Predicting and Mitigating Induced Seismicity in Oil and Gas Operations in Alberta and British Columbia

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Abstract:

Energy regulators in Alberta and British Columbia can respond to the increase in hydraulic fracturing induced seismicity events, and concerns about environmental and safety impacts, by expanding their induced seismicity regulations. In this paper we demonstrate that identifiable characteristics such as background seismicity, local geology, stress state, injection practices, and proximity to populated areas can be assessed prior to the start of hydraulic fracturing operations to improve induced seismicity risk assessments. We recommend that the AER and the BCOGC establish minimum criteria, including these characteristics, to be assessed by an operator in their induced seismicity risk assessment plans to ensure that a minimum level of assessment is reached. Events of induced seismicity that occur near populated areas or critical infrastructure will have the largest impact in terms of safety and property damage risks as well as damage to the perceived safety of hydraulic fracturing. We therefore propose that the AER and the BCOGC expand their induced seismicity regulations to include hydraulic fracturing operations within 5 km of a populated area or critical infrastructure to reduce the risk of a seismic event in these high impact areas. Finally, we recommend that the AER and the BCOGC implement policies intended to reduce the size (in terms of volume) of hydraulic fracturing operations as a measure to mitigate induced seismicity.

1.0 Introduction

Earthquakes are caused by the release of built up stress and energy along a geological fault. These releases – if large enough in size – can cause damage to property and pose safety risks. Hydraulic fracturing and waste water disposal, which both involve the injection of fluids into the ground, have been demonstrated to induce these seismic releases during oil and gas activities in Canada (BCOGC, 2012; BCOGC, 2014). The Alberta Energy Regulator (AER) and the British Columbia Oil and Gas Commission (BCOGC), each responsible for regulating the energy industry in their respective province, can manage the risks of induced seismicity by implementing seismic hazard evaluation and mitigation planning requirements for operators prior to operations.

We explore the state of literature to identify what regulatory improvements the AER and the BCOGC can make to reduce the incidence and risks of induced seismicity from hydraulic fracturing operations. We show that seismic hazard can be characterized using key criteria identified by Davis and Frohlich (1993) including: background seismicity, local geology, state of stress, and injection practices. These criteria can be supplemented by geo-mechanical modelling where a seismic risk is identified. We propose that the proximity of the hydraulic fracturing operation to population centres and critical infrastructure like dams and sour-gas pipelines be considered as an additional risk identification criterion, and that regulators in Alberta and British Columbia expand their induced seismicity regulations to include hydraulic fracturing operations near populated areas and critical infrastructure. Additionally, we recommend that the AER and the BCOGC direct operators to reduce the volume of fluid injected during hydraulic fracturing operations as much as possible as a mitigation strategy based on the finding of Schultz et. al (2018) that reduced injection volumes will reduce the risk (and severity) of seismic activity.

2.0 Background of Induced Seismicity in Alberta and British Columbia

Seismic events are measured from 0-10 on the Richter scale. Most events of induced seismicity caused by hydraulic fracturing operations are magnitude 4 or below, however, the largest recorded event of induced seismicity caused by fluid injection measured at a magnitude of 5.8, which is powerful enough to be felt by people at surface and damage structures (Foulger, 2018, Encyclopedia Britannica, 2018). Numerous groups in British Columbia, including representatives of Treaty 8 First Nations, industry operators, and environmental organizations have expressed concern with the potential environmental and health impacts associated with induced seismicity (Scientific Hydraulic Fracturing Review Panel, 2019).

With the increase in hydraulic fracturing operations in Canada there has been an increase in induced seismicity events (BCOGC 2012, BCOGC 2014, AER 20). The BCOGC has identified over 250 events of induced seismicity over a period of 4 years, over 75% of which they found to be caused by hydraulic fracturing operations (BCOGC, 2012; BCOGC, 2014). The AER similarly noted abnormally high volumes of seismic events through the period of 2013-2015; both the AER and the Alberta Geological Survey (AGS) believed these seismic events were associated with hydraulic fracturing operations (AER, 2015). Data from the AGS identifies almost 1600 seismic events since 2006, with seismic activity greatly increasing from 2014 onward, coinciding with increased hydraulic fracturing activities (Alberta Geological Survey 2019.; Schultz et. al., 2018). Of these seismic events, 7 were of a magnitude of 4.0 or greater (strong enough to potentially cause property damage) (AER, 2015). Most of these seismic events occurred in the Fox Creek area, however, a seismic event measuring a magnitude 4.1 occurred on March 4, 2019 12 kilometers south of Sylvan Lake, Alberta (Rumbolt, 2019). This event is being investigated for suspected links to hydraulic fracturing operations in the area

(AER, 2019; Rumbolt, 2019). This event is significant as it occurred in an area with no history of induced seismicity events of this magnitude and no induced seismicity regulations.

3.0 Current Regulatory Status

The AER issued Bulletin 2015-07 as a response to induced seismicity in the Fox Creek area. Licensees must "assess the potential for induced seismicity caused by or resulting from hydraulic fracturing operations, and adopt, and be immediately prepared to implement, a response plan to address potential seismic events" (AER 2015). This bulletin sets out a "traffic light" system to manage and monitor seismic activity if it occurs. With no observed seismic events, licensees may proceed with their operations (green light). A seismic event of 2.0 local magnitude or greater will trigger the licensee to implement their response (mitigation) plan (yellow light), and a seismic event of 4.0 local magnitude or higher requires licensees to cease operations completely (red light) (AER 2, 2015).

The AER issued Bulletin 2019-07 on March 15, 2019 in response to the above mentioned 4.1 magnitude earthquake 12 kilometers south of Sylvan Lake. This bulletin requires operators working within the Duvernay formation in the Red Deer Region to conduct a pre-operation assessment for the potential for induced seismicity, develop a plan to respond to induced seismicity, and monitor seismic activity near their operation (AER 1, 2019). The AER has implemented a stricter traffic light system than in the Fox Creek area, requiring operators to implement their seismic response plan in the event of a 1.0 magnitude or greater seismic event, and to suspend operations at a magnitude of 3.0 or greater (AER 1, 2019).

The BCOGC, as of May 28, 2018, requires operators do the following within the Farmington area: develop and submit a seismic monitoring and mitigation plan which includes a pre-assessment of seismic hazard, deploy accelerometers (which measure ground motion rate of change) less than 3 km from the drilling pad, and have access to real-time seismicity readings

(BCOGC 1-2, 2018). The BCOGC has also implemented a "traffic light system" with operators required to initiate their mitigation plan at a local magnitude of 2.0 and cease operations with an event of local magnitude 3.0 or higher (BCOGC 2, 2018).

The current regulatory framework can be improved on in two areas. First, neither the AER nor the BCOGC prescribe specific hazard pre-assessment or mitigation plans for operators, the regulations simply require operators to have plans and provide them to the regulators. Industry has worked to establish recommended practices, with the Canadian Association of Petroleum Producers (CAPP) releasing the *CAPP Hydraulic Fracturing Operating Practice: Anomalous Induced Seismicity – Assessment, Monitoring, Mitigation and Response* practice in 2012. The purpose of this practice is "to describe minimum requirements for assessing, monitoring, responding to and mitigating anomalous induced seismicity in shale gas, tight gas and tight oil development areas" (CAPP, 2012). This practice is voluntary with no obligation for operators, CAPP member or otherwise, to follow the outlined practices. While it is not necessary for the regulators to prescribe specific risk assessment and mitigation practices for operators, it is possible for them to take a more active role in the evaluation and development of practices.

Second, both the BCOGC and the AER limit their induced seismicity regulations to specific geographic areas (Farmington, Fox Creek, and recently, the Red Deer Region). These limitations help to reduce operation costs for operators outside of these higher risk areas as they are not required to assess seismic risks, develop mitigation plans, or monitor seismicity. However, these practices can increase the risk of incidents and result in a lack of preparedness to respond to an incident in non-regulated areas.

4.0 Key Considerations for Seismic Risk Identification and Mitigation

To prevent the occurrence of induced seismicity and limit the severity of seismic events it is important to identify and understand potential risk, the effectiveness of various seismic mitigation methods, and their context relative to current industry practices in Alberta and British Columbia. As both the AER and the BCOGC do not prescribe specific risk assessment or seismicity mitigation measures, we identify measures empirically tested in literature and assess their effectiveness to determine the feasibility of regulators establishing minimum risk assessment and mitigation requirements.

4.1 Risk Identification

It is presently impossible to predict the outcome of induced seismicity with certainty due to several reasons, including the difficulty in locating all underground faults prior to operation (Davis and Frohlich, 1993; Copper and Lee, 2016). However, potential seismic hazard can be approximated by evaluating an operating area based on four key points: background seismicity, local geology, state of stress, and injection practices (Davis and Frohlich, 1993).

Background seismicity refers to historical magnitudes and frequencies of seismic activity near an injection site. This can be assessed with historical data from regional seismic stations or other past records. Seismic activity from hydraulic fracturing in the Fox Creek area is, for example, primarily concentrated within the Kaybob region (Schultz et al., 2018), so it would follow that the risk is higher within that given region. However, it is still possible for an incident to occur in areas with no history of induced seismicity events. The March 4, 2019 magnitude 4.1 event south of Sylvan Lake demonstrated this, as there had been no previous significant events of induced seismicity within this area (Rumbolt, 2019; Alberta Geological Survey, 2019).

Local geology refers to the mapping of faults near the injection site, as well as other geological factors that can contribute to seismic hazard. Local geology can be assessed through the seismic mapping of faults, the proximity of the injection site to the bottom of the formation, the orientation of the well relative to the regional stress field, and the presence of underlying reef margins (Schultz et. al., 2016).

State of stress refers to the stress naturally present in the geological formation. If a formation is overpressured[1], it is more likely to result in a seismic event (Schultz et al., 2018). Injection practices including fluid rates, volumes, and pressures, have also been linked to induced seismicity. Reductions in injection rates (Weingarten et al., 2015), reduction in total injected volumes (Schultz et al., 2018) and changes in the shut-in period and stage completion have been shown to reduce induced seismicity (Capper and Lee, 2017).

Based on this review it is feasible for an operator to assess the risk of an induced seismicity event occurring using the above criteria.

4.2 Mitigation

Several mitigation methods are available to operators to reduce the severity of induced seismicity after an event has been triggered. Some of these methods include the reduction of injected volumes and injection rates, flow-back of injected fluid, and skipping completions stages, and injecting higher viscosity fluids (Zhang et al., 2016). An empirical study by Schultz et al. (2018) suggested that volume and geological factors could account for over 90% of anomalous seismic activity in the Fox Creek area.

The BCOGC in 2014 identified the early flow-back (bringing pumped fluids back to surface) of fracture fluids as "probably the best mitigation [technique]" (BCOGC 19, 2014). De Pater and

[1] Abnormally high subsurface pressure, greater than the hydrostatic pressure.

Baisch (2011) also identified a “rapid fluid flow back” as an effective mitigation through observation and modeling work. However, Zhang et al. (2017) found several events of induced seismicity which occurred during flow-back. Counter intuitively, several operators based in Alberta and British Columbia have described experiencing induced seismicity events during flow-back. Due to these conflicting results, we do not propose using flow-back of fracturing fluids as a mitigation method.

5.0 Policy Options

The current induced seismicity regulations in Alberta and British Columbia apply to specific geographic areas. These regulations do not require specific risk assessment actions or plans for specific mitigation techniques, instead relying on the expertise of an operator. We propose the expansion of Alberta and British Columbia’s respective seismicity regulations to include operations near population centers and critical infrastructure, where a seismic event could have a significant impact, and for the AER and the BCOGC to establish minimum standards for pre-operation risk assessments while also taking an active role in data collection/sharing and analysis to improve practices.

5.1 Establish minimum standards for seismic risk assessment

The current regulatory frameworks in Alberta and British Columbia require operators to submit risk management and mitigation plans. The AER and the BCOGC should establish a minimum level of risk assessment, which should consider the previously identified risk factors including: background seismicity, local geology, the formation stress state, proximity to populated areas and critical infrastructure, and proposed injection practices. As reducing injected fluid volumes is currently the most effective mitigation technique, along with skipping completion stages near a fault, we propose that the regulators direct hydraulic fracturing operators to limit their fluid injection volumes as much as possible. As the understanding of induced seismicity is constantly evolving, we propose that the regulator use its position to assess effectiveness and provide guidance as through data collection, sharing, and analysis.

The AER and the BCOGC can implement this minimum standard of assessment while maintaining their position as results-based regulators. Operators will continue to be incentivized to innovate and improve their induced seismicity prediction and mitigation capabilities to ensure reduce the risks of operation disrupting incidents.

5.2 Expand induced seismicity regulations to include hydraulic fracturing operations near populated areas and critical infrastructure

Currently the AER and the BCOGC requirements for seismic monitoring, risk management, and mitigation planning only apply to specific regions deemed to be high risk based on a history of induced seismicity in those areas. Induced seismicity is a risk with all hydraulic fracturing operations, so it is in the public interest to be prepared to monitor, react, and manage these operations safely if they are located near populated areas or critical infrastructure.

While seismic events are difficult to predict with certainty, especially in areas with no history of seismicity, preparation and mitigation planning will enable operators to quickly respond to potentially high impact events. As we have demonstrated in our analysis, mitigation techniques are effective when implemented, and can reduce the severity of seismic events.

This type of regulatory change would require operators to direct more resources towards risk assessment, mitigation planning, and monitoring in areas they were previously not required to, increasing operating costs. However, this measure would help lower the risk of high impact incidents which could impact safety, the environment, and industry reputation.

6.0 Conclusions

The increase in hydraulic fracturing induced seismicity events in Alberta and British Columbia provide motivation for the AER and the BCOGC to expand regulations to reduce the risks associated with these events. Background seismicity, local geology, stress state, injection practices, and proximity to populated areas and critical infrastructure are all important criteria for induced seismicity risk assessments and we recommend that the AER and the BCOGC direct operator's to at minimum consider these factors in their risk assessment plans. Due to the high impact of seismic events near populated areas and critical infrastructure, we propose that the AER and the BCOGC expand their induced seismicity regulations to include hydraulic fracturing operations within 5km of a populated area or piece of critical infrastructure. Finally, we recommend that the AER and the BCOGC implement policy direction for operators to reduce the injected fluid volumes during hydraulic fracturing operations as a mitigation measure.

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