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IERisk: A novel tool for induced earthquake mitigation

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Summary

Current efforts to analyze the risk of induced seismicity caused by fluid injection, and to develop mitigation strategies with a rigorous scientific basis, are hindered by a lack of numerical models incorporating the full physics of the problem. In particular, the complexity of the slip process is ignored, which neglects important details such as whether the induced slip is slow (aseismic) or dynamic rupture (seismic). Slow slip has increasingly been recognized as a major component of fault activation due to fluid injection. While slow slip has important implications for operations hazards such as wellbore deformation, it also has potential to trigger dynamic rupture in unstable regions of a fault. Such details are of vital importance for estimating the maximum expected magnitude of induced seismic events and seismic hazard assessment. We have developed a new computational toolbox to aid in producing quantitative mitigation and response plans by combining reservoir-simulation methods with advanced geomechanical and seismological computational tools. The toolbox includes modules for site-specific induced seismicity operational risk assessment, by augmenting relevant public data sources with additional site-specific information. Using case studies from western Canada, we demonstrate that the methodology shows good potential for providing realistic estimates of induced earthquake magnitudes based on operational design. This is the first tool aiming to address all areas integral to modeling and mitigating induced seismicity arising from hydraulic fracturing, and able to produce quantitative analysis of the effects of operational design. We are also developing the methodology for application to other fluid injection operations, e.g., wastewater disposal, geothermal, and gigaton-scale carbon dioxide storage.

Theory

Many natural fault systems exhibit a continuum of behavior, from dynamic rupture (conventional earthquakes) to slow (aseismic) slip (Bürgmann, 2018). Slow slip plays an important role throughout the earthquake cycle, as it releases stress aseismically in some fault regions. However, the aseismic slip can increase stress in unstable zones, leading to dynamic rupture. It is becoming increasingly apparent that such behavior is also observed on fault systems activated during fluid injection. There is a well-established link between fluid injection and induced earthquakes (Ellsworth, 2013), but recent studies have also demonstrated the link between industrial-scale fluid injection and slow slip events (Eyre et al., 2019, 2022; Pepin et al., 2022). While slow slip can release stress buildup on a fault without generating damaging radiated seismic energy, it can also play a major role in triggering induced earthquakes, whereby distal, unstable regions of a fault are progressively loaded by aseismic slip on proximal, stable regions of the fault that are stimulated by pore pressure and/or stress changes due to fluid injection (Eyre et al., 2019). In this model, the maximum expected magnitude of an earthquake is influenced by the size and proximity of the unstable fault region. A full simulation of seismic and aseismic slip is therefore necessary to account for this behavior when modelling induced seismicity to estimate maximum expected magnitudes.

Method

The software carries out site-specific pre-operational risk assessments by forecasting maximum expected seismic event magnitudes based on operational designs. This provides quantitative probabilities which can be used by decision-makers to design operations and/or mitigation strategies. Our approach incorporates realistic Earth stress models by utilizing well log and other calibration data. Fluid injection and the creation of hydraulic fractures are simulated, and subsequent stress changes on nearby faults due to pore pressure and poroelastic stresses estimated. When slip is initiated on faults due to exceedance of a defined failure criterion, both slow (aseismic) slip and dynamic rupture are simulated. The models provide probabilities for the expected maximum magnitudes of events (Figure 1) and the sensitivities of results to the different input parameters can be analyzed.

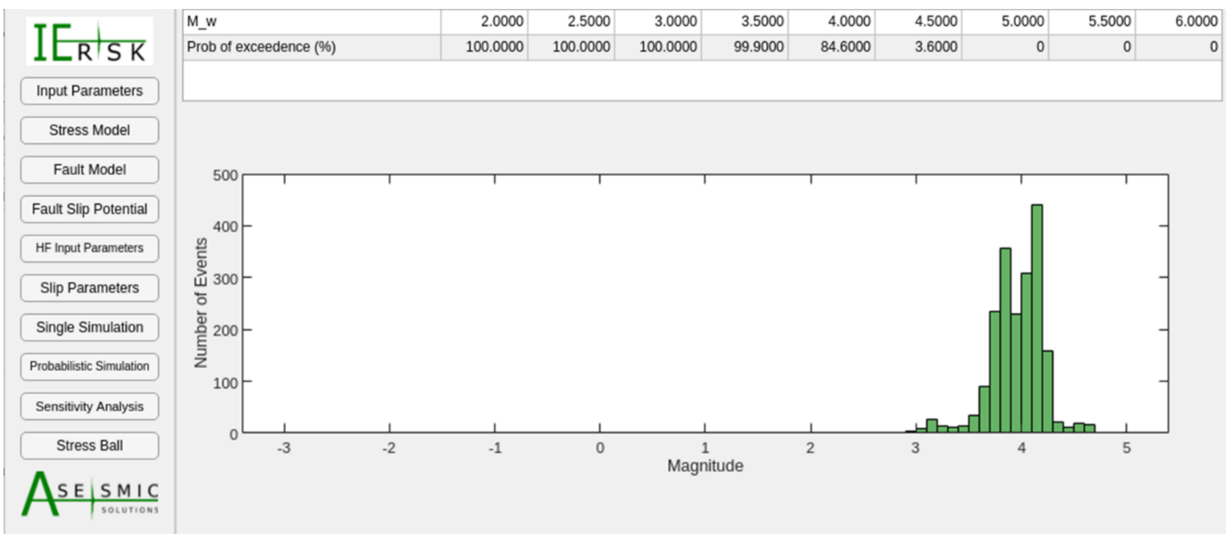

Figure 1. Example of probabilistic results showing histograms of maximum expected magnitudes for an example case study and corresponding probabilities of exceeding different magnitude thresholds.

Results, Observations, Conclusions

We have incorporated the modelling workflow into a workable graphical user interface for testing. It has been tested on various case studies from the Western Canadian Sedimentary Basin with promising results, with the median magnitude of the simulations less than 0.3 magnitude units from the observed earthquakes. Further tests will be carried out for a number of other basins worldwide. While the prototype version is working, we intend to further develop this into a user-friendly software package that can be used by industry for site-specific pre-operational risk assessments, aiding both internal decision-making and reporting to the regulators. The aim of our work is to significantly reduce the financial, environmental and social risk of induced seismicity, as well as the potential to cause damage to local populations and infrastructure.

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