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Systematic study of the effects of scaling techniques in numerical simulations with application to enhanced geothermal systems

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Numerical modeling is a well established tool in rock mechanics studies investigating a wide range of problems. Especially for estimating seismic risk of a geothermal energy plants a realistic rock mechanical model is needed. To simulate a time evolving system, two different approaches need to be separated: Implicit methods for solving linear equations are unconditionally stable, while explicit methods are limited by the time step. However, explicit methods are often preferred because of their limited memory demand, their scalability in parallel computing, and simple implementation of complex boundary conditions.
In numerical modeling of explicit elastoplastic dynamics the time step is limited by the rock density. Mass scaling techniques, which increase the rock density artificially by several orders, can be used to overcome this limit and significantly reduce computation time. In the context of geothermal energy this is of great interest because in a coupled hydro-mechanical model the time step of the mechanical part is significantly smaller than for the fluid flow. Mass scaling can also be combined with time scaling, which increases the rate of physical processes, assuming that processes are rate independent. While often used, the effect of mass and time scaling and how it may influence the numerical results is rarely-mentioned in publications, and choosing the right scaling technique is typically performed by trial and error. Also often scaling techniques are used in commercial software packages, hidden from the untrained user. To our knowledge, no systematic studies have addressed how mass scaling might affect the numerical results. In this work, we present results from an extensive and systematic study of the influence of mass and time scaling on the behavior of a variety of rock-mechanical models. We employ a finite difference scheme to model uniaxial and biaxial compression experiments using different mass and time scaling factors, and with physical models of increasing complexity up to a cohesion-weakening frictional-strengthening model (CWFS). We also test how mass scaling interacts with hydraulic fracturing. We also introduce some methods to assist analyzing mass scaling effects.
We find the tested models to be less sensitive to time scaling than to mass scaling, so mass scaling has higher potential for decreasing computational costs. However, we also demonstrate that mass scaling may lead to quantitatively wrong results, so care must be taken in interpreting stress values when mass scaling is used in complicated rock mechanics simulations. Mass scaling significantly influences the stress–strain response of numerical rocks because mass scaling acts as an artificial hardening agent on rock deformation.