Real time detection of rock fall events using a microseismic railway monitoring system

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ABSTRACT

Rock falls onto railway lines pose a significant issue for human safety and environmental disaster due to the risk of train derailment. Current rockfall detection systems near steep rock slopes typically consist of electrical slide fences or netting. These systems require personnel to investigate events and repair or reset the system in the event of a damaging rockfall, causing risk to workers and slowing transportation along the route. The increasing use of microseismic systems to detect rock fall events is appealing due to their ability to reset automatically and in many cases allow normal transportation to resume more quickly, especially the situation where a rock falls but does not remain on the tracks. This paper presents examples from two microseismic railway monitoring systems (MRMS) installed in North America. The MRMS can be setup to use customized logic to automatically distinguish between a true rockfall event and other sources of noise based on specific seismic signal characteristics. An example is presented of a rockfall event on a railway line in 2010 that was uniquely identified by an MRMS.

RÉSUMÉ

Chutes de pierres sur les lignes de chemin de fer constituent un enjeu important pour la sécurité humaine et un désastre environnemental dû au risque de déraillement. Systèmes de détection actuels chutes de pierres près raide pentes rocheuses diapositive sont généralement constitués de clôtures électriques ou filet. Ces systèmes nécessitent un personnel chargé d'enquêter sur les événements et la réparation ou réinitialiser le système en cas de chutes de pierres dommageable, causant risque pour les travailleurs et ralentir le long de la voie de transport. L' utilisation croissante de l' augmentation des systèmes microsismiques pour détecter des événements de l'automne de roche est attrayant en raison de leur capacité à réinitialiser automatiquement et dans de nombreux cas permettre le transport régulier de reprendre plus rapidement, en particulier la situation où un rocher tombe mais ne reste pas sur les pistes. Ce document présente des exemples de deux systèmes de surveillance microsismiques de chemin de fer (MRMS) installés en Amérique du Nord. Les MRMS peuvent être configurés pour utiliser la logique personnalisée à distinguer automatiquement un véritable événement de chutes de pierres et d'autres sources de bruit sur la base de signaux sismiques caractéristiques spécifiques. Un exemple est présenté d'un événement chutes de pierres sur une ligne de chemin de fer en 2010 qui a été identifié de façon unique par un MRMS.

1 INTRODUCTION

Microseismic monitoring has been used for many decades in the fields of underground mining, slope monitoring, blast monitoring, and reservoir monitoring (e.g. Alexander and Trifu 2005, Wu et al 2012) to help improve safety and production. Similar sensor types are also very important for ground vibration monitoring of critical buildings and structures as well as for understanding the effect of human induced noise (pile driving, power generating engines etc) to domestic buildings.

A relatively new area for microseismics is railway monitoring on critical track portions where there are safety issues associated with rock falls onto tracks, train derailment, and partial loss of load.

This paper focuses on the application of rockfall railway monitoring and presents two case studies of microseismic railway monitoring systems (MRMS) installed in North America through a partnership with Alstom Signaling. In regions with rugged terrain, railways are commonly located in environments where steep natural rock slopes or cliffs pose a risk of rockfall hazard. Rock fall risk management is critical along railway lines to minimize the risk of train derailment and ensure efficient service with minimal disruptions. Existing rockfall detection systems typically consist of electrical slide fences or netting to warn of rockfall events. However, these systems require personnel to investigate events and repair or reset systems in the event of a rockfall, posing risk to workers and slowing transportation along the route. The MRMS is an appealing alternative due to the ability to reset automatically and allow normal transportation to resume more quickly. An MRMS is designed and calibrated to automatically distinguish between a true rockfall event and other sources of noise based on specific seismic source characteristics.

2 MICROSEISMIC RAILWAY MONITORING SYSTEM

The MRMS consists of uniaxial microseismic sensors installed in a shallow trench along the side of a railway line. The sensors are responsive to ground vibrations from microseismic activity. Microseismic activity in rail monitoring can occur due to passing vehicles, rock falls, or any other major impact or vibration source close to the sensors and tracks. Data is digitized and analyzed in real time by Paladin acquisition units. The acquisition system can transfer alarm and system health information via the

internet and also via mechanical webrelay switches connected to track warning/speed lights.

2.1 Monitoring Array 1

Array 1 was installed in September 2008 along a 250 foot length of railway track (Figure 1) that was prone to rockfall events (Figure 2). A total of 12 uniaxial geophone sensors (frequency 15-1000Hz) were installed at a distance of 5-8 feet from the rail track. The sensor cables connect to a small water resistant splice box and a trunk cable running parallel to the tracks. The trunk cable passes to a junction box where the signals are digitized continuously at 5000Hz sampling and 24 bit resolution.

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Figure 1. The location for Array 1. Microseismic sensors are installed at 5-8 feet from the railway track near to the location of the electric fence. The white box to the right is the location where the signals are collected and analyzed.

Figure 2. Photo showing the steep rock slope beside the railway tracks in the vicinity of the MRMS sensor Array 1.

Figure 3 shows signals that indicate all 12 sensors are functioning correctly following the installation. In this example, a train has passed by, and the signals at each sensor show a similar character with a slight offset in time as expected due to the velocity of the train travelling along the tracks past each sensor from number 1 to 12.
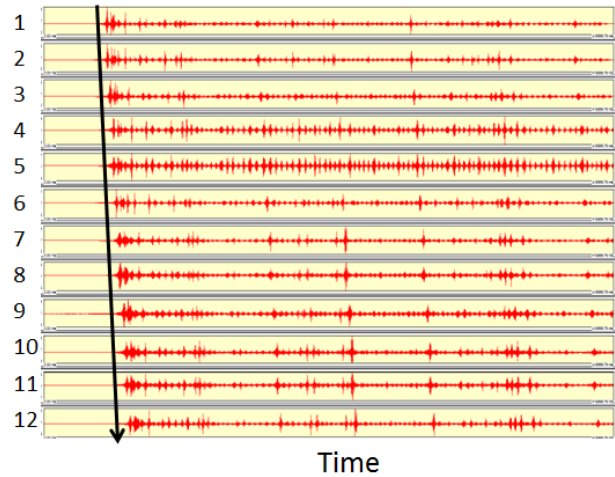

Time

Figure 3. Waveforms recorded on the 12 sensors of Array 1 showing all sensors to be functioning correctly. The signals are due to a train passing and show that the train passed from the top sensor to the bottom one at a relatively constant velocity.

A known rockfall event occurred on December 17 2010. The main rock involved in the rockfall appears to have fallen from a cliff face at a height of about 20m (Figure 2). Figure 4 shows the approximate 200kg rock that fell. The system recorded the initial rockfall activity and the main rock impact. The rock had sharp edges that cut the trunk cable between sensors 2 and 3 (Figure 5). To prevent damage, sensors and cables should be installed 0.5 – 1.0 feet below surface as shown in Array 2.

Figure 4. The approximate 200kg rock that fell on December 17 2010.
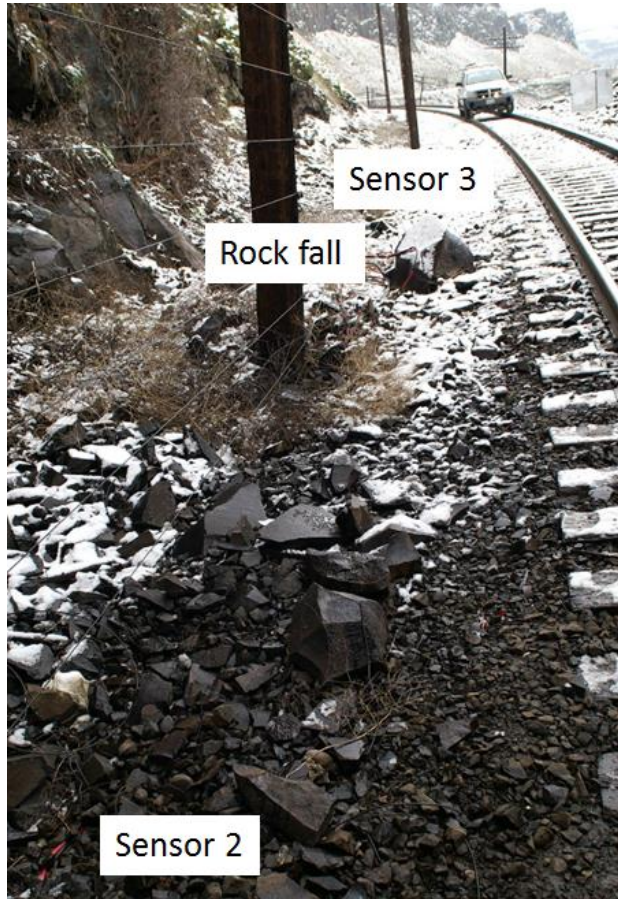
Figure 5. Photo showing the location of the approximate 200kg rock in relation to sensor 2 (bottom left) and sensor 3 (top right).

An analysis was performed of a one week period of continuous data (December 12-20 2010) from the system that included the rockfall. Using a standard threshold exceedence logic (3 times above sensor background noise levels), a total of 1915 triggered events were extracted from the dataset. The event triggers were classified into five types (passing train, car on tracks, electrical noise, small seismic event, rockfall event) based on the specific seismic characteristics of each type. By optimizing the triggering logic and implementing an event rejection function, the single rock fall event was uniquely identified (Figure 6).

Figure 7 provides more details about the rockfall event. The time marked by F is when the trunk cable was cut by the fallen rock. Interestingly five other impacts can be interpreted at markers A-E. The black lines interpret the time moveout curves of the energy arriving at each sensor, and show that all markers A-F were due to impacts near to sensors 1- 3. This can be interpreted as a 2 second rock fall involving the large 200kg rock and possibly smaller pieces. The large rock may have hit at time D and bounced resulting in E and F.
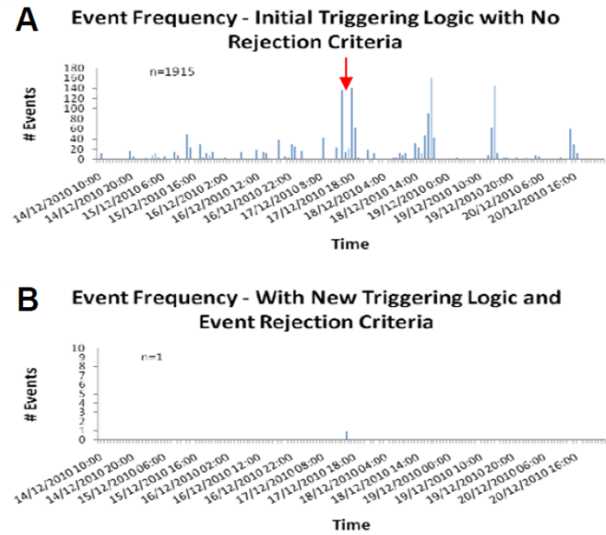

Figure 6. Event-time histograms with 1-hour windows using (A) initial triggering parameters; and (B) enhanced triggering logic and event rejection criteria. The time of the rockfall on December 17 is marked with an arrow in A.
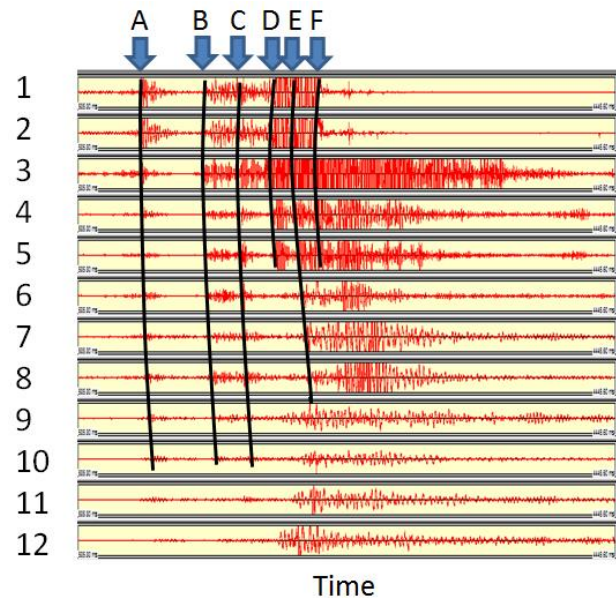

Figure 7. A five second capture of the microseismic waveforms centered around the time of the rock fall. The sensors are identified as 1-12. The black curved lines marked A-F are each interpreted microseismic events related to rock impact and all originate near to sensors 1-3. Marker F identifies when the cable to sensors 1-2 was cut by a large 200kg rock fall. The times marked A-E are rock fall activity before this.

Figure 8 shows more details of the seismic signals at marker A in Figure 7. The seismic signals in time, frequency and amplitude are characteristic of a small rock fall impact event. This event occurs about 2 seconds before the larger amplitude rockfall event associated with the 200kg rock.
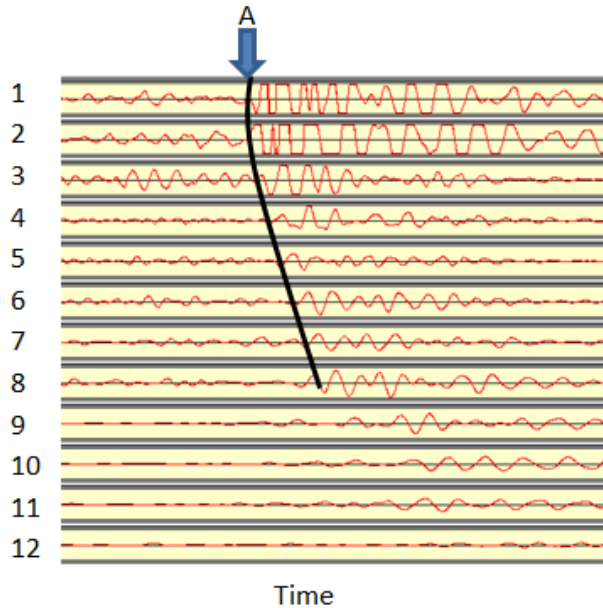
Figure 8. A 0.5 second time capture highlighting the waveforms related to a rock impact event occurring near sensors 1 and 2. Marker A is the same as the one identified in Figure 7.

2.2 Monitoring Array 2

Array 2 was installed in November 2012 alongside a 600 foot long rock-fall prone segment of railway. Figure 9 is a schematic drawing of the installation method which included covering the sensor and cable with 0.5-1 foot of sand and gravel for enhanced human and environmental protection. Covering the sensor also reduces background noise levels resulting in higher signal quality.
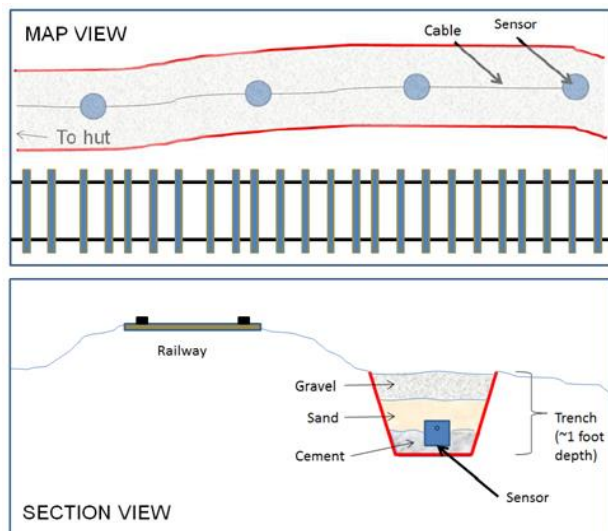

Figure 9. Schematic showing the sensor installation method for Array 2. The sensor and cables are protected from surface damage by a layer of sand and gravel overtop.

Figure 10 shows more details of the site with the sensors installed about 5-8 feet from the railway line. The sensors are spaced 35ft apart and mounted along a natural trench beneath the electric fence. Figure 11 shows the steep cliff and overhanging rocks along the monitored railway segment.

Figure 10. Photo identifying the location of some of the sensor for Array 2. The sensors are placed in a natural trench 5-8 feet from the railway line and near to the electric fence. The sensor cables pass through a conduit under the railway line and into the hut on the left of the figure where the digitization electronics is housed.

Figure 11. Photo showing the high rock slope above the location of Array 2.

The sensors for Array 2 are a fully integrated sensor cable design (Figure 12) with no separate splice box, that significantly speeds up installation time. The disc shaped sensor was pressed into a 1ft diameter concrete base

(Figure 13) using the bubble level to ensure horizontality. The sensors were subsequently covered with sand and gravel.

Figure 12. Photo of the end sensor before installation, highlighting the bubble level in the center and fully integrated design.

Figure 13. Each sensor was cemented in place to ensure good coupling to the ground and a horizontal orientation.

The analog seismic signals pass by trunk cable to the acquisition junction box (Figure 14) installed in a railway hut. The signals are digitized at 5000Hz and 24-bit resolution and synchronized to GPS time. A laptop computer stores all data to a ringbuffer harddrive and performs real time analysis of the continuous data. The analysis allows an alarm to be issued if certain user set signal characteristics are exceeded. A separate alarm is issued if system health checks identify an issue with any of the sensors, power, or junction box equipment.

Figure 14. Photo showing the MRMS junction box inside the railway hut. Signals from the sensors are continuously digitized and analyzed for potential alarms (certain trigger criteria). The system also performs regular checks of system health. A webrelay unit allows mechanical control over switches such as railway lights.

A rock fall simulation was performed using a loader bucket dropping on the track. Figure 15 displays the recorded seismic signals associated with this impact test at sensor 5. The seismic signals and interpreted moveout curve in black clearly show the unique type of signal characteristics and time response for an impact source. As expected, there are a number of similarities of this calibration test response to the rockfall response in Figures 7 and 8.
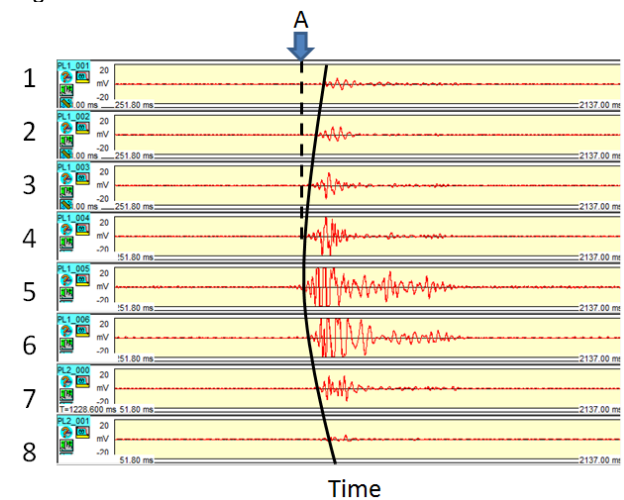

Figure 15. The signals recorded over a 2 second time window by Array 2 during a calibration impact test. The black line is the interpreted moveout curve and shows the impact test to originate at time A near sensor 5 as expected.
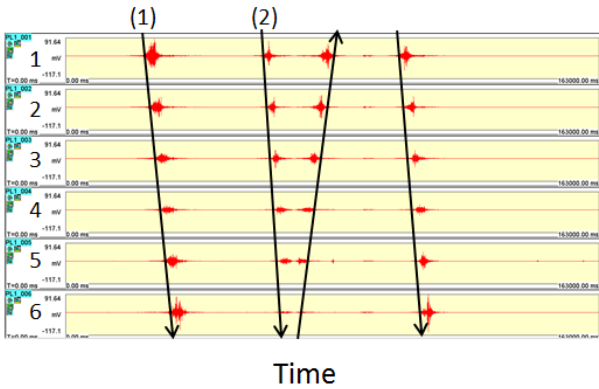
Figure 16. Signals recorded over a 163 second time period from 6 sensors in Array 2. The red arrows interpret signals associated with vehicles passing the sensors. Since the distance between sensors is known, the speed of each vehicle can be accurately determined.

The response of a train passing two of the sensors in Array 2 is displayed in Figure 17. The signals indicate that the train took over a minute to pass by each sensor, and the characteristics of the seismic signal can be used to indicate how many cars were in the train and the relative load in each car. The spectrogram (frequency versus time graph) of each signal shows a characteristic signature which could be used to identify a train.
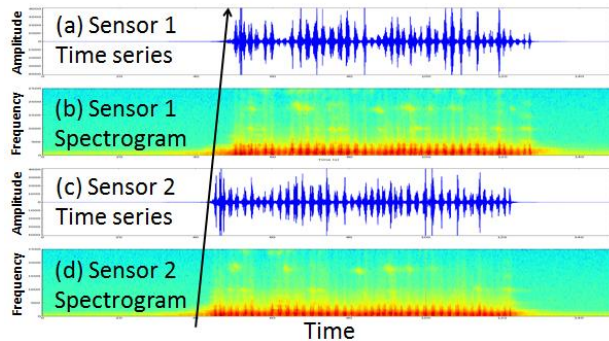

Figure 17. Time signals in blue recorded over a 145 second time period associated with a train passing two of the sensors in Array 2. Each train creates a unique seismic signature related to the number of cars and the load of the cars as they pass over joints along the railway track. The figure also shows the spectrogram of the signals identifying the variation in frequency content from 0 to 2500Hz (warm colors are high spectral amplitude, cool colors are low).

3   CONCLUSIONS

This paper has presented results from two seismic railway monitoring systems successfully installed in North America along rock fall prone regions of track. The systems are easy to install and offer a complimentary method to electric slide fences or netting.

Seismic signals generated by calibration impact tests, vehicles passing, trains passing, and a documented rock fall sequence have been presented. A rock falling and impacting the ground is shown to have a similar seismic signature to the calibration impact test and a very different signature to human noise such as vehicles or trains. This allows the MRMS to uniquely identify rock falls from other seismic background signals.

The MRMS offers an important way to automatically monitor portions of railway lines below steep rock slopes, and reduces the risk of train derailment from rock falls onto the tracks. It also reduces the requirement of personnel working alongside the tracks since the systems can be automatically reset.

REFERENCES

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