bulk modulus location. We may than have a model configuration like that sketched in Figure 2 a). By unmodified distribution of the parameters we get an asymmetric model.

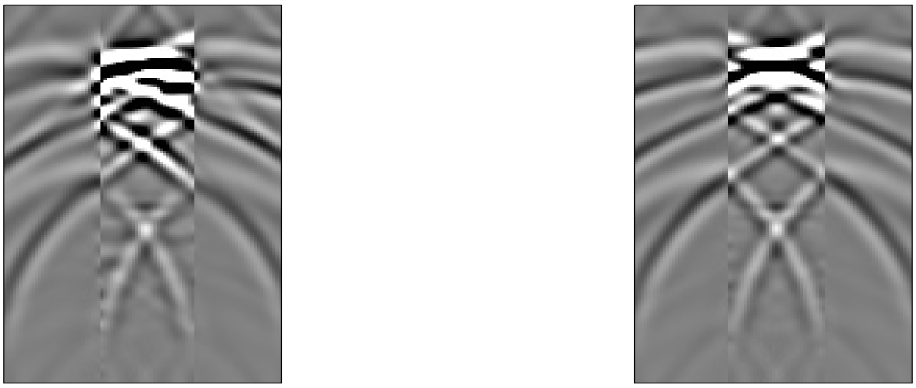

Figure 3: left) Fluid layer embedded in the solid; left and right interface conditions differ (right one is correct). right) Modified interface condition (as sketched in Figure 2) leads to accurate results

Left and right interface conditions obviously differ (Figure 3 (left)), where the left one leads to incorrect results. Modification of the shear modulus at the left interface as sketched in Figure 2 b (simple copy operation) leads to correct results for both interfaces (Figure 3 (right)). Of course the thickness of the fluid layer increases by half a grid spacing due to this treatment. The modification succeeds because the interface is aligned with the grid.

REFERENCES

Falk, J., and Tessmer, E., 1996, Tube wave modelling by the finite-difference method with varying grid spacing: Pure and Applied Geophysics, **148 Nos 1/2**, 77–93.