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Dynamic earthquake rupture modeling in fracture networks of georeservoirs accounting for the effects of thermal pressurization

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The presence of fractures in geo-reservoirs, natural or man-made, is crucial to the economics of oil & gas production and geothermal-energy harvesting. The related seismic hazard due to the (re-)activation of these fractures by external forces (fluid injection or extraction), and their ability to generate sizeable (that is, strongly felt and even damaging) earthquakes, has received increasing attention within the last years. Numerical models of spontaneous earthquake rupture and wave propagation allow to investigate the conditions under which earthquakes within these fracture networks nucleate, propagate and potentially evolve into larger events, addressing the need to address physics-based seismic hazard assessment in geo-reservoirs.
To study earthquake dynamics in fluid-rich fracture networks, we aim to i) account for fluid effects on fault stress and strength combined with modern friction laws and ii) quantify natural fracture networks for efficient geometrical representations within a high-performance computing framework (e.g. Uphoff et al., 2017). To this end, we extend the freely available software SeisSol (www.seissol.org) based on the Arbitrary high-order accurate DERivative Discontinuous Galerkin method (ADER-DG). SeisSol employs fully adaptive, unstructured tetrahedral meshes to combine geometrically complex 3D geological structures, nonlinear rheologies and high-order accurate propagation of seismic waves.
Following Noda & Lapusta (2010) our method accounts for thermal pressurization of pore fluids mimicking the effects of rapid co-seismic slip generating heat that increases temperature and pore pressure in case of low hydraulic diffusivity of the surrounding rock. Consequently, the elevated pore pressure reduces the effective normal stress, causing dynamic weakening. Networks of fractures provide conduits for (dynamic) pressure changes, therefore, motions of these fractures may change the permeability of the system.
Besides frictional effects, variations in fault geometry have a strong influence on earthquake dynamics. Existing descriptions of fracture network characteristics are based on multi-well observations, outcrop mapping, seismic based fracture prediction and laboratory studies and reveal a vast degree of geometric complexity. Incorporating such structures with a sufficient degree of their complexity in computational models poses a major challenge for physics-based dynamic rupture simulations. We here use the statistical nature of fracture density in a novel, physics-based Markov Chain approach. 3D distributed fracture surfaces are created either uniformly distributed, according to tensile crack opening angle or based on background stress orientation. The number of fractures and their length are determined by a power-law distribution (Bour et al. 2002). The generated network is subsequently mapped onto a high resolution unstructured computational mesh thus avoiding the bottleneck of explicit meshing.
The presented modeling framework will be used to run suites of 3D simulations including structural complexity of fracture networks in conjunction with realistic, laboratory based friction laws accounting for fluid effects.