Summary of Session 1.1:

Modelling the micro-physics underlying earthquake nucleation processes and rupture

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Modelling rock grain interactions: questions

Modelling the rupture process: questions

In the process of fracture, grains of rock can break down until a lower scale is reached, which may be microns or molecules. Cracks and complex structures are present on many scales. The disorder present at a microscopic scale can be significant at a larger scale. How can the evolution of micro damage such as micro cracks be used to predict macroscopic failure? What intrinsic factors in solids govern macroscopic failure?

Outcomes

Modelling rock grain interactions

Particle based models are applied to the study of the physics of rock and earthquakes and to the study of geophysical phenomena occurring at various scales. Because using a microscopic representation of rock (e.g. using molecules for instance) will be too costly, a mesoscopic representation of rock is used. Different properties can be modelled at the particle scale such as radial or shear elasticity, friction, fracture and thermal effects. A mesoscopic approach would consist of modelling these properties at the particle scale, whereas a microscopic approach would consist of simulating these properties by using a larger number of particles. A microscopic approach has the main advantage of limiting the number of input parameters while obtaining a greater complexity. For instance, in the Lattice Solid Model, shear elasticity and rotational dynamics are simulated at the grain scale (grains of model rock are composed of several particles) rather than modelled at the particle scale (Place and Mora [5]). Numerical experiments show that similar results can be obtained with both approaches. However, the computational needs can be enormous when using a microscopic approach, in which case a more mesoscopic approach should be used.

Calibration

Because models are often based on empirical definitions, they need to be calibrated such that a given process is correctly simulated. In order to check that the correct physics is modelled, laboratory experiments are reproduced and compared with numerical simulations. In a numerical experiment aimed at studying the damage process in a rock specimen (Peng et al., [4]), damage localisation or cracks were observed at the tip of a pre-existing crack when the specimen was subjected to bi-axial compression. As in all numerical experiments, even if the simulation can effectively reproduce results from laboratory experiments, no confirmation can be given to the validity of the results. This is because all the input parameters of the simulation cannot be calculated from observations or laboratory experiments. For instance, the damping process, introduced in order to overcome problems arising from using a closed system cannot be calibrated according to observations or laboratory experiments. Furthermore, when using complex interactions between particles of model rock, additional input parameters must be evaluated to simulate the correct physics (eg. shear elasticity and bending elasticity for instance). This is a difficult step since all quantities in laboratory experiments cannot be known. Hence, the calibration is achieved by matching macroscopic quantities of the simulations with observations or laboratory experiments. The distribution of discontinuities in rock can be an important factor in fracture processes (c.f. also Ke et al.[3]) and are difficult to quantify using laboratory experiments. Hence, the introduction of discontinuities into the model rock according to the rock specimen using in the laboratory experiment cannot be achieved from direct observation.

Damage localisation

In modelling rupture processes, the evolution of micro-damage can be described through a dynamic function (Bai et al., [2]). From this dynamic function, a condition for damage localisation is evaluated that specifies the instant of rupture. During numerical experiments, the condition for damage localisation is evaluated and gives an alarm before failure of the material. Results shows that the condition can be used to predict failure and to provide a proper warning.

The evolution of micro-damage is controlled by the distribution of pre-existing micro-cracks. Damage localization or failure occurs far from equilibrium and is driven by the nonlinear evolution of micro-damages. Using an Evolution Induced Catastrophe model (Ke et al., [3]), it was found that minor mesoscopic changes can eventually induce macroscopic failure of materials. This is called trans-scale sensitivity. However, dissipation present in real rock has the contrary effect of trans-scale sensitivity. If minor mesoscopic changes can affect the macroscopic behavior, dissipation will tend to attenuate mesoscopic changes such that only the overall evolution of the mesoscopic structure can affect the macroscopic behaviour.

Pore fluid and solid interactions

Earthquakes involve processes such as plastic deformation and rupture but also more complex processes such as pore fluid and solid interactions and thermal expansion. Pore fluid and solid interactions can be simulated with a particle based model using a hybrid modelling approach (H. Sakaguchi and H. Mühlhaus, [6]). To model pore fluid and solid interaction, a grid is constructed that connects the centers of mass of all grains of rock. With this grid, fluid flow is calculated using Darcy's law. From the solid deformations, the pressure inside each grid cell is calculated, from which the force exerted on grains is computed. The forces exerted by the fluid pressure are incorporated in the time integration used by the particle based model. Using this model, numerical experiments can reproduce behaviour observed in laboratory experiments such as quasi static fracture processes. Pore fluid and solid interactions are found to be an important factor in rupture processes, where development of fractures are mainly caused by the increasing pressure inside cracks. However, dynamic processes linked to fluid flow cannot be simulated using this kind of modelling. A possible approach to model these dynamic process would be to couple a lattice gas model with a particle based model.

Thermal expansion

Thermal expansion is modelled by changing the size of particles according to the the temperature of the media (Abe et al., 1998[1]). Due to the intrinsic friction of particles, rubbing particles against one another will generate heat which causes particles

[6] Sakaguchi H. and Mühlhaus H.B. *Hybrid modelling of coupled pore fluid-solid deformation problems,* in: this volume, 99-101.