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Seismic Hazard and Hydraulic Fracture-Induced Seismicity

Gisela Viegas, Adam Baig, and Ted Urbancic
ESG Canada Inc.

Summary

Recently, there has been a marked increase in the inter-coastal US and Canada of the observation of moderate magnitude seismicity in traditionally non-tectonic areas. The activity tends to be highly localized and for some cases, the proximity of these sequences to large volume injection wells has drawn questions as to the relationships of these events to these injections. Regulations have been proposed to implement a traffic light system to dictate the responses that the industry needs to take accounting for the feedback of the magnitudes or observed particle velocities or accelerations on the surface. In order to relate the seismic hazard potential in seismically active areas, empirical ground motion prediction equations (EGMPE) are used to relate event parameters like magnitude and location to site characteristics such as peak ground acceleration (PGA) or peak ground velocity (PGV) which tend to be how building codes are parametrized. Therefore, local hazard assessment near hydraulic fractures that generate relatively large magnitude events could be estimated more precisely by developing and using local EGMPEs.

Introduction

In order to properly characterize the magnitudes and hazard of these larger events that can be large enough to be felt on the surface, we complement typically deployed downhole monitoring using arrays of 15 Hz geophones with near-surface monitoring of low-frequency geophones and accelerometers. The goal is to achieve a monitoring configuration capable of recording frequencies down to 0.1 Hz to enable robust characterization of seismicity up to about M4. Using lower-frequency instruments provide the low-frequency response necessary for characterization, but the stations spacings in typical arrays are generally not sufficient for accurate locations, especially when combined with the lack of depth resolution at the surface. To achieve accuracy for both locations and source parameters, the low-frequency response can be used to determine magnitude and location accuracy can be determined using the 15 Hz sensors deployed downhole.

We have begun using such deployments to accurately capture the large magnitude events for hydraulic fracture monitoring across North America. In Figure 1, we document magnitude distributions observed with near-surface network recordings for completions in a number of different shale plays from across North America. The two examples from the Horn River basin are from the completions of two adjacent pads and show markedly different responses, with the first pad yielding activity up to M3 over the entirety of the completion the second completion showing a still vigorous, but more modest response up to just above M1. The difference in responses indicates how heterogeneous the subsurface conditions can be that would result in an almost 2 magnitude unit difference between the maximum event magnitudes. Completions in the Eagleford, Barnett, and Montney formations all also show a number of positive magnitude events. Based on these observations, we can suggest that hydraulic fracture stimulations can result in events with larger magnitudes than recorded with typical downhole arrays. However, for most observations, the maximum magnitudes are significantly lower than levels being contemplated for traffic light systems suggesting that hydraulic fracture related seismicity.

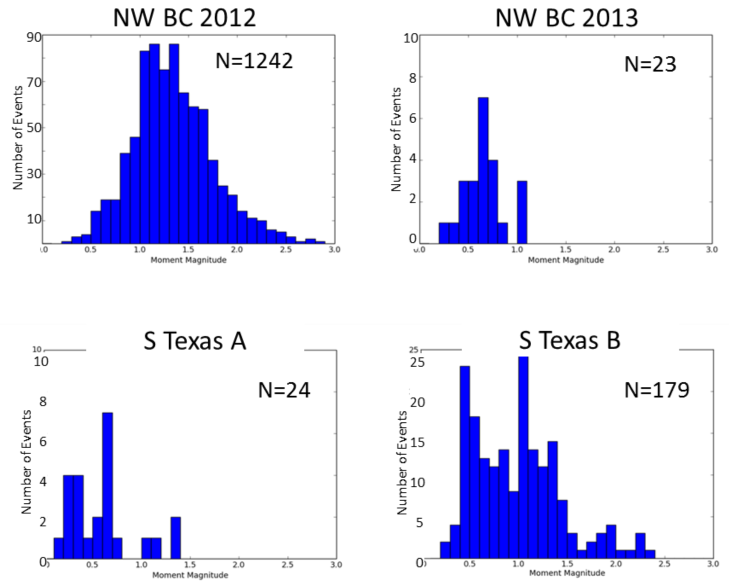

Figure 1. Magnitudes histograms of the >M0 events detected from surface monitoring of a number of different shale plays in North America.

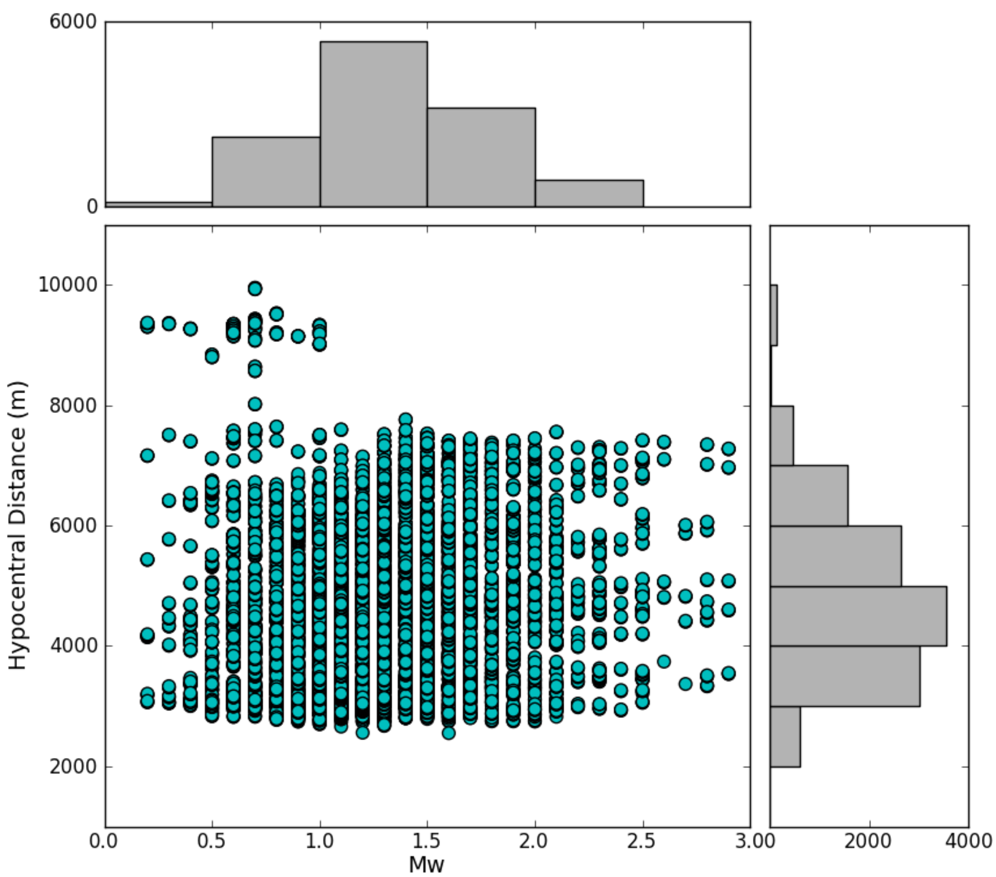

Figure 2. Moment magnitude and hypocentral distance for all records used in this study.

Application

The exact relationships between magnitudes and shaking are not necessarily one-to-one. Shaking also varies on the stress release of the events. As summarized recently by Hough (2014) for other fluid-induced seismicity, the lower stress releases typical for these sequences results in on-average less shaking than is observed for equivalent magnitude tectonic events. In order to quantify shaking over a seismogenic volume, we show how to develop EGMPEs from the Horn River Basin example. This dataset contains ~12000 records from with moment magnitude ranges from 0.2 to 2.9 and hypocentre distance from 2550 to 10000 m (figure 2). This magnitude-distance range is poorly covered by existing ground motion equations and present ones are associated with mining or enhanced geothermal systems. The rich database with homogenous moment magnitude from just hydraulic fracturing stimulation procedure is the base of the new model. The EGMPE predictions for vertical ground motion are shown in figure 3 for different magnitudes and hypocentral distances. The seismogenic depth is approximately 2.5 km in this case.

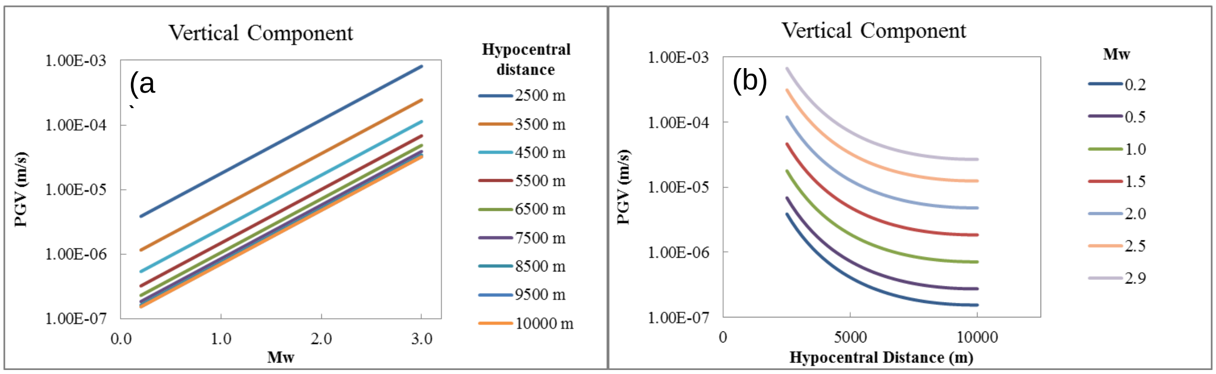

Figure 3. The vertical ground motion model plotted as a function of a) moment magnitude for hypocenteral distances of 2500 to 10000m and b) hypocenteral distance for moment magnitude of 0.2 to 2.9.

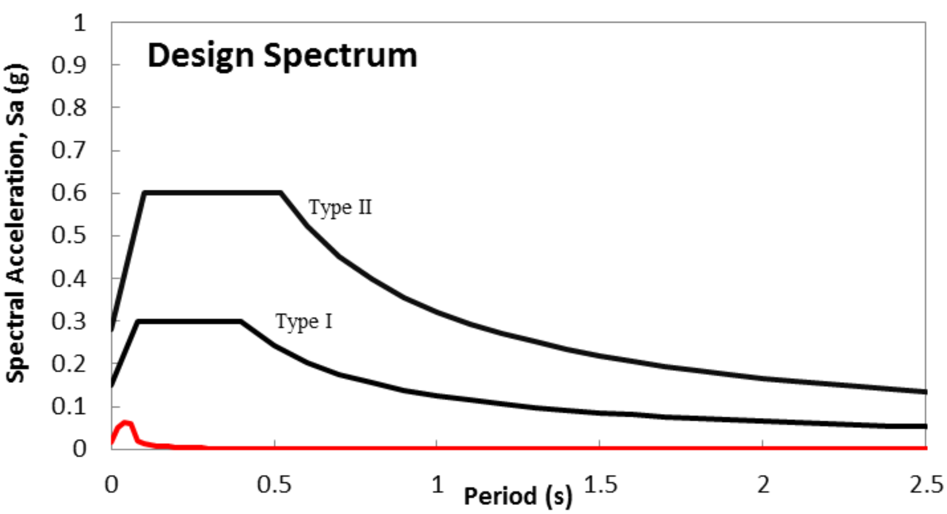

Figure 4. Red line is the response spectrum related to the Mw2.9 events in relation to the building code specifications related to the UBC-97 design spectra for difference soil and subsurface conditions.

Discussion

Proper characterization of seismic hazard requires the use of lower-frequency geophones than is typically used to monitor hydraulic fractures. However, with proper instrumentation in place, the hazard can be accurately assessed through the use of EGMPEs. In comparison to building codes, the largest events that we detect are producing ground motion well below building code thresholds such as UBC-97 suggesting that ground motion associated with the seismicity in these stimulations is likely not presenting a large degree of hazard. This is likely a combination of the factors that the maximum magnitudes are still very modest in comparison to earthquakes that are damaging and the tendency for fluid-induced seismicity to exhibit lower stress releases on average and therefore lower shaking.