Enhancement of Risk Mitigation Strategies for Induced Seismicity by Utilizing Hazard Scenarios

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Summary

Although induced seismicity is mostly small in magnitude, there have been a few moderate events that have been reported as felt on the surface. Traffic light protocols are in place for managing risks associated with induced seismicity, however these approaches are generally reactive, not proactive. Some operators go beyond regulatory mandates and develop internal protocols on the basis of ground motion hazard and potential impact of induced seismicity to further mitigate risk.

We present an example case study to demonstrate how ground motion hazard can be used to inform risk mitigation strategies for induced seismicity both before, and during the operations. To this end, an assessment was carried out to understand the seismic hazard posed by induced earthquakes generated at disposal wells on nearby oil and gas facilities. The exceedance probability of critical ground motion levels at the facilities is calculated using a probabilistic framework. The approach considered uncertainties in terms of earthquake location, size, rate and ground motions. Hazard findings are presented as distinct seismicity scenarios to enhance an operator's ability to plan risk mitigation protocols and invoke them during operations. Considering the ground motion hazard posed by future induced seismicity is a proactive approach an operator may utilize to further de-risk operations.

Methodology

Two primary seismogenic sources and scenarios were identified as either seismicity generated within close proximity to the injection zone or seismicity resulting from the activation of a nearby fault structure. Magnitude recurrence rates for both source types were characterized at each well. Historical seismicity observations after the void space has been filled from nearby injections into a similar rock formation were considered. Observations from hydraulic fracture operations are used as a proxy for seismicity related to fault activation. Maximum magnitude was determined by considering both the maximum magnitudes observed during previous operations as well as estimates of maximum activation area. In order to capture epistemic uncertainties, a weighted suite of alternative magnitude recurrence parameters and maximum magnitudes are considered through a logic tree approach (Figure 1).

An empirical ground motion prediction equation (GMPE) developed for the region of interest in a previous study is utilized to estimate maximum horizontal peak ground accelerations. Ground motion recordings from seismic stations near the target sites are used to calibrate the GMPE to local site conditions. For moderate magnitude and close distance ranges where data was sparse during the development of the original GMPE, alternative models that capture scaling with magnitude and distance in a different way were explored. These alternative expressions in the GMPE are weighted to capture the epistemic uncertainties due to differences in modeling approaches on the estimated ground motions in a logic tree framework (Figure 1).

Single site aleatory uncertainties account for between-event variability in ground motions that are not possible to capture within the model for a specific site. For each target site the single station variability is calculated by comparing ground motion recordings from a local monitoring network against the site specific GMPE.

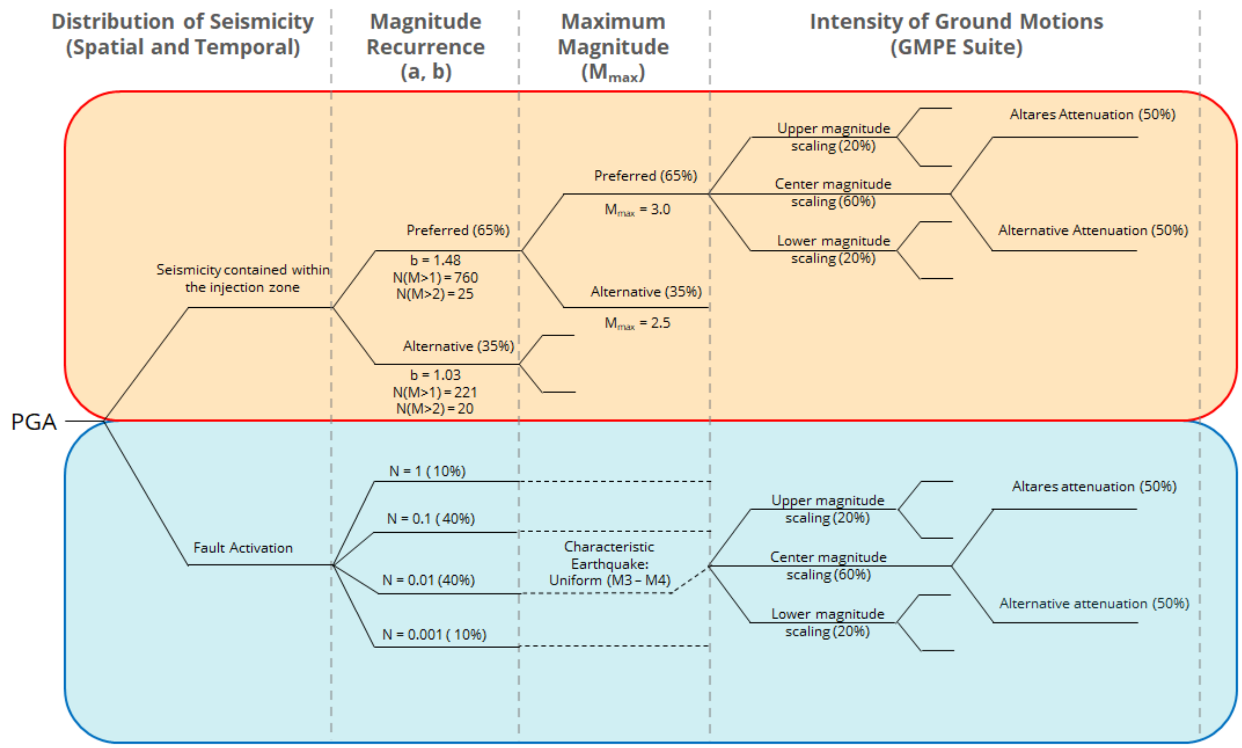

Figure 1: Logic tree capturing epistemic uncertainties in the source with alternative interpretations of the spatial distribution, magnitude recurrence, maximum magnitude, and ground motions. The upper orange box denotes the logic tree paths for alternative interpretations of seismicity contained within the injection zone where the lower blue box denotes the logic tree paths for alternative interpretations of seismicity resulting from nearby fault activation.

Results

The seismic hazard posed by the injection on the target site is determined using the EqHaz software (Assatourians and Atkinson, 2013), which utilizes a Monte Carlo simulation approach. Hazard at the target sites will result from one of two scenarios, the first is seismicity contained within the injection zone, and the second is if the nearby fault is also activated. The annual rate of peak ground acceleration exceedance (after the existing void space in injection wells is filled) is determined for each scenario and their combination to the overall hazard for one of the sites is shown in Figure 2.

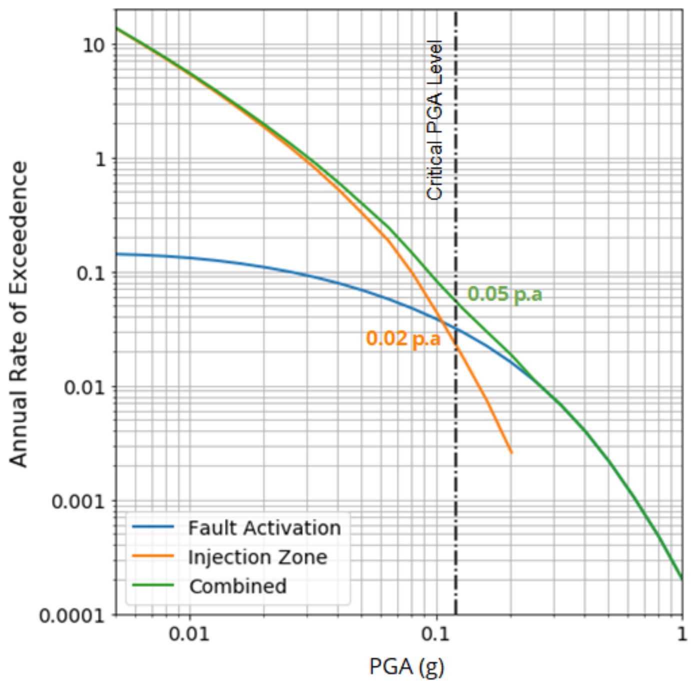

Figure 2: Annual rate of exceedance of peak ground acceleration for seismicity related to the injection zone (orange), seismicity related to fault activation (blue) and their combination (green) after the existing void space is filled.

The overall hazard estimate for a nearby facility is disaggregated into the hazard contributions from possible earthquake scenarios in Figure 3. Hazard could be between levels of 0.0012 p.a. – 0.09 p.a. depending on which maximum magnitude is likely to occur, and whether or not fault activation occurs.

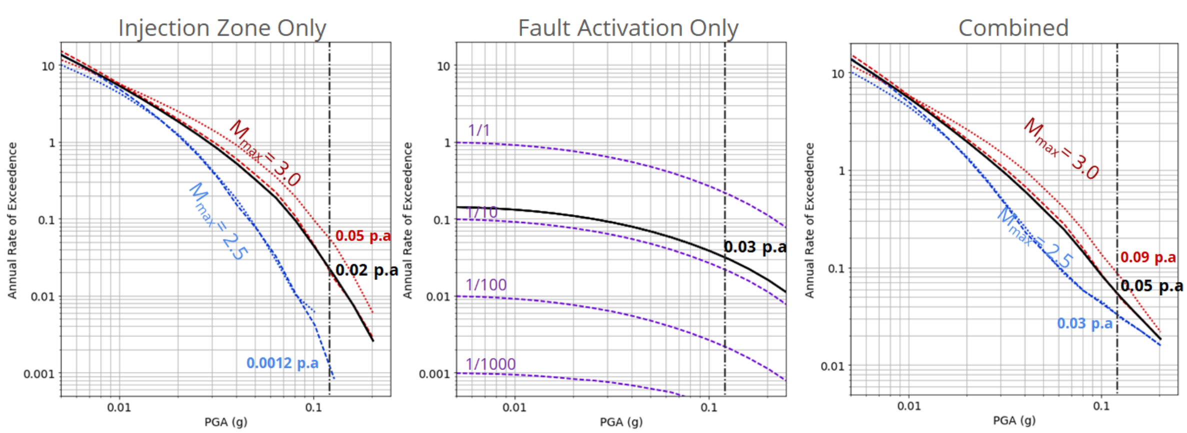

Figure 4: Disaggregated hazard scenarios. Dotted and dashed lines depict branches from alternative magnitude recurrences and the color corresponds to alternative M_{max} values.

Conclusions

Depending on the induced seismicity forecast and time evolution of seismicity characteristics (expansion of seismicity towards fault, change in seismicity rate or an increase in magnitudes), results from appropriate scenarios can be given more weight in the estimation of potential hazard during operations. Operators may consider the projected hazard level in their decision making process to invoke risk mitigation strategies if needed, taking a more proactive approach in reducing the risk of operations generating critical motions.

References

Assatourians, K., and G. M. Atkinson (2013). EqHaz: An open-source probabilistic seismic-hazard code based on the Monte Carlo simulation approach, Seismological Research Letters, 84: 516-524.