Description of the master's thesis

In the current discussion about the energy supply of the future, several technologies linked with underground resources, such as geothermal power generation, CO₂-storage and hydraulic fracturing regain importance. These technologies involve the injection of fluids under high pressures into deep geologic formations. Thus, the rock matrix is deformed and hydraulic and mechanical conditions of the reservoir are changed. The increased pore pressure of the fluid can reduce the effective normal stress of the rock up to a critical stress, at which failure occurs.

Two different kinds of failure have to be distinguished: Tensile failure refers to the creation of new fractures due to normal, tractional forces. Shear failure occurs due to shear stress along an already existing fault plane without the creation of new flow paths for the present fluids. However, both types of fracture events influence the flow field of coupled flow through the rock as porous medium in a crucial manner and have to be considered when modelling any of the mentioned technologies.

The potential for both failure scenarios can be evaluated with the help of failure criteria for shear and tensile failure according to Darcis (2013). In the considered conditions with high loads of the overlaying rock strata, the shear failure criterion is the one to occur first (Darcis, 2013). Thus, as a first step, an approach to account for shear failure was implemented as a numerical model in the simulator DuMux within this Master's thesis.

At shear failure, potential energy of the initially elastic deformation is dissipated as wave energy and non-radiated energy such as heat due to the slippage. Abercrombie et al. (1993) revealed, that the stress drop of an earthquake lies between very limited ranges of 5 – 50 bars despite its magnitude. These characteristics were summarized to a conceptual approach. Here, the shear failure is not resolved in detail, but the characteristics are reproduced: The shear failure corresponds to changed mechanical properties of the rock. The shift of two respective rock parts constitutes an irreversible deformation combined with a reduction of the shear stress. This material behaviour is represented by the one-dimensional rheological Maxwell model of viscoelasticity. The viscosity is introduced as parameter for the resistance of the failing rock against irreversible deformation. This parameter is decisive for the amount of stress that is reduced during the shear failure.

The change of the material parameters was implemented as a change in the constitutional relation of stress and strain. Once the criterion for shear failure is reached, the calculation routine switches
from the initial linear elastic law to a viscoelastic law.

It was shown, that the shift from the linear elastic to the viscous-elastic calculation routine does not affect the results for very high viscosities. According to the characteristics of earthquakes, the numerical model produces a certain stress drop within a defined time. The numerical model is even able to reduce the stress state below the failure criterion. The stress reduction is dependent on the viscosity of the failing rock. However, shear failure is only a first step to simulate fluid flow through failing rock. Tensile failure has to be the next step to approach the completeness of the numerical model.

Figure 3: Stress drop of the simulated shear event as a function of the viscosity, the parameter for the resistance of the rock against irreversible deformation.

References

