3D DATA COLLECTION FOR RAPID ROCK FALL RESPONSE SITUATIONS

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Challenges from North to South
Des défis du Nord au Sud

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ABSTRACT
Linear infrastructure corridors in rugged terrain are typically vulnerable to rockfall and rockslide type natural hazards. Once a hazardous event has occurred that warrants investigation in relation to the safety of the site it is critical to collect detailed information quickly. The Railway Ground Hazard Research Program has invested in the development of remote sensing techniques that can be deployed in a rapid response scenario. Oblique Helicopter Photogrammetry (OHP) is a technique that enables the generation of 3-dimensional (3D) point cloud data from photos using Structure from Motion (SfM) photogrammetry. This paper discusses two case studies in which the operator of a single track railway line experienced a rockslide event that required an immediate engineering response. The first site is located along a QNS&L railway line 20 km north of Sept-Iles, QC where a rockslide covered the tracks and forced the temporary closure of the railway. The second case study is located along a CN railway line 150 km northeast of Vancouver, BC where a rockslide activated a slide detector fence. An immediate response was undertaken by both railways. In both instances the time between data collection and initial model development was less than 24 hours.

RÉSUMÉ
Les couloirs d'infrastructures linéaires en terrains accidentés sont souvent vulnérables aux aléas naturels comme les éboulements et les glissements rocheux. Une fois qu'un événement dangereux, qui demande une investigation en lien avec la sécurité, survient, il est essentiel de récolter les informations rapidement. Le Railway Ground Hazard Research Program a investi dans le développement de techniques de télédétection qui peuvent être déployées dans un scénario d'intervention rapide. La photogrammétrie oblique à partir d'un hélicoptère (POH) est une technique qui permet la génération de données sous forme de nuages de points tridimensionnels (3D) à partir des photos et de la méthode de corrélation d'images Structure from Motion (SfM). Cet article discute de deux études de cas dans lesquels l'opérateur d'une ligne de chemin de fer est sujet à un glissement rocheux qui exige une réponse d'ingénierie immédiate. La première étude est située le long d'une ligne de chemin de fer du CN à 150 km au nord-est de Vancouver, en Colombie-Britannique, où un glissement a activé une clôture de détection. Le deuxième cas est situé le long d'une ligne de chemin de fer QNS&L à 20 km au nord de Sept-îles, Qc, où un glissement rocheux a couvert les rails et forcé la fermeture temporaire de la voie ferrée. Une réponse immédiate a été entreprise par les deux opérateurs. Dans les deux cas le temps écoulé entre la collecte de données et l'élaboration d'un modèle initial était de moins de 24 heures.

1 INTRODUCTION

Linear infrastructure corridors in rugged terrain are typically vulnerable to rockfall and rockslide type natural geohazards. The operational consequence of such an event can range from minimal maintenance and repair of warning systems, to removal of debris from the corridor, through to complete closure and rebuilding of the infrastructure impacted by the hazard. The consequence of repairs, maintenance, and construction along single track railway lines is compounded by the fact that during any such activity the flow of traffic is impeded or stopped. Once a hazardous event has occurred that warrants investigation in relation to the safety of the site it is critical to collect detailed information in very quickly.

The Railway Ground Hazard Research Program has invested into the development of remote sensing techniques that can be deployed in a rapid response scenario (Lato et al. 2015). These techniques have diverse applications including rock slope mapping (Gigli et al. 2013; Hutchinson et al. 2015), rock fall slope change detection (Lato et al. 2014), landslide fissure detection (Stumpf et al. 2013), and pre-failure rock block deformation (Kromer et al. 2015).

Oblique Aerial Photogrammetry (OAP) is a technique that enables the generation of 3-dimensional (3D) point cloud data from photos using the Structure from Motion

(SfM) photogrammetry technique. Using a high quality digital Single Lens Reflex (dSLR) camera equipped with real time GPS enables the generation of 3D point cloud models, typically within +/- 2% scale accuracy with surface noise less than 0.1 m when shooting in optimal situations with respect to lighting and site accessibility.

This paper discusses two case studies in which the operator of a single track railway line experienced a rockslide event that resulted in the requirement for a rapid engineering response. The first site is located along the QNS&L Railway line 15 km north of Sept–Iles, QC, where a rockslide covered the tracks and forced the temporary closure of the railway. The second case study is located along a CN railway line 150 km northeast of Vancouver BC where a rockslide activated a slide detector fence and caused damage to infrastructure. An immediate response was undertaken by both railways. The initial phase of work required 3D surface data to be collected without direct access to the site. The utilization of the OAP method enabled the construction of 3D surface models to assess geometric properties, identify the source zones, calculate volumes, and assist the railway operators in making informed decisions. In both instances the time between data collection and initial model development was less than 24 hours after data collection.

2 IOC ROCK SLIDE

On 8 November, 2014 a rock slide occurred along the east side of Moisie River approximately 20 km NNE of IOC facilities in Sept-Iles, Quebec, at mile 14.6 of the Wacouna Subdivision (Figure 1). The rock slide originated from a WNW-oriented rock slope above the railway track. The rock slide caused damage to the railway infrastructure and resulted in the derailment of an empty ore train travelling northbound (Figure 2).

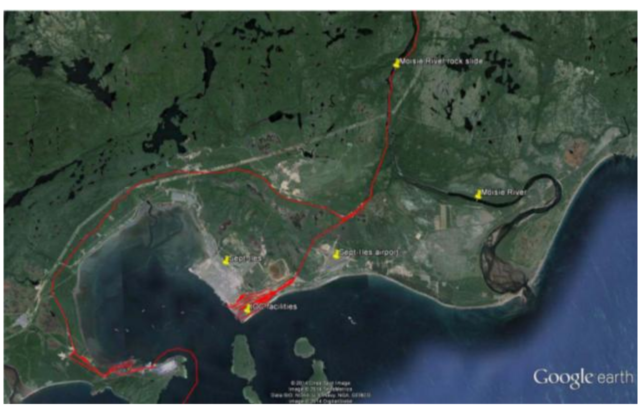

Figure 1. Site map of the Wacouna Mile Post 14.6 rock slide with respect to Sept Iles, QC. Railway tracks in red.

2.1 Data collection logistics and technique

Photogrammetry data were collected from a helicopter on 10 November 2014 to enable the development of a 3D surface model of the rock slide source zone and the derailed train, and extending approximately 100 m to the north. The photographs were collected from a helicopter using a Nikon D800 dSLR with an 85 mm 1.8/G prime Nikkor lens. 178 photos were collected at ISO 800, f/4.5, at 1/1000 shutter speed; each photo was geotagged using a directly connected peripheral GPS unit. The local accuracy of the 3D photogrammetry model dimensions were assessed to be within 1.5 % of true scale through a comparative analysis of discrete points captured by Terrestrial Laser Scanning (TLS) data. Individual measurements are presented in Table 1.


Figure 2. Photograph of the rock slide and train derailment site taken from helicopter on 12 November 2014 (track north is to the left).

Table 1. Photogrammetry error analysis comparing distance measurements between identifiable features in the OAP-H data and the TLS data.

Test ID	TLS	OAP	% error
1	57.33	56.71	1.09
2	40.21	39.68	1.34
3	58.50	57.88	1.07
4	9.28	9.24	0.43
5	49.51	49.12	0.79

The OAP model was developed within 24 hours of data collection and was used on site during the assessment and analysis phase of the investigation.


Figure 3. 3D photogrammetry point cloud model of the rock slide and train derailment site

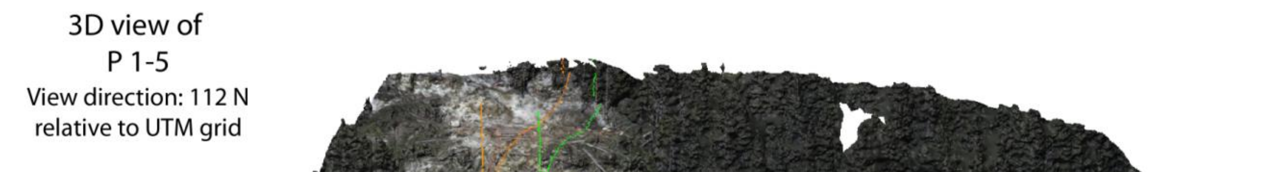

Figure 4. Annotated 3D surface model of the OAP with five profiles identified.

2.2 Applications of 3D data

The OAP model was used to in this project were used to assist in the geomechanical interpretation, stabilization design, train recovery, and visualizing the accident scene with various company representatives and engineers. This work was performed using the 3D point cloud data and the 3D surface model data.

3 CN RAIL ROCK SLIDE

On 11 December, 2014, CN Rail engineers were notified of a rock slide event at Mile 109.4 of the Ashcroft subdivision, approximately 50 km north of Hope, BC in the Fraser Canyon. The rock slide was at the location know to have significant landslide risk based on past failures. A 73 m long rockshed was constructed in 2014 to minimize the exposure to the rock fall. The immediate response was to collect 3D OAP-H data to support the track recovery operations. The objective of the data collection was to identify the location and volume of:

- rock and soil material released from the landslide source zone(s);
- rock and soil accumulation behind the existing rock shed barrier wall;
- rock and soil accumulation on top of the rock shed; and,
- rock blocks on the down slope side of the rock shed.

3.1 Data collection methods and data processing

The OAP data collection was carried out on 14 December 2014, the earliest possibility due to low clouds in the Fraser Canyon. The photographs were collected from a helicopter using a Nikon D800 dSLR with a 50 mm 1.8/G prime Nikkor lens. 163 photos were collected at ISO 1250, f/4.5, at 1/320 shutter speed; each photo was geotagged using a directly connected peripheral GPS unit. The scale accuracy of the model is approximately 2%, calculated from an alignment with Airborne Laser Scanning (ALS) data collected in April of 2014.

The photographs were converted to a 3D point cloud data using the SfM software program PhotoScan V1.0 (Agisoft, 2014). The 3D photogrammetry data were spatially aligned to TLS data collected on 04 November 2014, as illustrated in Figure 5. In Figure 5 the bronze (TLS) regions in the centres of the image represent sections of the rock mass that were not present when the OAP-H was collected.

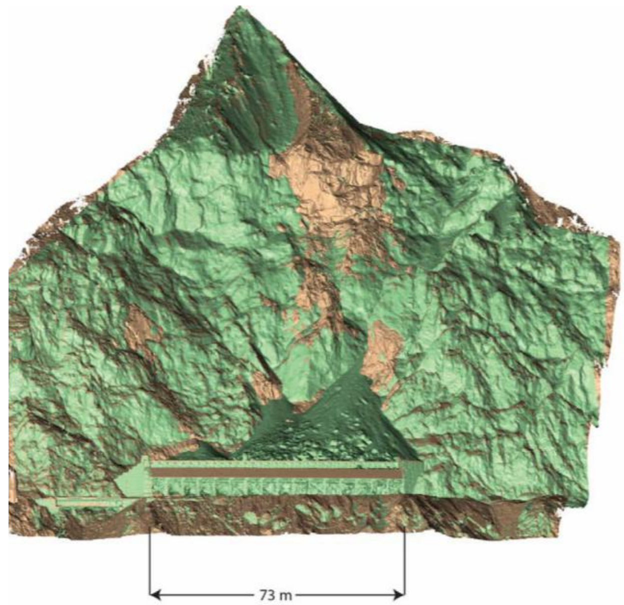

Figure 5. Visualization of the aligned 3D OAP surface model (green) to the TLS data (bronze).

3.1.1 Data processing assumptions

Three main assumptions were made in this analysis:

- Topographic changes to the rock slope between 4 November, 2014 and failure on 11 December, 2014 are negligible, apart from the rock slide itself.
- Topographic changes to the rock slope between 11 December, 2014 directly after failure and 14 December, 2014 when the OAP data were collected are negligible, apart from the possibility of minor rockfall.
- The space between the rear wall of the rock shed and the slope behind was filled prior to the slope failure on 11 December. This area is occluded (shadowed) in the TLS mode due to the presence of the shed and leads to uncertainty in calculating the volume of failed mass behind the rock shed.

3.1.2 Volumetric change methodology

Volume changes are estimated in the source zones and deposition areas using the following methodology:

- Isolate sections of the 3D surface model in the TLS and OAP data that correspond to zones of loss or accumulation using 3D polylines.
- Determine the average orientation of the surface in which the topographical change occurred.
- Integrate the volumetric change between the pre and post failure surface models.

3.2 Results

The ‘isopach’ image illustrated in Figure 6 is computed by assessing the shortest distance from each node in the OAP dataset to the surface of the mesh generated from the TLS data. This process determines the thickness of material accumulation or loss at any given location. The 'grey' zone in Figure 6 corresponds to a shortest distance surface change of +/- 0.3 m, representing regions where the accuracy of the change detection method is unreliable due to accuracy limitations or due to the presence of occluded regions in the TLS (baseline) dataset; +/- 0.3 m is therefore taken as the limit of detection. This section of the change detection spectrum does not imply that no change has occurred, it implies that change cannot be addressed with confidence.

The volume of material loss from the primary source zone (zone "a" in Figure 7) due to the 11 December, 2014 landslide is estimated to be approximately 3,300 m^3 of rock and 900 m^3 of soil. The proportion of rock versus soil is inferred from pre-landslide imagery and may vary from actual conditions. The deposited material in the accumulation zone above the rock shed barrier wall is approximately 5,900 m^3, with an additional 15 m^3 on top of the rock shed structure, and one rock with an estimated volume of 2.5 m^3 on the ground on the downslope side of the tracks. There are two smaller failure zones (identified in Figure 6 and Figure 7) with source zone volumes of approximately 200 m^3 and 250 m^3. Both of these smaller failures appear to have occurred in rock (not soil).

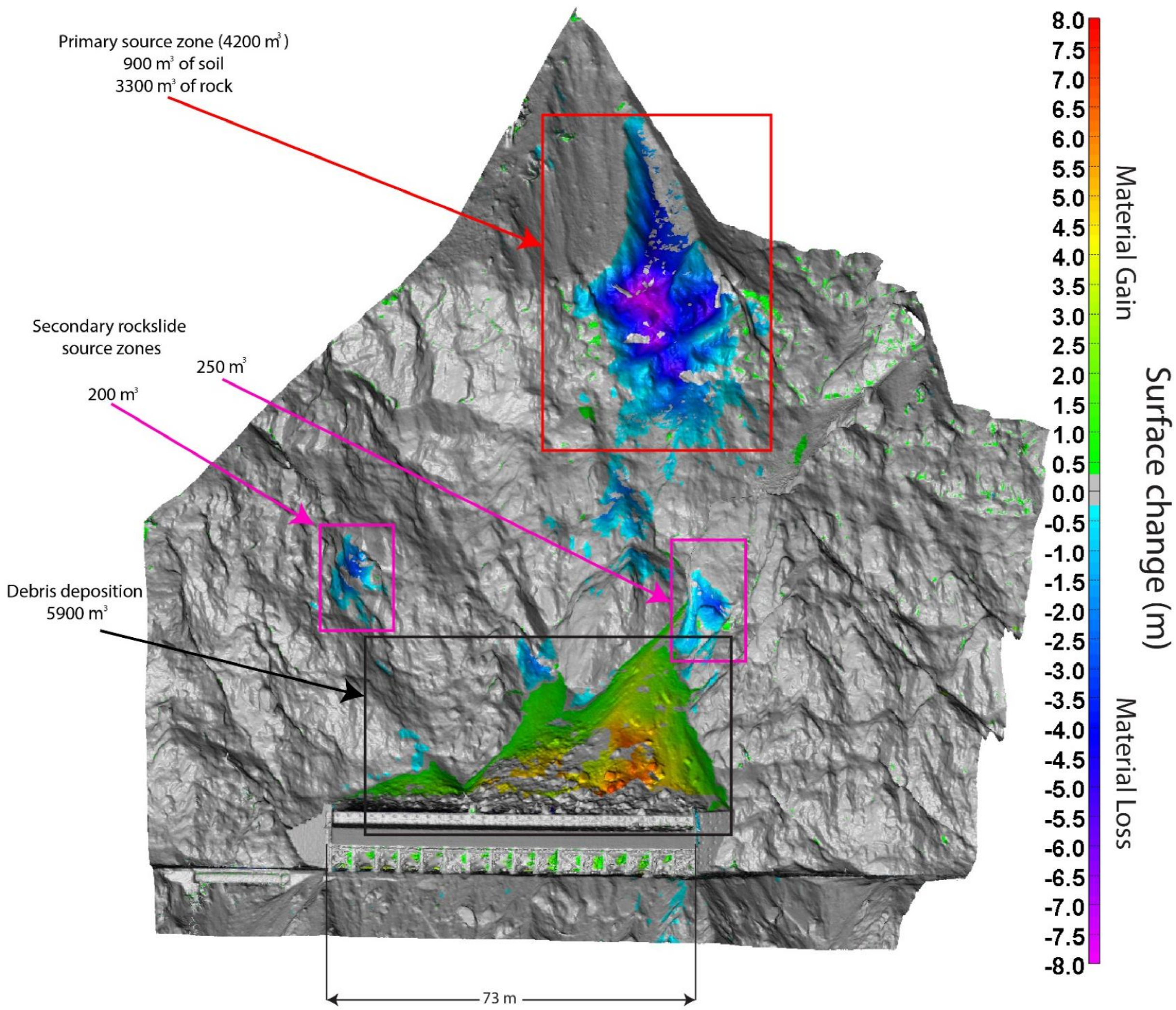

Figure 6. Shortest distance change detection 'isopach' model between the OAP data and the TLS data. Blue-purple colours indicate zones of material loss; green-red zones indicate zones of material gain.

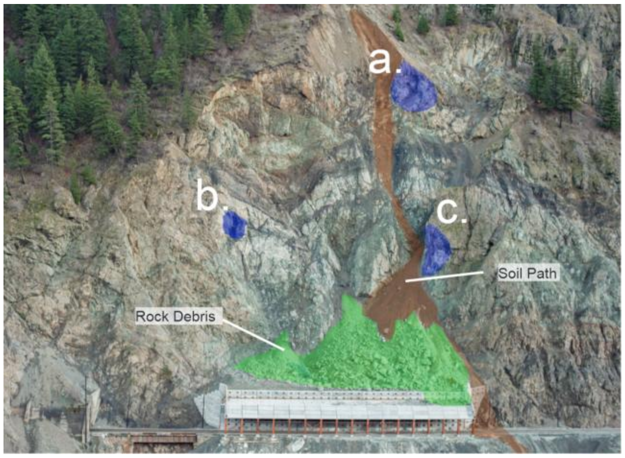

Figure 7. Annotated photograph of the rock fall source zones and depositional regions.

Assuming approximate bulking factors of 1.3 for rock and 1.1 for soil, the expected material in the accumulation area should be about 5,900 m^3 (3,800 m^3 of rock in situ = 4,900 m^3 bulked rock; 900 m^3 of soil in situ = 990 m^3 of bulked soil). Note that the bulking factors for rock and soil could be different than assumed, and the values used are provided only as a starting point for comparison of in-situ versus deposited volumes. There is little evidence of material on the down slope side of the rock shed. The approximate agreement between source and deposition volumes suggests that most of the failure material came to rest in the catchment area of the rock shed.

The OAP-H and TLS data collected during this project can be presented through traditional engineering figures as well as 3D images and files. An example of a traditional engineering profile is presented in Figure 8. This profile illustrates the zone and thickness of the regions of loss and gain along a fall line of the rock mass.

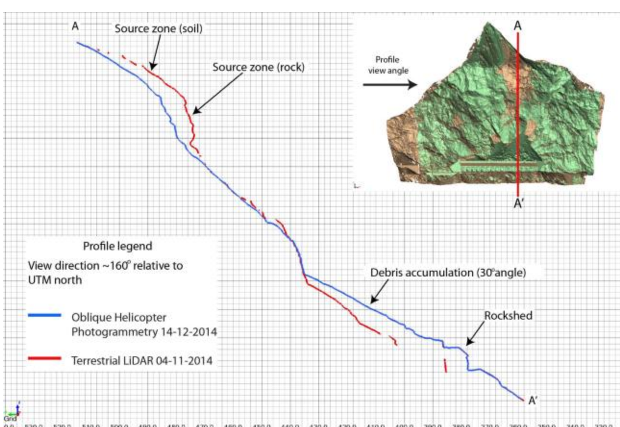

Figure 8. Profile perpendicular to the railway illustrating the pre failure slope topography (red) and the post failure slope topography (blue). Source and accumulation zones and identified in the figure.

4 CONCLUSION

This paper presents the application of a newly developed photogrammetry technique for use in response situations. In both case studies the rapid deployment and flexible data collection enabled the generation of centimetre level accurate 3D models to aid in the understanding of the geohazards event. The accuracy of these results is controlled by both datasets, in the event that both datasets were collected by OAP-H the expected limit of detection would be reduced to an estimated 100 cm, from 50 cm. This method of data collection and interpretation is a beneficial asset is such situations.

5 ACKNOWLEDGEMENTS

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