Impact of deposition borehole geometry on mechanical spalling in nuclear waste repositories

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Predictions of rock spalling around deep-drilled boreholes and tunnels in underground geologic repositories in crystalline rocks remain a significant challenge, due to the heterogeneities present in the rock mass, uncertain stress fields, and the complex thermo-mechanical behaviour of the rock mass at elevated temperatures.

This study presents a three-dimensional numerical analysis of multiple fracture growth leading to spalling around a deposition borehole. The mechanical spalling due to stress amplification after drilling is simulated using a finite element-based discrete fracture growth simulator. Fractures are grown by computing stress intensity factors at each fracture tip, and the mesh is adapted to accommodate the changing fracture geometries at every growth step. The model is validated using the Äspö Pillar Stability Experiment (APSE), calibrated to simulate the drilling of a borehole in the Forsmark granite, and subjected to a far-field anisotropic triaxial stress, corresponding to the in situ stress model from Forsmark. The deposition tunnel is implicitly simulated by attaching the deposition borehole to a free domain boundary.

The effect of borehole geometry on the predicted spalling around a typical deposition borehole is studied. The cylindrical borehole is modified at the top to provide an access ramp for the spent fuel canisters, which can effectively improve the repository design by reducing the height of the deposition tunnel. Three cases are investigated, in which the borehole top is cylindrical, conical, and wedge-shaped, respectively. Numerical results show that spalling occurs in all cases, but the borehole geometry affects fracture nucleation and growth patterns. The enlargement of the borehole top induces higher stress concentrations at the borehole-tunnel junction, increasing the severity of spalling at the top of the borehole. The final spalled zone and the fractures-borehole interaction are illustrated for each stress and geometry scenario.