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Geomechanical Assessment of Seismic Hazard from Hydraulic Fracturing

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Summary

A coupled hydro-mechanical model is used to evaluate fault activation associated with hydraulic fracturing in the Horn River Basin. The model is used to simulate hydraulic fracture growth through a discrete fracture network, examining the pore pressure diffusion and associated fracture dilation and shearing. Based on the geomechanical, the seismic activity can be predicted and used to compare with the actual seismicity monitored during the fracture treatment. The synthetic microseismic prediction includes location, timing and magnitude of the activity and can be used to validate the geomechanical attributes and calibrate the model to match the field data. Applying such a ***microseismic geomechanics*** approach not only improves the interpretation of the microseismic image but also improves the understanding of the geomechanical response of the reservoir.

In this study, the impact of the hydraulic fracturing on a pre-exisiting fault was examined to quantify seismic hazard. A geomechancial model was created to investigate a Horn River Basin hydraulic fracture and the associated seismic magnitudes. The model was designed to investigate the mechanism of fault activation and the impact of fracturing at different locations around the fault. The study indicated that the stimulated fracture network had to grow directly into the fault in order for the injection pressure front to trigger fault slip. Geomechanical assessment of ***absolute*** seismic hazard can be used to modify the engineering design prior to operations to minimize the seismic hazard including the placement of the well, and modifiy staging along the well to avoid fracturing in the regions likely to lead to fault activation. In scenarios where induced seismicity occurs during the treatment, the method can also be used to examine operational changes to lessen the ***relative*** seismic hazard.

Introduction

With hightened public concerns of environmental issues with hydraulic fracturing, attention is raising around the few isolated cases of injection-induced seismicity. An increasing number of reports have recently been made of felt seismicity associated directly with hydraulic fracture treatments or disposal of waste water from extraction of unconventional resources. In order to safely and efficiently develop unconventional reservoirs in areas of concern, industry protocols have been developed to deal with induced seismicity issues. Typically these protocols rely on local seismic monitoring to define traffic light systems, where operations are modified depending on the seismicity levels. As part of these protocols, methodologies are required to assess the seismic hazard both prior to the initiation of operations in addition to modifications to planned operations when required by traffic light levels.

The mechanism of induced seismicity is well established as fault slip caused by either total stress changes, or pore pressure increases during injection operations. Coupled hydro-mechanical models are therefore ideally suited to assess the conditions for induced seismicity, quantifying the pore pressure changes from injections along with associated fracture opening and potential fault slip. The fault slip can then be related to seismic magnitudes and allow quantification of the seismic hazard.

Method

Often induced seismicity studies utilize simplistic flow simulators to predict the pressure changes associated with uniform radial flow. However, the simplistic models do not handle flow heterogeneity that are typically included in the relatively sophisticated petroleum reservoir simulators used for reservoir management providing more accurate estimates of pressure changes associated with fluid injection and extraction. For induced seismicity investigations, however, the geomechanical response of the system to pressure changes is also important. Particularly during hydraulic fracturing where injection pressures are intended to dilate fractures and thereby enhance the permeability. The fracture mechanics aspects of the fault are also important, controlling the deformation characteristics of the fault and ultimately the slip associated with the seismic source. Therefore proper assessment of induced seismicity requires accurate flow simulation and associated geomechanical and fracture mechanics effects to investigate how the injection may lead to seismic sources.

In this study, a dynamic distinct element method (Damjanac and Cundall, 2014) is used to assess seismic hazard associated with hydraulic fracturing. The geomechanical model includes fluid flow through a discrete fracture network (DFN), and also includes hydro-mechanical coupling such that the fracture dilation with pressure is intrinsically handled during the simulation. In addition to fracture dilation, the geomechanical deformation of the fractures can also be assessed to determine fracture slip. Furthermore, the dynamic rupture of the fracture or fault can be assessed enabling a direct prediction of the occurrence of seismicity, including the timing, location, magnitude and source mechanism/moment tensor (Figure 1). The geomechanical modeling can also be applied to induced seismicity investigations from any type of injection, although in some cases matrix flow may be more important than flow through a DFN. Therefore these methods are well suited to assess hazard associated with injection.

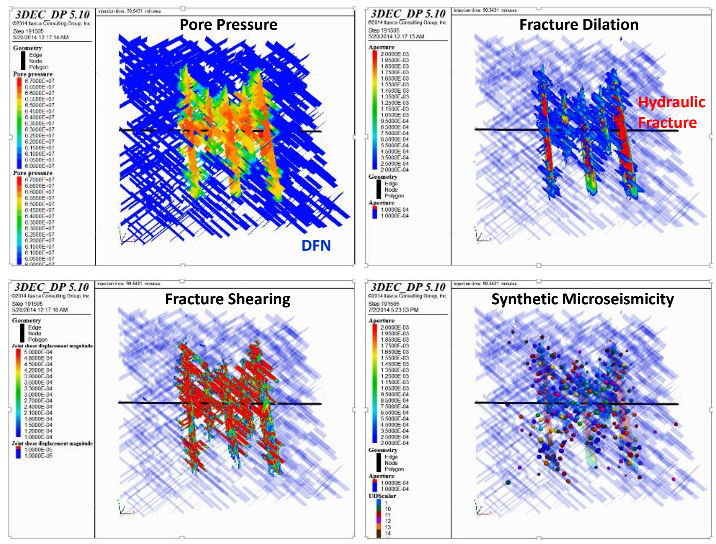


Figure 1. *Geomechanical simulation of a hydraulic fracture network. Upper left shows the simulated pore pressure diffusion within a DFN (blue). Upper right shows the fracture dilation or opening of the primary hydraulic fractures (red segments). Lower left shows the calculated shear displacements, indicating the induced slip within the DFN. Lower right shows the estimated microseismicity.*

Example

This study examines fault activation and induced seismicity in the Horn River Basin (HRB), in NE British Columbia.Hydraulic fracturing has induced seismicity during certain operations in the area (BCOGC, 2012). For example, Snelling and de Groot, 2014, described a microseismic monitoring project in the HRB where hydraulic fracturing activated a fault (Figure 2). We created a geomechanical model to examine hydraulic fracturing at different offsets from a fault. The model included five perforation clusters and a DFN to simulate hydraulic fracture growth in the vicinity of the fault (Figure 3).

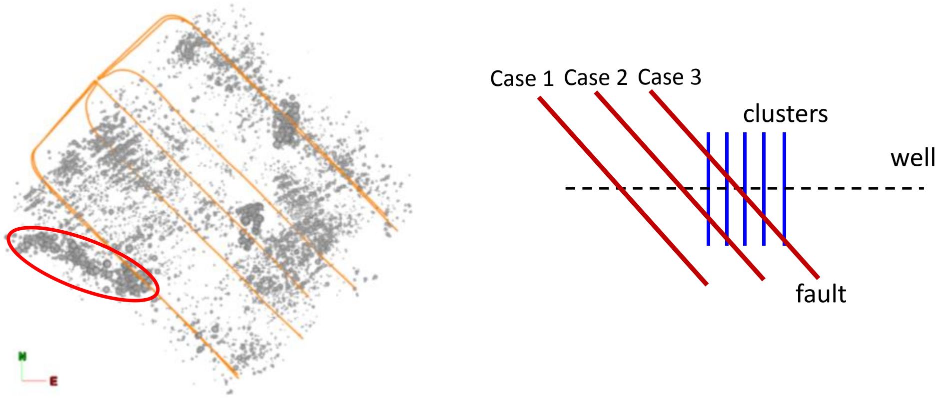
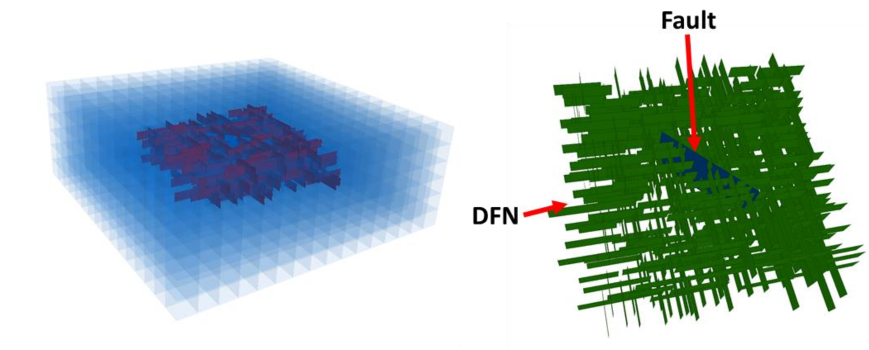


Figure 2. *Microseismic monitoring of HRB hydraulic fracture (left) showing an example of fault activation (red oval, after Snelling and de Groot, 2014). Schematic of geomechanical model (right) showing three cases of a fault crossing the well at different positions relative to five perforation clusters.*



(a) (b)

Figure 3. *a) Geomechanical model with faulted region in center. b) Fault region (blue) and DFN (green).*

Figures 4 and 5 show the pressure, fracture dilation, shearing and estimated microseismicity for the three different fault offsets. In the first case the fault does not slip. However, in the second and third the hydraulic fracture network intersects the fault, causing the fault to slip. The modelling results show that the stress changes around the fracture network are not sufficient to induce fault slip (case 1), but once the pore pressure diffuses into the fault slippage occurs (cases 2 and 3).

Figure 6 shows a frequency-magnitude plot for the three cases, indicating the larger fault activation magnitudes. In this example, the models have not been adjusted to match the microseismic monitoring, by changing the DFN density and orientation, frictional characteristics or principal stress magnitudes. However, the modelling is consistent with the elevated magnitudes along the fault in the HRB.

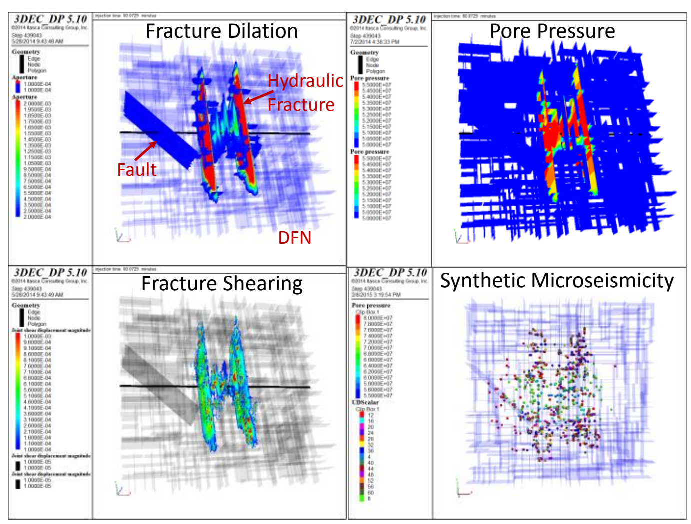


Figure 4. *Geomechanical modeling results of Case 1. Upper left: the fracture dilation or opening. Upper right: the pore pressure contours. Lower left: the shear displacements contours. Lower right: the estimated synthetic microseismicity.*

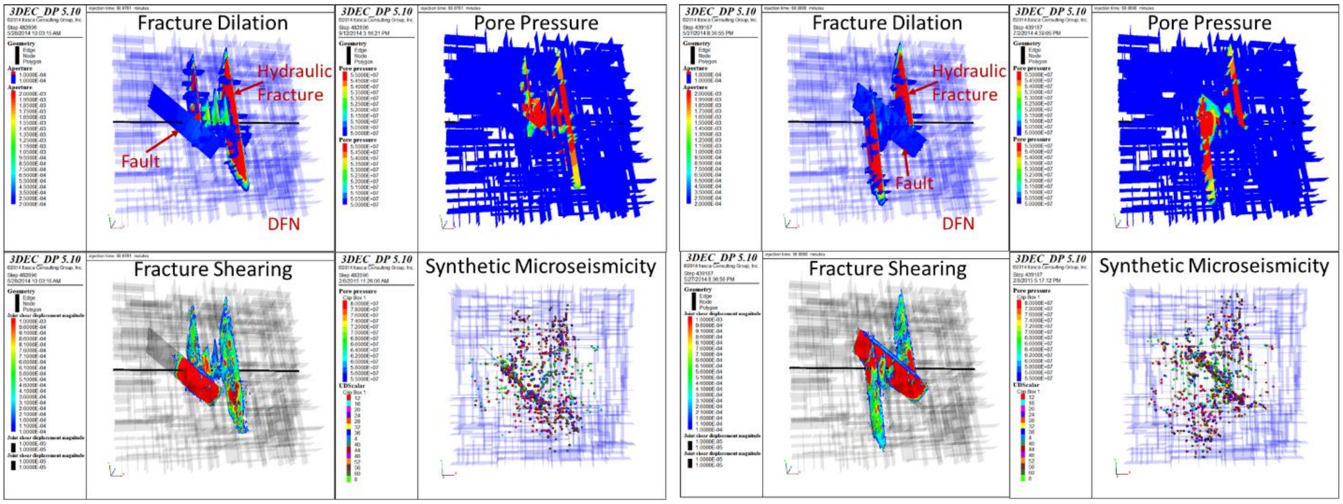


Figure 5. *Results of Case 2 (left) and 3 (right).*

Conclusions

The case study demonstrates the application of a geomechanical model to assess the interaction between a stimulated fracture network with a local fault and associated seismic magnitudes. In this case, fault activation only occurred when the hydraulic fracture network grew into the fault, and the pressure increases triggered fault slip and larger magnitude seismic events.

There are a number of ways that such a methodology could be used to design hydraulic fracturing to minimize seismic hazard prior to the operations:

1. Well placement could be selected to minimize the seismic hazard by considering different well positions in relationship to a known fault and modeling when the hydraulic fracture grows into the fault.
2. The position of hydraulic fracture stages along a well could be tested to assess skipping stages that would lead to fault activation.

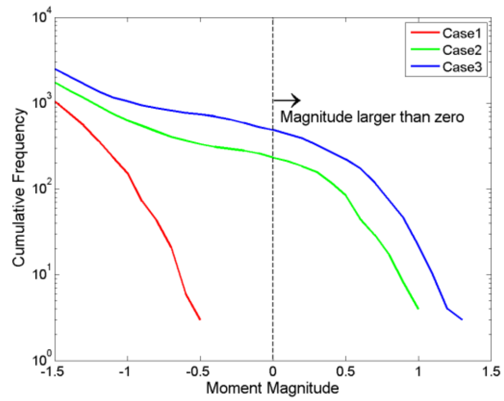


Figure 6. *Frequency-magnitude characteristics, magnitudes above 0 correspond to fault activation.*

Furthermore, the methodology could also be used to test different engineering design scenarios if induced seismicity problems are encountered during the operation:

3. Changes in injection rate or volume could be examined to mitigate the relative seismic hazard.
4. Assess stages that could potentially be skipped to lower hazard.
5. Microseismic patterns could be identified associated with different fracture networks and ranked in terms of characteristics (e.g. fracture containment or asymmetry) that tend to lead to increases in fault deformation.

Similarly, in cases of induced seismicity from fluid disposal, geomechanical investigations can be made to quantify and potentially reduce seismic hazard.

References

BCOGC, 2012, Investigation of Observed Seismicity in the Horn River Basin, BC Oil and Gas Commission Report.

Damjanac, B., and P. Cundall, 2014, Application of Distinct Element Methods to Simulation of Hydraulic Fracturing in Naturally Fractured Reservoirs, in Recent Advances in Numerical Simulation of Hydraulic Fracture 2014.

Snelling, P.E., and M. de Groot. 2014, The Effects of Faults and Fractures on Microseismic in Horn River Basin Shales, GeoConvention 2014.