The Traffic Light System and the Management of Induced Seismicity in Alberta

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Abstract

Concern over public safety has risen over the past decade due to the increase of induced seismic events near the town of Fox Creek, Alberta. These induced seismic events are highly correlated with the increase in hydraulic fracturing activities in the region starting in 2013. The Traffic Light System is a mitigation method implemented by the Alberta Energy Regulator in an attempt to reduce the risks to infrastructure damage and human well-being caused by induced seismic events. Currently, the Traffic Light System in Alberta only considers earthquake magnitude when determining thresholds. We have completed Alberta-specific earthquake modeling that confirms findings in scientific literature suggesting that ground motion is a better parameter to determine induced seismicity risks. This is because ground motion describes what is felt on the surface while the local magnitude only describes the total energy exerted by seismic event at the source. We present recommendations to utilize ground motion as a parameter for determining thresholds for the Traffic Light System instead of earthquake magnitude. Thresholds that account for the exposure and vulnerability of individuals to the ground shaking will provide significantly more protection to personal well-being compared to the current system. Our recommendations would provide greater protection in more vulnerable areas, and higher tolerances for shaking in remote areas. This flexibility provides benefits to both private industry and the public.

1. Introduction

The increased use of hydraulic fracturing[1] (fracking) in recent decades has resulted in public concern over potential environmental, social, and health impacts (Boudet et al. 2014; Rivard et al. 2014; Fox Creek 2018). A specific concern associated with fracking activities is the increase of induced seismic events (Fox Creek 2018). Schultz et al (2015) found more than 160 induced seismic events in central Alberta to have extremely high temporal correlation (>99.99%) with fracking operations in the Duvernay Formation. However, induced seismic events have only been triggered in approximately 0.3% of all fracking operations in the Western Canada Sedimentary Basin (Atkinson et al. 2016). While this number may seem insignificant, thousands of fracking operations occur every year (Atkinson et al. 2016). Most induced seismic events in Alberta are isolated to a relatively small area near Fox Creek (AER n.d.(b)).

As a result of these induced seismic events, the Alberta Energy Regulator (AER) requires that any company drilling within the Duvernay in the specified area around Fox Creek must comply with *Subsurface Order No. 2* (SO2) (AER 2015a). SO2 contains the regulatory requirements for what is commonly known as the "Traffic Light System" (TLS). The TLS is a mitigation method that relies on the near real-time monitoring of seismic activity within a 5 km radius of drilling activities to determine if the fracking operations are causing seismic activity. While this reactive monitoring-response system has been effective, improvements to the TLS

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[1] Fracking is a process used to develop unconventional oil and gas resources by injecting a combination of water, sand, and chemicals into a geologic formation via a wellbore (United States n.d.(c)). This process creates and enhances fractures in the formation, which increases permeability and allows for greater production, especially in low permeability geologic formations. Fracking is commonly done in association with horizontally drilled wells to produce oil and gas more efficiently (AER n.d.(a)). Injecting fluids into the geological formation increases the pore-fluid pressure, and in some cases may reactivate existing faults or fractures resulting in an induced seismic event (Atkinson et al. 2016).

are required. The Town of Fox Creek has stated that "The traffic light system, in the Town's opinion, is not working to ensure the safety and wellbeing of the Town and its Residents" (Town of Fox Creek 2018).

A significant weakness of the TLS is that it utilizes earthquake magnitude on the local magnitude scale to determine thresholds instead of ground motion, as ground motion provides a more accurate estimation of what is felt at the surface. This paper evaluates impacts from induced seismicity on public health and the limitations of using magnitude in the current TLS. We propose new thresholds based on ground motion in proximity to urban areas and indigenous communities to better address the aforementioned concerns and weaknesses. There is significant ongoing research examining the causation of induced seismic events in Alberta, but little literature examining the effectiveness of the TLS. This paper is designed to initiate the discussion of moving towards using ground motion in the Alberta TLS. Our work on an improved TLS will complement other proactive and predictive measures to improve the safety and predictability of induced seismic events, including seismic susceptibility and hazard mapping.

2. Induced Seismicity in Alberta

Between 1985, when Natural Resources Canada started recording seismic events near Fox Creek, and 2013, the region only experienced two earthquakes with a magnitude greater than 2.0 M_L (Canada 2018). Since 2013, the area has experienced 91 earthquakes with a magnitude greater than 2.0 M_L, with three of those greater than 4.0 M_L (Canada 2018). The location of these earthquakes is presented in Figure 1. This increase in seismic events has been highly correlated to the increase in fracking activities in the Fox Creek area starting in 2013 (Schultz 2018).

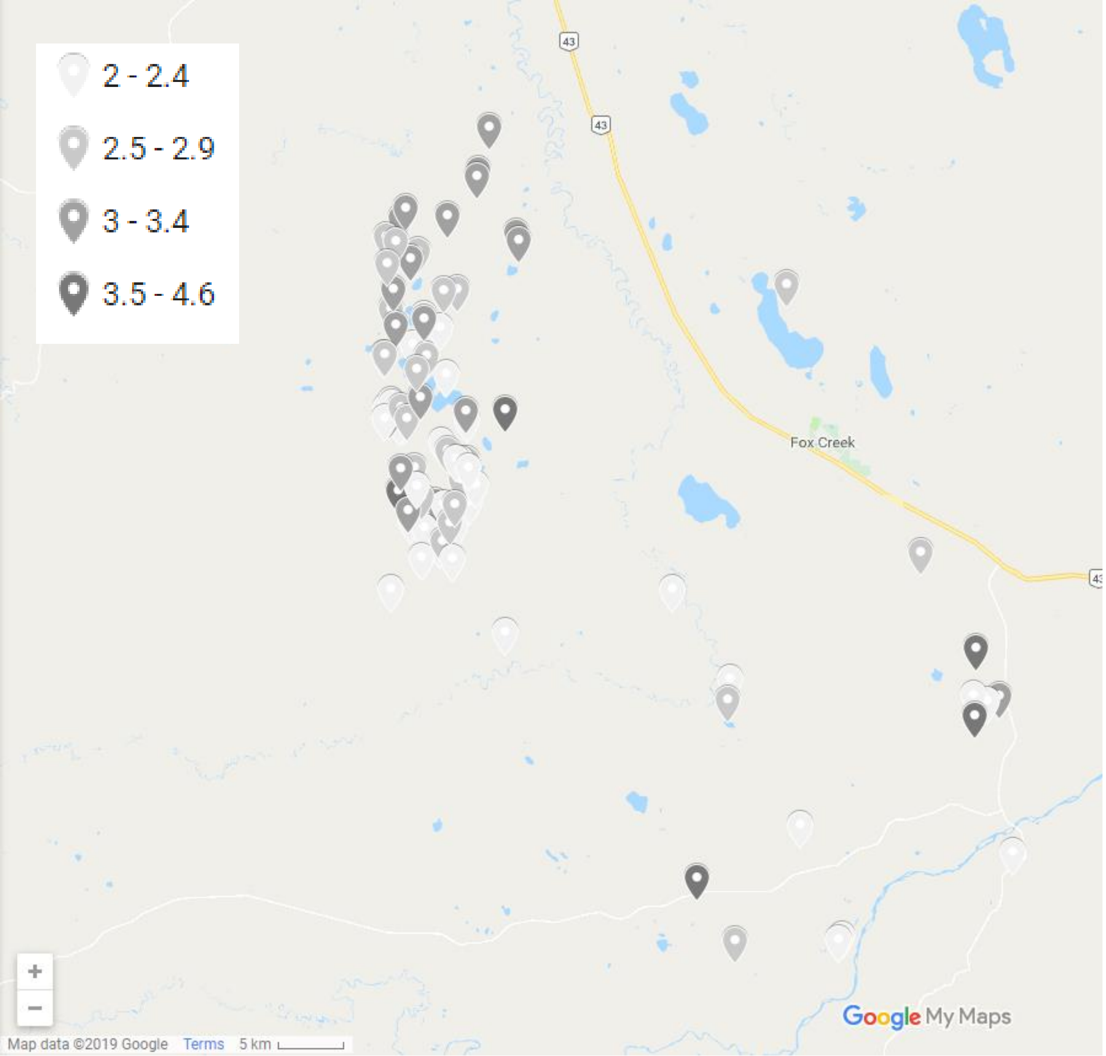

Figure 1. Induced seismic events in the Fox Creek Area since 2013.

The AER is accountable for the responsible development of hydrocarbon resources in Alberta, including managing induced seismicity from fracking activities. On February 19, 2015, the AER released SO2 in direct response to two greater than 4.0 M_L induced seismic events in January 2015 (AER 2015a). SO2 introduced the TLS to mitigate the effects of induced seismicity in the Fox Creek area (AER 2015b). SO2 requires that if a seismic event of 4.0 M_L or greater is recorded, operations must be halted immediately. A seismic event between 2.0-4.0 M_L invokes the operator's induced seismicity plan in a manner that reduces or eliminates the induced seismicity. If seismic events less than 2.0 M_L are present, no change in fracking operations is required. In order to effectively monitor and measure seismic activity, there are over 50 permanent seismic stations installed in Alberta. These stations allow for the real-time monitoring of seismic activity during fracking operations. On June 13, 2015, a 4.4 M_L earthquake approximately 30 km south of Fox Creek was the first seismic event to trigger the TLS stoplight, halting fracking operations (Wang et al. 2015).

3. Impacts of Induced Seismicity

Mitigating induced seismicity is extremely important as earthquakes have the potential to cause damage to public and private infrastructure and to negatively affect personal well-being and mental health. While the potential for infrastructure damage may initially seem to be the top risk, policy makers must also consider the impacts on the mental health of individuals who experience the effects of induced seismicity. Jim Ahn, the Mayor of Fox Creek, stated that the people of Fox Creek felt unsettled about the increase in seismic activity (Giovannetti 2015). Earthquakes have been found to cause fear and anxiety in individuals, and these effects occur at lower seismic levels than damage to infrastructure (Bommer et al. 2006; Sekiguchi 2013; Bommer, Crowley, and Pinho 2015). Casey, Goldman-Mellor, and Catalano (2018) found that induced earthquakes associated with fluid injection in Oklahoma may elicit a more pronounced negative psychological response than naturally occurring earthquakes. McComas et al. (2016) surveyed American adults and concluded that participants deemed induced earthquakes to be significantly less acceptable than natural earthquakes. Respondents appear to consider man-made hazards worse than equivalent natural hazards.

Industry should be concerned about the impacts that induced seismicity has on public and stakeholder perception of oil and gas activities. Negative public perception can be detrimental to future development of resources (Hall et al. 2015). Public protests of shale gas exploration in southern Quebec have almost completely eliminated oil and gas development in the region (Malo et al. 2015). Media coverage of induced seismic events may reduce the trust in industry (Trutnevyte and Ejderyan 2018).

Among those negatively affected by induced seismicity in the Fox Creek area are the Indigenous people of Alexander Indian Reserve #134a. It is important that the unique concerns of Indigenous peoples are reflected in policy. Historically, consultation with Indigenous peoples has been inadequate (Arbelaez et al. 2018; CAPP 2018). Fortunately, industry has now realized Indigenous consultation is a fundamental process that needs to occur during oil and gas development. The Canadian Association of Petroleum Producers (CAPP 2018) states that "the oil and gas industry acknowledges the importance of Indigenous reconciliation in Canada, and considers natural resource development to be linked to the broader Canadian reconciliation process." The mitigation of induced seismic events provides an opportunity to move from a one-sided conversation to collaboration between Indigenous people and industry. Industry should incorporate Indigenous knowledge systems when they are calculating and mitigating risk from induced seismicity.

4. Implementing Ground Motion Guidelines

A weakness of the current TLS is the usage of local magnitude as a parameter to determine thresholds. Bommer, Crowley and Pinho (2015, 631) state that “characterizing induced seismic hazard only in terms of the size (magnitude) of the possible earthquakes is of limited value.” This is because magnitude only describes how much energy an earthquake exerts at its origin, or hypocenter (Bertolino 2018). Therefore, magnitude is not a good descriptor of what is felt at the surface and the potential for (or actual) damage. Moreover, the United States Geological Survey (n.d.(a)) states that “there is not one magnitude above which damage will occur.” As a result, Canada’s National Building Code (NBC) does not use magnitude when calculating the risk of seismic hazards, but instead uses ground motion (Canada 2016). The potential damage to infrastructure is better defined by ground motion rather than earthquake magnitude (Bommer, Crowley and Pinho 2015; Bertolino 2018).

Peak ground acceleration (PGA) and peak ground velocity (PGV) are more appropriate metrics to account for potential damages and shaking felt by people due to induced seismicity. PGV describes how fast the ground is shaking and PGA is the largest change in ground motion velocity during an earthquake (United States n.d.(b)). While the ground motion (PGA and PGV) are related to earthquake magnitude, they are also dependant on the subsurface lithology and the distance from the hypocentre (Field 2000). Figure 2 provides a basic visualization of the effects of different lithologies on ground motion for earthquakes of equal magnitude. From this, we can see that magnitude alone is not an accurate descriptor of what is felt on the surface. Ground motion is the more appropriate metric to estimate potential damage at ground level caused by induced seismicity because it accounts for the site specific:

1. Impedance of the surficial sediments and rock beneath the site;
2. The total thickness of soil to bedrock; and,
3. The surface topography.

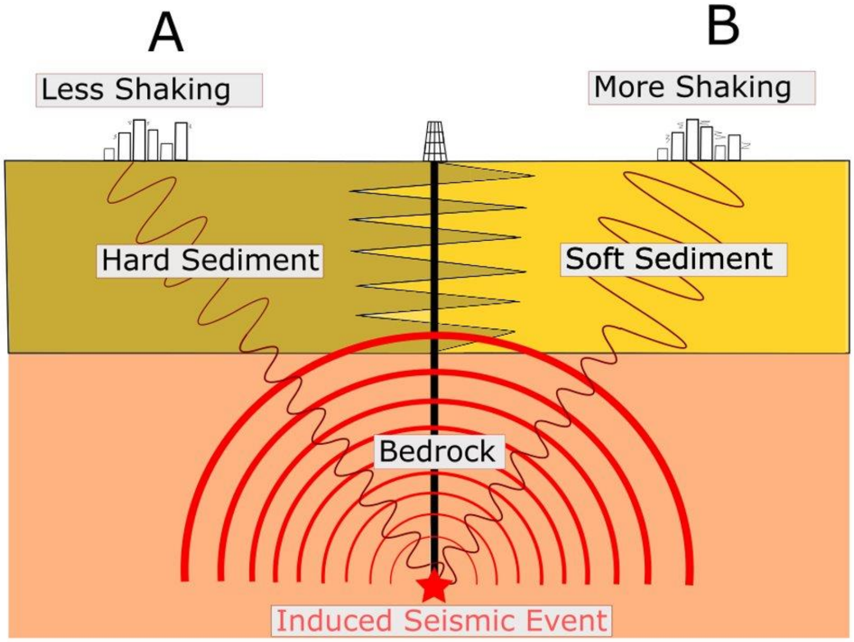

Figure 2. Effects of lithology on ground motion from an earthquake of equal magnitude (Li, Mei, Ryan Green, Yiru Zhou, and Neil Fleming 2019).

When designing a TLS in El Salvador in 2003 to mitigate induced seismicity from a geothermal field, Bommer et al. (2006) determined that ground motion would be the most appropriate indicator. Ground motion becomes distressing to people at levels lower than which structural damage starts to occur (Bommer et al., 2006); therefore, the criteria for the TLS system should be based on the levels of ground motion that would cause distress to local residents. As the TLS system should be based on the effects of ground motion, Bommer et al. (2006) used PGV in the monitoring system.

Bommer, Crowley and Pinho (2015) separate seismic risk into four factors: seismic hazards, exposure, fragility, and consequence (Equation 1). Seismic hazard is defined by ground motion (in PGV or PGA). Exposure refers to the number of inhabitants in the area where shaking may be felt and the infrastructure type exposed to the ground motion. Fragility and Consequence describe the vulnerability of individuals and infrastructure in the area to the negative effects of ground shaking. Unfortunately, due to the number of factors influencing this formula, there is no world-wide standard of what constitutes an acceptable seismic risk. Risk models for each specific geographical area are required to properly evaluate seismic risk.

Equation 1: Seismic Risk = Seismic Hazard x Exposure x Fragility x Consequence

There are several benefits to creating a geographically-specific seismic risk model, including: more consistent thresholds, better Indigenous relations from utilizing their knowledge systems, and better understanding and mitigation of negative risks associated with induced seismic events. As discussed above, variability in the geological environments has a significant effect on ground motion at the surface. By creating a geographically specific seismic risk model, we can create a more sophisticated TLS system.

Using data from Incorporated Research Institutions for Seismology (IRIS) we modeled shaking maps in the Crooked Lake area, which is located approximately 30 km west-northwest of Fox Creek. Simulations were made utilizing the modelling software SPECFEM 3D Cartesian to show the variation in ground motion based on varying sediment types and thicknesses. This technique illustrates how induced seismic activity causes different levels of ground motion depending on the impedance and thickness of sediments in the area. A single induced seismic event can produce different ground motions at different geographic locations depending on local geologic conditions and depth of the hypocentre. The results of this modeling support our proposal that the Alberta TLS should adopt ground motion to better mitigate potential damages caused by induced seismic events.

We propose that the TLS be revised according to the following thresholds:

- Green Light – No Action Required: PGA <1.0 cm/s^2;
- Amber Light – Inform the AER, invoke response plan: PGA ≥1.0 cm/s^2; and,
- Red Light – Cease operations, inform the AER: PGA ≥3.0 cm/s^2.

The Red Light at 3.0 cm/s^2 will prevent moderate perceived shaking while the Amber Light at 1.0 cm/s^2 will be triggered when weak perceived shaking occurs. These PGA thresholds apply to the ground motion felt at the nearest residence, not at the wellsite. This will allow a greater tolerance for ground shaking in remote areas where citizens are unlikely to experience the ground motion, and stricter thresholds in close proximity to residences. In addition, this would also allow greater tolerance to induced seismic events at greater depths, since this would not necessarily cause noticeable ground motion at the surface. The flexibility in our proposed modified TLS will benefit both industry and the public, and allows for adaptation to other regions threatened by induced seismic activity.

Data for surface sediment type and thickness is readily available in Alberta for incorporation into models for forecasting seismic risk (AGS 2017b). Our examination of this data was a further indication of the variability in surficial sediment types and thicknesses, and the potential they may have in modifying ground motions from induced seismic events. Companies would be required to monitor real-time seismic activity, and then use the best available ground motion prediction equation for the specific geographical area to calculate the PGA at the nearest residences. Ground motion prediction equations currently exist (Atkinson

2015, Yenier and Atkinson 2015), however, they may need to be refined for use in this specific application.

5. Conclusions

While the current TLS in Alberta is functional, the system can be significantly improved to better mitigate potential damages from induced seismic events. Using predicted ground motion instead of magnitude for developing TLS thresholds would provide a more comprehensive management of the perceived and physical risks of induced seismicity. Since ground motion describes what is actually felt at the surface, it is the ideal parameter for mitigating the damage to personal well-being, mental health, and infrastructure. By factoring in the exposure to ground shaking along with the negative effects on mental health to residents, the TLS will become much more robust. We propose new TLS thresholds of <1.0 cm/s^2 (Green Light), ≥1.0 cm/s^2 (Amber Light), and ≥3.0 cm/s^2 (Red Light), applied to the calculated ground motion at the nearest residence. Industry should collaborate with Indigenous peoples and utilize Indigenous knowledge systems in calculating and mitigating risk associated with induced seismicity.

Supplementary studies are required to further explore ground motion prediction in Alberta. Available ground motion prediction equations may need to be refined for use in the TLS. In addition, studies are required in the Fox Creek area, including the Alexander Indian Reserve #134a, to confirm an appropriate threshold for ground motion considering the vulnerability of the individuals and infrastructure to induced seismic events.

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