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Numerical models of extension fracture propagation in mechanically layered rocks

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Depending on the relative displacement across the fracture plane, all fractures are either extension fractures or shear fractures. For extension fractures, the relative displacement is perpendicular to the fracture plane. Extension fractures include tension fractures, which form when the minimum principal compressive stress is negative, and hydrofractures. Hydrofractures are fractures that are formed as a result of internal fluid overpressure, including dykes, mineral veins, many joints and man-made hydraulic fractures.

Here we present numerical models (boundary-element method, www.beasy.com) of the stress fields affecting extension fracture propagation in mechanically layered rocks. In the first series of static 2D-models we explore the effects of different stiffnesses (Young's modulus) and thicknesses of soft (low Young's modulus) layers on the maximum tensile stress concentration at the tip of a hydrofracture as well as on the position and magnitude of local stress concentrations at the layer contacts ahead of the fracture tip. The results show that the tensile stress concentration at the hydrofracture tip increases with increasing thickness of the soft layer above, enhancing fracture propagation within the stiff layer. Both the positions of maximum tensile stress concentrations (indicating positions of newly induced fractures) at the lower and upper boundaries of the soft layer are shifted away from the centre of the model with increasing layer thickness. The models also show that already thin layers of soft rocks may arrest fracture propagation in layered sections.

In a second series we run dynamic numerical models using the Beasy fracture wizard (www.beasy.com). As for the two-dimensional models we use realistic geometries and rock stiffnesses representing limestone outcrops in northern Germany (Lower Triassic, Upper Muschelkalk). In the first models, the stress field resulting from remote tension is calculated. The results indicate areas of tensile stress concentrations, where new fractures would be induced. At these positions (commonly at the thinnest parts of stiff layers) extension fractures are then inserted into the model and their (mode I or mixed-mode) propagation paths are discretised step by step using the dual-boundary-element method. For each step, stress intensity factors, and the combined efficient stress intensity factor, are calculated with the J-Integral. Some fractures are propagating straight on, others show kinking towards or away from pre-existing fractures. Generally, however, fractures become arrested at contacts to layers with lower stiffness.

The numerical modelling results compare well with previous quantitative field studies which show that the mechanical layering in many rocks affects the propagation of natural and man-made extension fractures. These results have significant implications for fluid transport in reservoirs (for petroleum, natural gas, geothermal and ground water).