Challenges and Strategies for Monitoring Induced Seismic Activity

Designing and operating induced seismic monitoring networks to meet regulations

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Introduction

- Induced seismicity a well-known phenomenon
- Felt events are rare
- Following increased public awareness a number of regulations and protocols have been put in place to mitigate risk associated with induced seismicity
- Regulations to date have the following common points:
  - Characterize the risk of induced seismicity ahead of time
  - **Establish local seismic monitoring**
  - Develop a mitigation plan (modify operations)

Some of the induced seismic monitoring network challenges:

<table>
<thead>
<tr>
<th>Network design</th>
<th>How many stations are required to meet magnitude or location accuracy requirements at minimum cost?</th>
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<tbody>
<tr>
<td>Monitoring protocol robustness</td>
<td>When does a monitoring network not meet its mandate?</td>
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<td>Magnitude type</td>
<td>What is the best magnitude scale to use in magnitude based traffic light protocols?</td>
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<tr>
<td>Instrumentation</td>
<td>Which instrument types have the most suitable dynamic range and response?</td>
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Example Regulations – Key Points

Alberta Energy Regulator – Subsurface Order # 2
- Continuous monitoring – 24/7 traffic light system
- Magnitude scale: Local (Richter) ML
- Yellow light: M2.0, Red light <4.0, Mc <M2.0
- Location uncertainty: better than 5 km
- Defines specific monitoring region
- AER has a 10-station backbone monitoring network

Ohio Department of Natural Resources
- Applies to wells within 3 miles of a known fault or area of seismic activity with M>2.0
- Continuous monitoring – 24/7 system
- Stop operations if >M1.0 detected and investigate
- Location uncertainty: unspecified
- Backbone network in place – Ohio Seismic Network

How do we ensure seismic monitoring network will meet the criteria set out by the regulator?
Network Performance Modeling

- Example modeling results required to monitor 116 km by 170 km Duvernay region
  - 25 stations
  - Average $Mc$ of ~1.8
  - Epicentral location uncertainty ~1.5 km
  - Average station spacing ~ 30 km
- Idealized first pass station distribution diagrams:
Magnitude Scales

**Local (Richter) Magnitude Scale**

- Based on the maximum measured amplitude scaled with distance
- Easy to compute
- Seismology standard
- Requires regional distance correction factors
- Site amplification can have significant effect

**Moment Magnitude Scale**

- Based on the scalar moment and related to the physical properties of the earthquake:
  - Computationally more expensive
  - Microseismic monitoring standard
  - Several computation methods
  - Can account for radiation pattern

<table>
<thead>
<tr>
<th>Earthquake (time)</th>
<th>NRCan $M_L$</th>
<th>USGS NEIC $mb$</th>
<th>Spectral Fitting $M_W$</th>
<th>PGC RMT $M_W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>23/01/2015 06:49:19</td>
<td>4.4</td>
<td>3.9</td>
<td>3.8</td>
<td>3.7</td>
</tr>
</tbody>
</table>

*Compute ALL $>M3.0$ red light threshold event magnitudes using RMT method*
**Instrumentation**

- **Induced seismicity**
  - Epicentral distances ~2-30 km
  - Magnitude range ~ 0 to 4.5
  - Frequency range of interest ~ 1 to 30 Hz

- **Seismometers** have the right instrument response, clip level and noise floor to do the job

- More cost effective with fewer number of stations required

- Broadband 3-ch instruments enable Mw from RMTs

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![Graphs showing seismic data and instrument responses.](image)
Monitoring Protocol Robustness

When does the network not meet its operating mandate?
Does the monitoring protocol account for station data outages?

- Example network - Brazeau Dam, Alberta
- Brazeau network meets monitoring mandate with ~ 1 station down
- Model impact of each station on network performance
- Include redundancy in network design
- Incorporate pre-defined data outage alerts into the protocol
Example Data Set

- 12-station induced seismic monitoring network
- 180 earthquakes recorded during and one week after the hydraulic fracture stimulation
- Magnitude range -0.9 to 1.3
- Three main clusters:
  - Two deeper clusters consistent with mapped faults
  - Third cluster within expected stimulated volume
- Multiple coupling mechanisms associated with different clusters (stress field changes vs. injection fluid)
Applications of Induced Seismic Data Sets

• Identify (delineate) new fault structures
• Refine maps of existing fault structures
• Perform local stress field inversion and estimate SHmax direction
• Get a better understanding of the fracture mechanics during hydraulic fracturing
• Assist in evaluating completions efficiency – investigate fluid pathways

• Establish empirical local/regional attenuation relationships and site amplification maps
• Drive more accurate ground motion predictions (shake maps) and enable structural monitoring alerts – seismic hazard maps
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<tr>
<td>Meet monitoring criteria out of the gate</td>
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<td>Report the most robust magnitude scale</td>
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<td>Select appropriate instrumentation for the job</td>
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<td>Important to build robust monitoring protocols</td>
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<td>Potential to use data to manage operations, monitor infrastructure and map fault structures in addition to risk management</td>
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Thank You

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