Assessing Liquefaction Triggering Hazard due to Induced Seismicity

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Project Background

Induced seismicity refers to seismic activity caused by human activity. Anthropogenic sources of seismicity may include fracking, oil and gas extraction, wastewater injection, carbon capture and storage, and reservoir filling. These activities can change pore pressures and stresses in fault zones, which may lead to rupture. These ruptures release induced stresses as well as pre-existing tectonic stresses. In some cases, these activities can even reactivate faults that were previously considered dormant.

Induced seismicity, primarily associated with wastewater disposal into injection wells, has led to a significant increase in the seismicity of some areas of the Central and Eastern United States (CEUS), with especially extreme increases in areas of Oklahoma, Kansas, and Texas where oil and gas production and wastewater injection are prevalent. Figure 1 shows the cumulative count of earthquakes of magnitude 3 or greater per year in the CEUS from 1973 to 2015. Seismicity in the region was fairly constant up until about 2008, when seismic activity increased dramatically. This large increase has been attributed to wastewater injection. Although many of the earthquakes induced have been small, there have been several events of magnitude 5+ in Oklahoma in the last few years, with the largest being the M_w5.8 Pawnee, OK earthquake in 2016. Recent regulation enacted to limit wastewater injection volumes in these areas has served to lower seismicity rates, but seismicity in these areas is still much higher than natural tectonic rates. Additionally, it has been observed that the largest induced seismic events can actually occur after the causative activities have ceased.

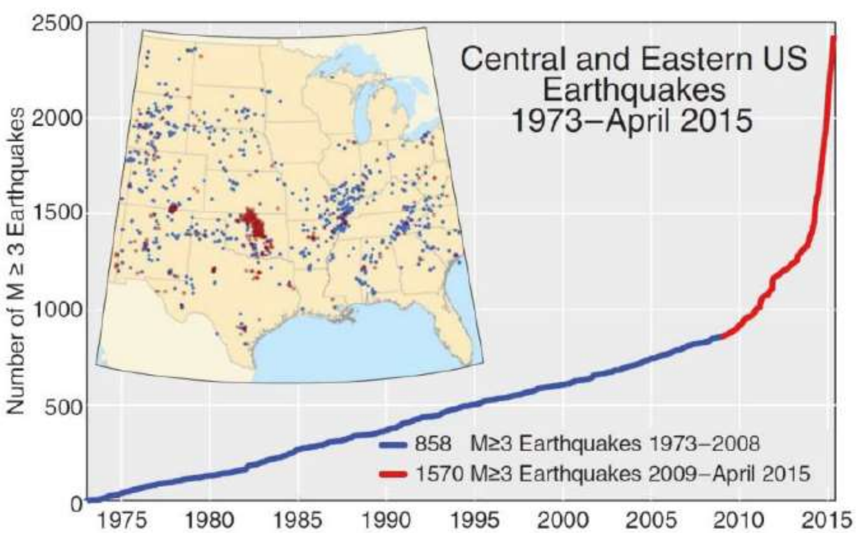

Figure 1. Cumulative Number of M ≥ 3 earthquakes in the Central and Eastern US from 1973-2015 (Rubinstein and Mahani 2015)

Despite the occurrence of several M5+ induced earthquakes, there have been few observed manifestations of liquefaction as a result of these induced events. However, evidence of liquefaction was noted at a several sites during the 2016 Pawnee Earthquake, including the sand boil shown in Figure 2. Although there have been no fatalities or major damages to infrastructure as a result of induced seismic activity, the significant increase in induced seismicity in the CEUS still poses a significant seismic risk. Of particular interest to this study, there is concern that further induced seismicity in areas more susceptible to liquefaction triggering may lead to more significant consequences. As a result, it is important to develop an accurate method for evaluating liquefaction potential due to induced seismicity.

Figure 2. Liquefaction Feature from M_w5.8 Pawnee, OK Earthquake in 2016 (Kolawole et al. 2017)

Presently available methods for estimating liquefaction potential under tectonic earthquake shaking include stress-based simplified procedures (e.g., Boulanger and Idriss 2014), energy-based procedures (e.g., Lasley et al. 2016), strain-based procedures (e.g., Dobry et al. 1982), and others. However, there are several factors that make it questionable whether methods developed for tectonic earthquakes are appropriate for use in evaluating liquefaction potential due to induced earthquakes. Current stress-based procedures are in reasonable agreement for large magnitude events (M≥6) but deviate for lower magnitude events such as those more typical of induced earthquakes. Additionally, induced earthquake motions have higher amplitudes and are richer in higher frequencies, so factors such as the stress reduction factor (r_d) and magnitude scaling factor (MSF) developed for tectonic earthquakes may not apply to induced earthquakes, even of similar magnitudes. Therefore, it is important to develop a framework for evaluating liquefaction potential specifically for induced earthquakes.

Project Objective

The object of this research is to develop and test a framework for assessing liquefaction potential due to ground motions generated by induced earthquakes.

Research Plan

The research plan tasks and progress (*in italics*) to date are:

1. Characterize sites that experienced significant shaking during induced earthquakes. *Both liquefaction and no-liquefaction sites from the 2016 M_w5.8 Pawnee Earthquake have been identified. These sites will be tested in March 2019. Testing will include cone penetration tests (CPT) and multichannel analysis of surface waves (MASW) tests.*
2. Develop a framework for liquefaction evaluation. *New r_d and MSF relationships are being developed based on site response analyses conducted using induced earthquake ground motions and representative regional soil profiles. Site response analyses are currently underway using a catalog of induced ground motions provided by UT Austin and representative regional soil profiles from Oklahoma.*
3. Test the new framework. The new evaluation framework will be used to assess liquefaction susceptibility at the test sites. The predictions will be compared to field observations to evaluate the new evaluation framework.