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Modelling of fluid-injection-induced fault reactivation using a 2D discrete element based hydro-mechanical coupled dynamic simulator

Jeoung Seok Yoon[a,*], Arno Zang[a], Ove Stephansson[a], Günter Zimmermann[b]

[a]Section 2.6 Seicmic Hazard and Stress Field, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam 14473, Germany
[b]Section 6.2 Geothermal Energy Systems, Helmholtz Centre Potsdam GFZ German Research Centre for Geosciences, Telegrafenberg, Potsdam 14473, Germany

Abstract

Fluid-injection-induced seismicity often accompanies reactivation of natural fault systems which has become a major environmental problem in the fields of development of Enhanced Geothermal Systems, extraction of hydrocarbon in shale gas reservoirs, and waste water disposal. We present a numerical modelling and investigate how the seismicity induced by nearby high-rate fluid injection evolves depending on the effect of permeability contrast between the fault systems and the reservoir rock. Modelled magnitude of induced seismicity tends to be higher with presence of less permeable fault system than the reservoir rock.

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Keywords: Fluid injection; Induced Seismicity; Fault reactivation; Seismic hazard

* Corresponding author. Tel.: +49-331-288-1716; fax: -49-331-288-1127.
E-mail address: jsyoon@gfz-potsdam.de

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1. Introduction

Fluid-injection-induced seismicity often accompanies reactivation of natural fault systems. This issue has become a major environmental problem in the fields of development of Enhanced Geothermal Systems [1], extraction of hydrocarbon in shale gas reservoirs, and waste water disposal [2]. In particular, several damaging earthquakes have been reported in the USA in the areas of high-rate massive amount of waste water injection mostly with natural fault systems. One recent seismic event occurred in 2013 near Azle, Texas where a series of earthquakes began along a mapped ancient fault system [3]. These examples demonstrate that the presence of natural fault systems has significant impact to the environment in the development of energy systems and emphasize the necessity for better understanding of the physical processes that are hydro-mechanical-thermal-(chemical) and even dynamically coupled. In this context, we present a numerical modelling and investigate how seismicity induced by nearby high-rate fluid injection evolves under the presence of fault systems that are in a near-critical stress state. Furthermore, we investigate the effect of permeability contrast between fault systems and reservoir rock mass on seismic responses in terms of induced seismic magnitudes and stress drop and we provide geomechanical interpretation to the results by looking closely into the hydro-mechanical and dynamically coupled processes.

2. Modelling tool and description of the model

As a modelling tool, we present, 2D discrete element based hydro-mechanical coupled dynamic simulator. The simulator is based on commercial software called Particle Flow Code 2D, where the algorithms for fluid flow modelling and seismicity computing are additionally implemented by FISH programming. Details of the modelling method can be found in [4].

A reservoir model is constructed and shown in Figure 1 which represents a 10 meter thick horizontal layer at depth and subjected to maximum and minimum horizontal stresses. An inclined fault zone is modelled as a combination of damage zone and core fractures. The damage zone is represented by smaller particles and bonded with stiffness and strength lower than those in the host rock mass (Table 1). This fault zone structure resembles what is commonly observed in the field at different spatial scales in all kinds of lithologies (siliciclastic or carbonate geological settings). The damage zone is 100 m wide and the fault core is represented by the smooth joint model of PFC2D [5] of which the properties are listed in Table 1. Hydraulic behavior of the fault zone is modelled differently from the host reservoir rock mass by assigning different normal stress vs. hydraulic aperture relation (assumed) to the contacts that are in the damage zone and the host rock mass as shown in Figure 2. Distribution of the permeability at the flow channels in the damage zone and in the host rock mass are shown in Figure 3 to mimic high permeability fault (fluid conduit) and low permeability fault zones (fluid barrier), and named as high-k-FZ-model and low-k-FZ-model, respectively.

Table 1. List of model parameters.

Particle and Parallel bond model property	Host rock mass	Fault zone
Particle density [kg/m^3]	2630	2630
Particle elastic modulus [GPa]	60	40
Particle friction coefficient [-]	0.9	0.5
Bond tensile and cohesion strength [MPa]	9, 25	2, 5
Bond friction angle [Deg]	53	30
Smooth joint model property	**Rock fracture**	**Fault core fracture**
Normal and shear stiffness [GPa/m]	60, 5	30, 2
Friction coefficient [-]	0.9	0.5
Tensile and cohesive strength [MPa]	2, 5	0.1, 0.5
Friction and dilation angles [Deg]	50, 3	30, 3