DEVELOPING QUANTITATIVE WEATHER-BASED APPROACHES FOR ROCK FALL RISK MANAGEMENT ALONG TRANSPORTATION CORRIDORS

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Rock falls are a common hazard along transportation corridors through the Canadian Cordillera. In particular, rock falls have caused a number of service disruptions and infrastructure damage to the railway corridors. Although protective structures can be (and have been) allocated at rock fall hazardous areas, protective structures along all railway sections susceptible to rock falls become cost-prohibitive. Moreover, the variations in weather patterns associated with climate change are likely to affect the spatial and temporal distribution of rock fall occurrences, increasing the uncertainty in the deployment of rock fall risk mitigation strategies for the future. In this regard, weather-based approaches can aid rock fall risk management by: 1) identifying periods when rock falls are more likely to occur, and 2) providing a quantitative relationship between weather seasonality and the annual frequency trends in rock falls, such that potential weather fluctuations can be used to assess future changes in rock fall risk.Recentresearch at the University of Alberta aims at developing quantitative weather-based approaches that will aid the railway industry.

The difficulty in rock fall forecasting:Rock fall processes are generally well understood; however, theirvolume/frequency quantification is treated stochastically. The perceived randomness of rock falls has been attributed to limitations in gathering and processing the necessary details of the mechanical properties, atmospheric conditions and topography at locations of potential rock fall. Another explanation is that the stability of a rock mass depends upon the previous state(s) and conditions to which it has been subjected, thus leading to the appearance of unpredictability when deterministic models are used. This behavior, well known to many natural sciences, is known as “chaotic” behavior. Recent studies have shown that annual rock fall frequencies can be modelled with a chaotic model (Figure 1)[1]. One implication of this study is the shift in scope from providing a deterministic rock fall forecast (achievable through high-frequency displacement monitoring along particular sections) to providing assessments of periods of high rock fall hazard.

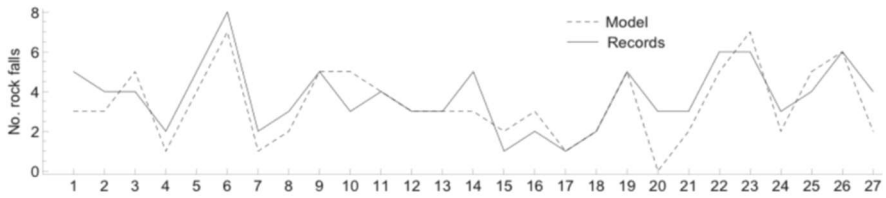
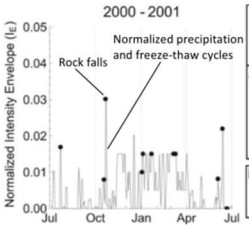


Figure 1. Rock fall annual frequencies at a section of railway and chaotic model (27 years of data)[1]

Weather thresholds for rock fall hazardous periods:To this aim, weather patterns for antecedent and short-term conditions have been analyzed to correlate weather thresholds to the occurrence

of rock falls[2]. Precipitation, freeze-thaw cycles and spring thaw are known triggers along railway sections in the cordillera. These were used[2]to assess the probability of rock fall occurrences based on exceeding thresholds for normalized precipitation and freeze-thaw cycles (daily values of annual average). These, together with observations of spring thaw, were then used to develop a hazard warning system for rail operations (Figure 2 right). Inspections are now conducted during the hazardous periods (per Figure 2) before a train passes.



Weather-based criteria for periods of higher rock fall hazard - Squamish 124-157		3-day cumulative precipitation	
		≤ 2 mm	> 2 mm
a) Has there been a freeze-thaw cycle within 3 days?	No	Non-hazardous period	Hazardous period
	Yes	Hazardous period	Hazardous period
b) Within 2 first weeks of spring thaw?	No	Non-hazardous period	
	Yes	Hazardous period	

Figure 2. Precipitation, freeze-thaw cycles and rock fall occurrences (left), hazard management (right)[2]

Quantitative relationships between weather and rock fall seasonality:A quantitative relationship between weather seasonality and rock fall occurrences is required to quantify the effect of climate change in rock fall occurrences and their temporal variability. Recent research[3] has initiated such quantification with the aid of statistical analysis of the seasonality of weather normals (e.g. precipitation) and the use of circular and mixture probability distributions. This was developed for a section of railway, where monthly freeze-thaw cycles and precipitation were fitted to von Mises distributions, and used to fit the rock fall monthly distribution, providing direct quantitative association between weather and rock falls(Figure 3)

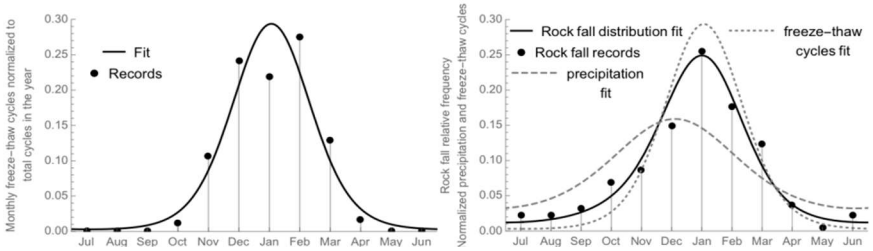


Figure 3. freeze-thaw cycles distribution fit (left) and mixture distribution fitting rock fall data (right)

There is an ongoing effort to enhance our forecasting abilities for rock fall hazard management based on weather trends and weather events, and to better assess the impact of climate change in rock fall occurrences.

Keywords: Rock falls, weather triggers, rock fall forecasting, climate change

References

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3. R. Macciotta et al. (2017) Quantifying rock fall probabilities and their temporal distribution associated with weather seasonality. Landslides14(6):2025-2039.