Fault activation induced by human activities: uncertainty quantification and parameter update

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Introduction

Activation of faults due to human-induced operations is becoming extremely important for risk assessment analysis and reservoir management. The variation of the loading conditions due to injection and/or extraction of fluids may cause the faults re-activation and the opening of new fractures that may generate (micro)seismic events. The aim of this work is at developing a Bayesian framework to quantify and possibly reduce the uncertainties linked to such human activities.

Methods

The simulation of the possible activation of pre-existing faults and the generation of new fractures is carried out by discretizing the solution operator with the aid of a FE model where the faults are conceived as discontinuity surfaces within the 3D porous rock formation. The discontinuous behavior of the displacement field is modeled by introducing interface elements (IE) in the FE formulation to discretize the pair of friction surfaces in contact each other [1]. The discontinuity surfaces are modeled using principles borrowed from contact mechanics as inner boundaries embedded in the continuous body. The fault activation allows for the relative displacements between opposite points whenever the stress state violates a certain failure condition. In this application, the Mohr-Coulomb criterion is employed. Different model inputs are investigated to assess the variance of the model output due to the input factors. In particular, the initial stress regime on the faulting system, the Mohr- Coulomb cohesion and friction angle, and the geometry of the faults are assumed highly uncertain.

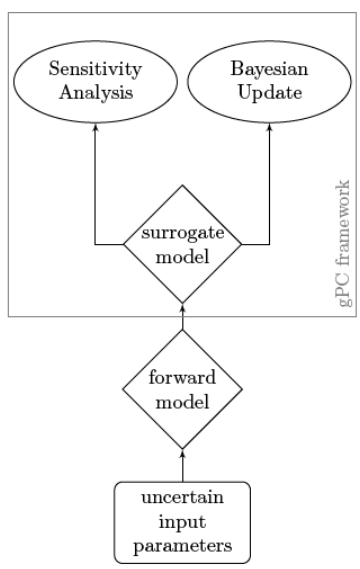

Figure 1: The study workflow: the sensitivity analysis and the Bayesian update of the uncertain model input are computed within a general polynomial chaos expansion (gPC) framework.

In Figure 1, the study workflow is illustrated. A global sensitivity analysis (SA) is first carried out to assess the influence of each parameter and their combination on the model outcome. The SA is performed by computing the Sobol indices through the general polynomial chaos expansion (gPC) framework [2,3]. Then, the inverse problem is solved by assimilating seismic moment observations originating from the fault activation. A Markov Chain Monte Carlo (MCMC) sampling method based on the gPC is used to constrain the model parameters. The proposed methodology is applied on a 3D synthetic test where Underground Gas Storage activities are simulated through cycles of injection/extraction of gas into/from a depleted reservoir. Fault geometry is expected to highly influence the onset of the fault activation although the interaction of geometry and initial stress state on the model outcome must be properly considered.

Preliminary results

Preliminary results show the model sensitivity to the input parameters, namely the Mohr- Coulomb cohesion (τ_0) and friction angle (ϕ), and the initial stress regime (M2). Note that M2 is defined as the ratio between the maximum horizontal and the vertical stresses. Figure 2 shows the results within the time interval t=2-10 years on the quantity of interest Aa, i.e., the activated area of the fault. The first order indices $S\tau_0$ and S_{M2} generally increase in time until t=9 years. $S\phi$ presents lower values with respect to $S\tau_0$ and S_{M2} and it is almost constant during the simulation. The interaction among parameters is evident at low-pressure values whereas, once the fault starts moving, the model outcome is mainly influenced by the first-order effect of τ_0 and M2.

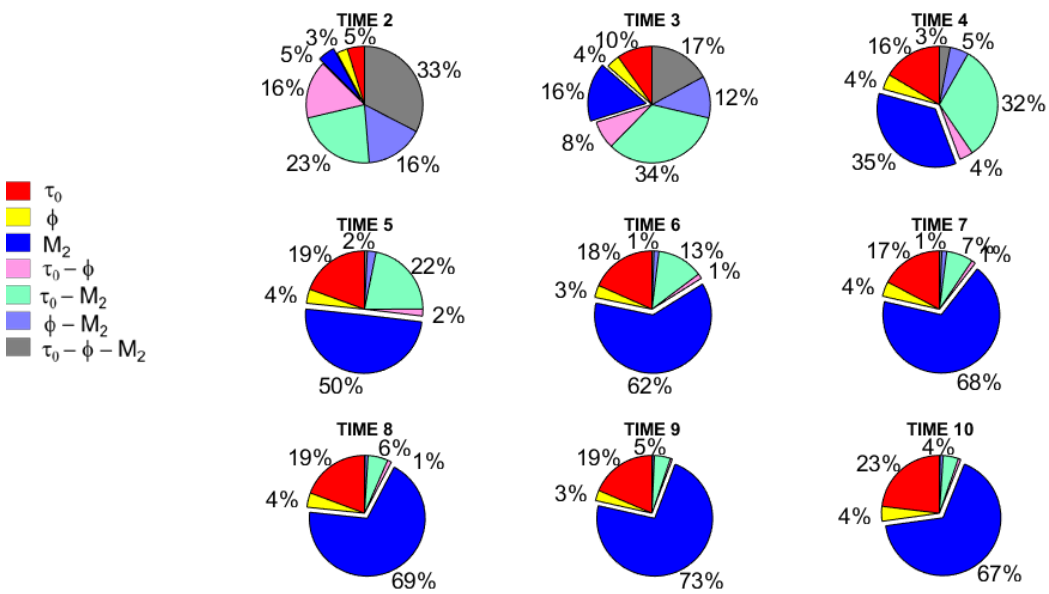

Figure 2: Sobol indices of the activated fault area at varying time steps of the geomechanical simulation.

References

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