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RISK ANALYSIS AND RISK MANAGEMENT TOOLS FOR INDUCED SEISMICITY

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ABSTRACT

Decision-making regarding induced seismicity benefits greatly from quantitative risk assessment, and transparent frameworks for managing risk. This paper highlights recent work to assess these risks. Because of unique aspects of induced earthquakes, risk assessment requires new tools to estimate occurrence rates of future earthquake in a more dynamic context, to understand unique features of resulting ground motions, and to predict potential consequences at a regional scale. These tools can then support decision-making. In that regard, we present a framework that includes a site characterization component to determine the hazard in the area, followed by the utilization of exposure and risk tolerance matrices for regulators, operators, stakeholders, and the public.

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Risk analysis and risk management tools for induced seismicity

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Decision-making regarding induced seismicity benefits greatly from quantitative risk assessment, and transparent frameworks for managing risk. This paper highlights recent work to assess these risks. Because of unique aspects of induced earthquakes, risk assessment requires new tools to estimate occurrence rates of future earthquake in a more dynamic context, to understand unique features of resulting ground motions, and to predict potential consequences at a regional scale. These tools can then support decision-making. In that regard, we present a framework that includes a site characterization component to determine the hazard in the area, followed by the utilization of exposure and risk tolerance matrices for regulators, operators, stakeholders, and the public.

Introduction

Decision-making regarding induced seismicity benefits greatly from quantitative risk assessment, and transparent frameworks for managing risk. Risk assessment and hazard assessment are frequently used for natural seismicity [e.g., 1,2], and are valuable tools for induced seismicity as well [e.g., 3–6]. Induced seismicity, however, has several unique aspects that make adoption of standard hazard and risk analysis approaches non-trivial. This manuscript thus highlights several recent developments that enable improved assessment of risks from induced seismicity.

A defining feature of induced seismicity is that the long-term rate of earthquake activity is not constant, and so past earthquake rates are not necessarily indicative of future activity. Pore pressure and other stress perturbations due to anthropogenic activities can cause earthquake activity to vary dramatically over time. Thus, the estimation of future earthquake activity rates requires more than simply computing average earthquake rates over the window of available past data. Historical seismicity data can more effectively be used to estimate current earthquake rates when analyzed using a so-called change point model [7,8]. This model assumes that earthquakes occur as a Poisson process with rate λ_1, but that after some change time τ they occur as a Poisson process with a new rate λ_2. The parameters for this model are estimated from a prior distribution and a likelihood function applied to the observed data, in order to produce a Bayesian estimate of the parameters (the current rate λ_2 being the important parameter for hazard and risk

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assessment). A model selection step is also used to determine whether observational data is more consistent with a constant rate (i.e., no change in seismicity) or a change point model. Gupta and Baker [9] detail this approach, and develop and calibrate a spatial windowing rule so that it can be applied to estimate spatially and temporally varying earthquake rates.

Another important challenge for induced seismicity is prediction of ground motions from induced earthquakes. Given the limited historical seismicity in many regions experiencing induced seismicity, and uncertainty about how induced earthquakes may differ from naturally occurring earthquakes, ground motion modeling has been noted by the USGS among others as an important open question [10]. A number of researchers have developed ground motion prediction models that potentially account for potential unique aspects of induced earthquakes--primarily the typically-shallower depths, and potentially unique aspects of source and site properties [11–15]. Gupta et al. [13] observed that the ground motions from potentially induced earthquakes in Oklahoma, Texas and Kansas appeared to decay faster in amplitude with distance than natural earthquakes, at distances of less than 20 km. It also suggested that natural earthquakes elsewhere in the Central and Eastern US had somewhat larger amplitudes than the potentially induced ground motions at distances of greater than 60 km. Despite the relatively large set of ground motions from that study (46,178 recordings) constraints at large magnitudes and small distances are still relatively weak, and so numerical studies and site-specific studies are promising for advancing our understanding of these issues [e.g., 12,16].

Integration of time-varying seismicity, ground motion and vulnerability information can facilitate assessment risk in order to support decision-making [e.g., 4,6]. To illustrate, Figure 1 reports the loss level estimated to be exceeded in the state of Oklahoma with a 10% probability in a given one-year period, where the results vary in time based on the change point seismicity rate estimation approach. Ground motion prediction is performed using the model of Gupta et al. (2017), building exposure and vulnerability are from HAZUS models [17], and results were produced using OpenQuake [18]. The figure shows that for Oklahoma, risks increased from near zero prior to 2009, to substantial levels in the past few years. The figure likely indicates higher risk than has actually been present in recent years (based on comparison with actual loss observations in the state), and ongoing work is investigating the source of this issue, but the result indicates the feasibility of performing dynamic risk analysis at a regional level in the presence of induced seismicity.

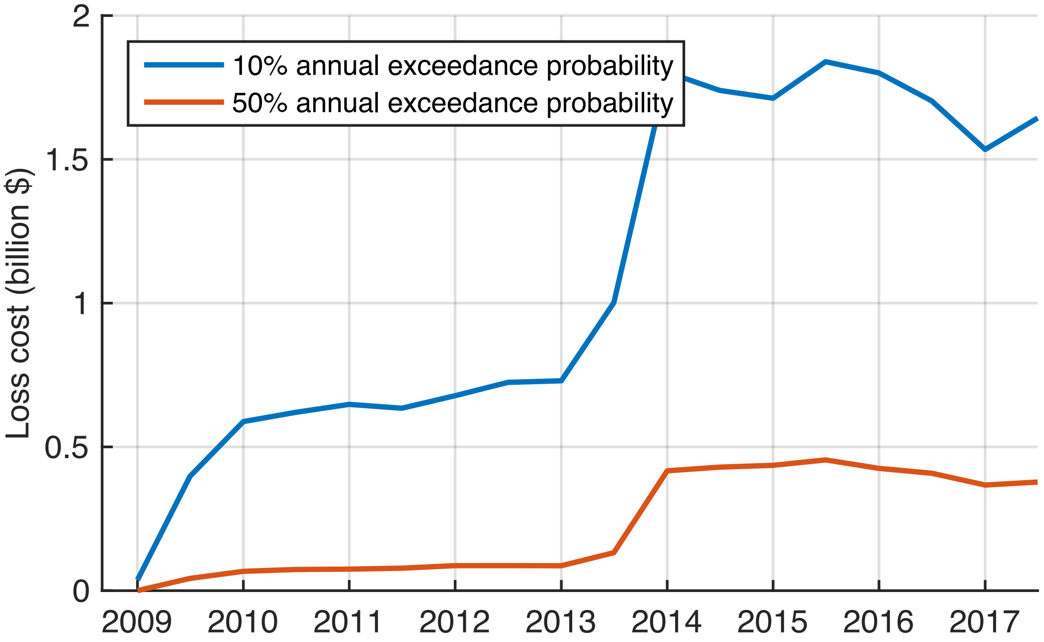

Figure 1. Time-varying risk analysis results for statewide losses in Oklahoma [19].

Conclusions

The time-varying nature of induced seismicity, and its occurrence in regions with low rates of natural seismicity, lead to challenges in assessing hazard and risk. Nonetheless, statistical approaches that account for these unique issues can be developed. Further, if the dynamic aspects of the problem are addressed using models that are automatic in incorporating new data (e.g., Bayesian models), then risk metrics can be evaluated in real time and used to support decision-making. Further opportunities with these approaches lie in incorporating other data besides observed seismicity, such as incorporating seismicity predictions based on fluid injection processes, so as to better predict the impact of actual or potential changes in fluid injection [e.g., 19,20].

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