Potential Injection-Induced Seismicity Associated With Oil & Gas Development

A primer on technical & regulatory considerations informing risk management & mitigation

Induced Seismicity Work Group
Sept. 28, 2015
Induced Seismicity in the News

**The New York Times**

*U.S.*

*Oklahoma Acts to Limit Earthquake Risk at Oil and Gas Wells*

**The Wichita Eagle**

Kansas oil drilling rules credited with limiting quakes set to expire (+video)

**TIME**

*Geologists: Fracking Likely Cause of Ohio Earthquakes*

**NewsOK**

*Record 5.6 magnitude earthquake shakes Oklahoma*

The Saturday night earthquake had a magnitude of 5.6, and its epicenter was four miles east of Sparks in Lincoln County, according to the Oklahoma Geological Survey. The quake hit at 10:53 p.m., and it was reportedly felt as far away as Illinois, Kansas, Arkansas, Tennessee and Texas.

**The Washington Post**

*Study links fracking to dozens of small Ohio earthquakes*
Agenda

- ISWG Background
  - Rick Simmers, Chief, Ohio Department of Natural Resources (ISWG Co-chair)

- Primer Overview
  - Understanding induced seismicity
    - Rex Buchanan, Interim Director, Kansas Geological Survey (ISWG Co-chair)
  - Assessing induced seismicity
    - Ivan Wong, Principal Seismologist, AECOM
  - Risk management & mitigation
    - Leslie Savage, Asst. Dir. Tech. Permitting, O&G Div., Railroad Com. of Texas
  - External engagement & communication
    - Rex Buchanan, Interim Director, Kansas Geological Survey (ISWG Co-chair)

- Acknowledgements
  - Rick Simmers, Chief, Ohio Department of Natural Resources (ISWG Co-chair)
Introduction

- StatesFirst: Collaborative partnership between the Ground Water Protection Council and the Interstate Oil & Gas Compact Commission
- StatesFirst *Induced Seismicity Work Group* (“ISWG”) chartered in 2014 and led by States
- The ISWG is focused on addressing public concerns associated with induced seismicity
- Work Group deliverable: a “Primer” document to summarize and share knowledge
StatesFirst Induced Seismicity Work Group

- ISWG Co-Chairs
  - Rick Simmers, Chief, Ohio Department of Natural Resources
  - Rex Buchanan, Interim Director, Kansas Geological Survey

- ISWG is comprised of representatives from state agencies
  - 24 volunteers from AK, AR, CA, CO, OH, OK, IL, IN, KS, TX, UT, WV, & WY

- ISWG supported by technical advisors (subject matter experts)
  - Over 60+ volunteers - academia, research entities, federal agencies, industry, consultants, and NGOs

- ISWG Primer developed via broad stakeholder engagement
- ISWG Primer vetted with Independent Technical Review Panel
ISWG Objectives

- Share science, research, technical understanding and experience
- Provide forum for stakeholder discussion and communication
- Identify potential approaches and decision making tools to manage and mitigate risks
- Develop a “Primer” document that summarizes current knowledge and potential approaches for managing / mitigating risk and responding to anomalous seismicity
Primer Overview

- Primary emphasis on potential induced seismicity associated with Class II disposal wells
- Document is solely informational and is not intended to offer recommended rules or regulations
Primer Content

- 4 Chapters
  - Understanding induced seismicity
  - Assessing potentially induced seismicity
  - Risk management & mitigation strategies
  - External engagement & communication

- 9 Technical Appendices
  - Relevant earthquake science
  - Class II injection wells
  - Induced seismicity case studies
  - Design & installation of seismic monitoring networks
  - NRC Report on induced seismicity potential in energy technologies
  - Methods for estimating reservoir pressures changes associated with injection
  - Tools for risk management and mitigation
  - Data collection & interpretation
  - Considerations for hydraulic fracturing
Primer Chapter 1

Understanding Induced Seismicity

Rex Buchanan, Interim Director, Kansas Geological Survey
Focused on:

- Magnitude and depth of induced earthquakes
- Hazard and risk of induced seismicity
- Ground motion models for induced seismicity
- USGS hazard maps
- Estimated number of induced seismicity locations
- How fluid injection may induce seismic events
- Potential for seismicity related to hydraulic fracturing
- Future research opportunities
Key Observations - Frequency of Earthquakes in Central USA

Cumulative earthquake count for events $M \geq 3$ in central and eastern U.S. showing a notable increase in the rate of seismicity since 2001, with a significant increase since 2009 (figure from Ellsworth, 2013)
Key Observations

- Majority of earthquakes tectonic but seismicity can be triggered by human activities
  - Induced seismic activity has been documented since at least the 1920s underground injection, oil and gas extraction, impoundment of reservoirs behind dams, geothermal projects, mining extraction, construction, underground nuclear tests, and carbon capture and storage projects

- Most cases of felt injection-induced activity have been attributed to:
  - Direct injection into basement rocks
  - Injection into overlying formations with permeable avenues of communication with basement rocks
Key Observations - Faults of Concern

- The majority of faults are stable and will not produce a significant earthquake

- “Faults of Concern” are characterized by:
  - A fault optimally oriented for movement
  - At or near critical stress
  - Sufficient size and accumulated stress/strain, such that fault slip has the potential to cause a significant earthquake.

- Identifying Faults of Concern is challenging and generally they are not effectively mapped in the United States
Key Observations - Earthquake Magnitude

- Induced earthquakes are typically smaller size with less energy than tectonic earthquakes.
- Largest potentially injection-induced earthquakes almost always occur in Precambrian rock.
- Induced seismicity seems to be usually confined to shallow part of earth’s crust in vicinity of injection.
- Ground shaking levels are characterized by Modified Mercalli Intensity scale and “PGA / PGV”.

*Example only: Establish based upon local conditions, demographics and codes

Source: AXPC SME 2013/2014
Key Observations - Hazard & Risk

- The primary hazard is associated with ground shaking
- Modern engineered structure damage generally occurs in earthquakes larger than M 5
- Non-structural damage reported in earthquakes as small as ~M 3 in rare cases
- Injection induced earthquakes are typically smaller than ~M 5
- Currently, there is no generalized U.S. empirical ground motion model for injection-induced earthquakes because data from injection-induced earthquakes are currently quite limited
Key Observations - Hydraulic Fracturing

- Felt-level seismicity occur infrequently with hydraulic fracturing.
- Typically have low magnitudes.
- Process of hydraulic fracturing significantly different than disposal well operations, resulting in lower risk.

Figure I.1. Histogram of maximum magnitude microearthquake detected in six major unconventional reservoirs (Warpinski 2013).
Some Key Questions & Research Needs

- What new methods and techniques can be used to better identify the presence of critically stressed faults in proximity to injection sites?
- Can the maximum magnitude of induced earthquake be estimated?
- Are ground motions of injection-induced earthquakes different from natural earthquakes?
- If intensity is a measure that the induced seismicity community wants to continue to use, how is it related to other ground motion parameters? Is the relationship site-specific?
Primer Chapter 2
Assessing Potentially Induced Seismicity

Ivan Wong, Principal Seismologist, AECOM
Focused on:

- Evaluating General Patterns of Seismicity
- Detection and Location
- Seismic Monitoring by States
- Evaluating Causation of Specific Seismic Events
- Methods Used in Causation Studies
- Further Analysis to Evaluate Causation
Key Observations - Evaluating Seismicity

- Three components necessary forfelt injection-induced seismicity:
  - Sufficient pore pressure buildup from disposal activities
  - Faults of concern
  - A pathway allowing increased pressure to communicate with fault

- State considerations:
  - Evaluate general patterns of seismicity to reveal areas of concern
  - Perform an investigation to evaluate possible causal factors of specific events; recognizing a detailed seismological and subsurface characterization and modeling effort may be needed.
Key Observations - Evaluating Seismicity

- Characterize the anomalous seismic activity
  - Spike in number and sizes of earthquakes
  - Occurrence of earthquakes in areas that historically have not experienced seismic activity
- Historic seismicity can be obtained from:
  - Instrumental records: National, regional and local seismic networks
  - Non-instrumental records - Academic reports, historical summaries, newspaper archives (more qualitative)
Key Observations - Monitoring Considerations

Seismic Station in Northern California
Image Credit: USGS

- Public Safety
- Managing & Mitigating Risk
- Public & Stakeholder Response & Education
- Permanent Networks
- Temporary Networks
Key Observations - Monitoring Accuracy

- Earthquake locations initially reported by the national USGS network can have substantial uncertainty across most parts of the USA
  - epicentral uncertainty ~5-10 km
  - depth uncertainty ~10 km
- Some states have augmented seismic monitoring with improved accuracy

### Table 2 Performance targets for the ANSS for different areas. Adapted from Advanced National Seismic Systems Performance Standards Version 2.8

<table>
<thead>
<tr>
<th>Metric</th>
<th>Units</th>
<th>Hi-Risk Urban Areas</th>
<th>Mod-High Hazard Areas</th>
<th>National</th>
<th>Global</th>
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<td>Depth Uncertainty</td>
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<td>10</td>
<td>10</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 2 Performance targets for the ANSS for different areas. Adapted from Advanced National Seismic Systems Performance Standards Version 2.8
Key Observations - Evaluating Cause

- Difficult to clearly differentiate between induced and tectonic earthquakes using seismological methods
- Investigations & research studies may consider:
  - Accurately locating seismic events
  - Locating critically stressed faults that may have been reactivated
  - Identifying temporal and spatial evolution of seismic events and fault segment slip
  - Characterizing subsurface stresses near or on fault
  - Developing a physical reservoir / geomechanics engineering model predicting whether induced pressure change could initiate earthquake
Primer Chapter 3

Risk Management and Mitigation Strategies

Leslie Savage, Assistant Director for Technical Permitting
Oil and Gas Division
Railroad Commission of Texas
Focused on:

- Risk and Hazard
- Science-Based Risk Management
- Mitigation and Response Strategies
Key Observations

- States have developed diverse strategies for avoiding, mitigating and responding to risks of induced seismicity in siting, permitting & monitoring of Class II injection wells

- “One-Size Fits All” regulatory approach not appropriate
  - Differences in geology across US
  - Varying conditions across states
Key Observations - Science Based Risk Management

- **Hazard**: Any source of potential damage, harm or adverse impact on something or someone
- **Risk**: The chance or probability that a person or property will be harmed if exposed to a hazard
- Risk assessment addresses 2 distinct questions:
  - How likely is an injection operation to pose an induced seismicity hazard?
  - What is the risk - the probability of harm to people or property?
Key Observations - Risk Mitigation

- Risk mitigation options in siting and permitting new Class II disposal wells may include:
  - Avoiding injection into crystalline basement
  - Avoiding direct injection into known faults of concern
  - Locating faults in vicinity of proposed project area; place well outside “at-risk” area

- Considerations attached to permits may include:
  - Temporary seismic monitoring at sites
  - Procedure to monitor operations if ground motion event occurs
  - Procedure to suspend operations if seismicity levels increase above threshold
  - Metric to determine if operations could be re-started

- States may determine different response strategies “fit for purpose”
Primer Chapter 4

Considerations for External Communication and Engagement

Rex Buchanan, Interim Director, Kansas Geological Survey
Focused on:

- Communications planning process
- Communications plan elements
- Responding to an event
Key Considerations

- Clear and direct communication with public important responsibility of states
- Many states choose proactive approach
- Earthquakes arrive without warning and are unpredictable
- Most of US has no public training on what to expect from earthquakes
- Public anxiety
- Determining cause is very difficult in most instances, and studies take time
Key Considerations: Communicating & Response

Communications Planning
- Involve stakeholders with multiple areas of expertise
- Tie communication strategies to risk management thresholds and local situation
- Conduct training

Responding to an event
- Be professional and objective
- Review all information
- Avoid speculation
- Identify & engage all stakeholders
- Provide information and updates on a timely and frequent basis
In Conclusion

- Induced seismicity is a very complex issue where the base of knowledge is changing rapidly.

- State regulatory agencies that deal with potential injection induced seismicity should be prepared to use tools, knowledge, and expertise, many of which are offered in this document, to prepare for and respond to occurrences of induced seismicity.

- Risk management, risk mitigation, and response strategies are most effective when developed considering specific local conditions and situations.
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