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Modeling of Borehole-Guided Waves and Reservoir Formation Reflections with a Discontinuous Galerkin Finite Element Method

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We model seismic downhole sources and wave propagation in and around a wellbore with discontinuities in the surrounding rock formation. We use a discontinuous Galerkin (DG) finite element approach to solve the elastic wave equation in velocity-stress form (Dumbser and Käser, 2006). The DG scheme allows for high approximation order in space and time using fully unstructured tetrahedral meshes to account for geometrically complex computational domains as typically encountered in realistic reservoir applications. Furthermore, local time stepping and space-dependent approximation orders are applied to reduce computational cost. In this work we take advantage of the flexible mesh refinement strategy of the DG modeling approach to study how borehole-guided waves affect the amplitudes of seismic reflections that occur from small faults or from the boundaries of the reservoir. Furthermore, we investigate how various sonic sources can provide different insights in understanding the impact of borehole-guided waves on reservoir formation reflections.

We apply the SeisSol simulation code (Käser et al., 2010) to a realistic scenario of an inclined well penetrating a reservoir layer that is bounded by different rock at the top and bottom. The discretized model contains a problem-adapted mesh with elements of tetrahedral edge length chosen proportional to the seismic wave velocities. In the vicinity of the wellbore, the mesh is refined to accurately capture the cylindrical geometry. Due to the local time stepping, smaller elements are computationally more expensive even if the local approximation order can be reduced. Therefore the area of interest in and around the wellbore are partitioned separately such that the computational work load is distributed equally among processors for parallel calculations. The simulated wave field clearly shows that strong reverberations due to guided waves from the wellbore might obscure the weak reflections from the material interfaces of the layers bounding the reservoir.

A typical sonic measurement consists of a fluid-filled borehole where a source and an array of receivers are placed in the fluid. Three types of sources generally are used: a monopole, a dipole, and a quadrupole, all producing dispersive waves. A monopole source excites axisymmetric waves propagating along the borehole, whereas a dipole source directed perpendicular to the borehole axis excites flexural waves propagating along the borehole. Quadrupole sources produce so-called screw waves in a borehole. In this study we use monopole, dipole, and quadrupole sources to compare the synthetic wave forms with respect to their sensitivity to discontinuities and small faults in the surrounding rock formation. In comparison to the conventional monopole sources with a symmetric radiation pattern, dipole and quadrupole sources might be better suited to suppress the P wave for S-wave velocity logging (Chen, 1988). Furthermore, quadrupole sources often reach higher resolution results (Chen, 1989) as they are typically operated at higher frequencies. Accurate modeling of these phenomena allows one to predict the operating frequency bandwidth under which tool and borehole-guided waves are reduced while allowing formation S-wave velocities to be measured with dipole or quadrupole sources.

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