Review of Management of Induced Seismicity

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October 26th, 2018
Establishing the Context:
What are the potential outcomes (negative or positive) of the induced seismicity?
- safety to people and infrastructure, groundwater impacts, social perception/security, economic realities. What can be tolerated by induced earthquakes? Where? Why?

Risk Identification
Where is induced seismicity occurring?
What are the interaction that could lead to induced seismicity? Geologic condition or operations behavior.
What are the best predictors of induced seismicity?

Risk Analysis
If an geological association, then;
What is the regional distribution of susceptibility?
If an operational association, then;
What parameter is most associated with triggered events?
How should this be mitigated?

Risk Evaluation
Evaluation of risk with using a heat map, common risk framework, bounded by acceptable risk.

Risk Treatment
Decisions: develop regional strategies for management with allowances/thresholds/avoidance areas
Compliance: monitoring and improved reporting
Policy for long term planning.
Risk Treatment

Process to modify risk. Can involve avoiding the risk, taking or increasing the risk in order to pursue an opportunity; removing the risk source, changing the likelihood; changing the consequences, sharing the risk with another party or parties, and retaining the risk by informed decision.
Risk Treatment

Reactive
- Suspend Operations
- Modify Operations
- Normal Operations

Proactive

Forecast

AGS
Reactive Risk Treatment

» Risk treatments that allow for non-damaging induced seismic events to occur with a threshold based zone of enforcement

» React to these with mitigation that allows the reduce the risk.
Typical Traffic Light Protocol

- Seismic Monitoring
  - Subsurface Data
  - Geomechanical Data
  - Ground Motion

- Real-Time Data

- Reaction Plan

- Mitigation

Fluid Injection

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Subsurface Order #2, Traffic Light Protocol for Induced Seismicity

- Issued February 19, 2015
- Applies to hydraulic fracturing operations in Duvernay Zone in Fox Creek area
- Requires an assessment of induced seismicity, a plan to respond to induced seismicity, and seismic monitoring
- Uses a Traffic Light Protocol for response to seismic events
AER's Subsurface Order No. 2

Operators are required to...

- Establish a response plan should seismicity be recorded within 5 km radius of well.

Pre-assessment of potential for seismicity:

- If ≥ 4.0 M, report to AER and initiate response plan to reduce further seismicity.
- If ≥ 2.0 M, report to AER.
- If < 2.0 M, no action required.

AER Acceptance Decision:

- Revise Plan
- Resume

Report to AER and provide resumption of operation plan.

Cease operations report to AER.

Resume

Revise Plan

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HF Operations near Fox Creek

After Schultz et al., 2018
Operators are required to...

- Install at least one ground motion monitor per common well pad
- Submit a ground motion monitoring report within 30 days of completion

Ground motion monitors must be:

- Within 3 km of the well pad
- Dynamic range: ±2 g
- Detectability: 0.02 g
Risk Treatment

Reactive
- Suspend Operations
- Modify Operations
- Normal Operations

Proactive

Forecast
Proactive Risk Treatment

- Risk treatments prevent risky activity through avoidance.
- This includes mitigation of operational behavior, avoidance of susceptible areas, and/or setbacks.
What options are there for managing the risk for induced seismicity?

Avoidance
- Geological susceptibility- effective stress, structures
- Infrastructure-measured ground motion, distance activity, PSHA, Shake Maps

Moratorium
- Activity driven- disposal, conventional extraction, HF
- Depth driven- prevent all operations near formations that are known to cause IS
- Location driven- near susceptible areas, such as faults, zone where induced seismicity is more likely
Induced Seismicity Near Critical Infrastructure

Area of restricted oil and gas development

- Resources under application
- Well
- Site-specific mitigation strategy, traffic light, etc.

Radius of TLP w/ modifications

Radius of monitoring and reporting

Critical Infrastructure
Seismic Susceptibility

Are there other underlying geological factors which we can correlate to induced seismicity?
Geological Predictors

- Faults/Reef Edges
- Formations of Interest, including influence of temp and pressure (present/not present)
- Dolomite occurrence
- Li and Sr concentrations (indication of basement involvement)
- Pressure and Stress data
- Natural earthquake occurrence
- Basement structure

Duvernay Formation
Geological features may be used to infer areas with faults that could be prone to reactivation; seismic events near Fox Creek and central Alberta follow a trend along an ancient fossil reef (Schultz et al., 2016)
Susceptibility Modeling
Risk Treatment

**Reactive**
- Suspend Operations
- Modify Operations
- Normal Operations

**Proactive**

**Forecast**
Forecasted Risk Treatment

» Risk treatments that forecast the risk in order to mitigate it.

» This is a combination of a reactive and proactive treatment, which allows for activity in high risk areas and reacts to change in risk in order to avoid any damaging induced seismicity.
Adaptive Traffic Light Protocol

Seismic Monitoring

Subsurface Data

Fault Proxy Indicators

Pore pressure

Real-Time Data

Operation Data

Geomechanical Data

Velocity Model

Stress Data

Building inventory vulnerability estimates

Seismic Susceptibility Models

Ground Motion Prediction Equation

Vs30 Database

Seismic Susceptibility Models

Synthetic Seismic Catalogue

PSHA Calculator

Risk Calculator

Scenario Calculator

Weighting process based on system performance

Real-Time Performance Assessment

Reaction Plan

Mitigation
## Risk Management Approach to Induced Seismicity

### Establishing the Context:
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### Risk Treatment
- Decisions: develop regional strategies for management with allowances/thresholds/avoidance areas
- Compliance: monitoring and improved reporting
- Policy for long term planning.
Adaptive Traffic Light Protocol

Establish the Context
Identify the Hazard

Seismic Monitoring
Real-Time Data
Operation Data

Subsurface Data
Geomechanical Data

Faults Indicators
Velocity Model
Stress Data

Pore pressure
Building inventory vulnerability estimates

Seismic Susceptibility Models
Ground Motion Prediction Equation
Vs30 Database

Real-Time Performance Assessment

Synthetic Seismic Catalogue
PSHA Calculator
Risk Calculator
Scenario Calculator

Weighting process based on system performance

Risk Analysis and Risk Evaluation

Risk Treatment

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Thank you