Cedar Pit Highwall and Fault Monitoring with Photogrammetry at Elkview Mine

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Abstract

A highwall located in the southern part of Cedar Pit at the Elkview Mine has an overall slope of 50°. A 1.4 km long tunnel containing a coal delivery conveyor is located behind and beneath this highwall. The main access road to the mine buildings and equipment shops transects the highwall. The stability of the highwall is important due to its proximity to the tunnel and the access road. Recently, surface erosion of an exposed fault cutting through the highwall has resulted in loss of ground that encroached on the main access road, resulting in the closure of this road in May 2011. This paper presents results from fieldwork undertaken to gather stereo photographs of the highwall in 2009 and 2010. The photographs were used in photogrammetry software to create digital terrain models, which were used to measure the orientation of geological structures and to measure the changes occurring in the highwall caused by erosion of ground within the fault zone.

1 Introduction

The Elkview Mine is located 3 kilometres east of Sparwood in south-eastern B.C. In 2010, the mine produced approximately 5.6 million tonnes of coal (Teck 2011). The main coal strata of this mine lies in the Jurassic-Cretaceous Mist Mountain Formation (East Kootenay Group) (Marston 2008). Within the mine, the basal #10 coal seam is the most important seam (Fig. 1); it varies in thickness from 9 m to 15 m and provides 61% of the in-situ coal tonnage (Marston 2008). The Elkview Mine consists of a few open pits, including the Cedar Pit in the northern part of the mine. The focus of this paper is the highwall along the southern edge of the Cedar Pit.

2 Cedar Pit - south highwall

2.1 Highwall significance

The southern highwall of Cedar Pit has an overall slope of 50°. The main access road to the mine buildings and equipment shops ran across this highwall until the road was closed due to highwall deterioration in the summer of 2011. In addition, the main coal delivery tunnel is located behind and beneath this highwall. A conveyor within the mine carries the excavated coal from different pits to the east portal of the tunnel. The tunnel carries a coal conveyor for a distance of 1.4 km at an 8.5° decline underneath the southern portion of the Cedar Pit to the western portal. From the western portal, coal is conveyed down to the bottom of the Elk River Valley to a wash plant and loading facility on the railway (Fig. 1).

The highwall is up to 150 m high measured from the pit floor to the mine access road. The overall pit depth is even higher when the benches above the road are included. Given the proximity of the main access road and the conveyor tunnel to this highwall, the long term stability of the highwall is important. Moreover, long-term plans for the mine involve pushing back the highwall even closer to the tunnel in order to excavate more coal out of the #10 seam, making the highwall stability an even greater concern.
2.2 Highwall geological characteristics

The Cedar Pit is located on top of the Harmer Ridge to the east of the Bourgeau Thrust Fault and the Sparwood Syncline (Fig. 2). The coal seams are contained within the Mist Mountain Formation of the Jurassic-Cretaceous Kootenay Group. Sandstones, siltstones, mudstones and coal seams are the most dominant rock types in the Mist Mountain Formation. The Mist Mountain Formation has a stratigraphic thickness of approximately 665 m in the area (Marston 2008). The #10 coal seam lies near the base of the Mist Mountain Formation and has an average thickness of 11.3 m. Three normal faults have been mapped in the immediate vicinity of the western side of the Cedar Pit, on the western flank of the Harmer ridge. One of these faults is named the Harmer West Fault (Fig. 2).
Flat to shallow dipping bedding planes can be observed everywhere along the highwall. The stronger sandstone units contain well-developed cross-joints. The highwall also contains small faults or shears and small fold structures. The bedding orientation is locally altered by these geological structures.

Two significant, steeply dipping faults extending the full height of the highwall are seen in the western portion of the highwall. These faults strike approximately perpendicular to the highwall. It is possible that the larger fault located to the east of the pit’s survey shack is the Harmer West Normal Fault (Fig. 3) and this fault will be named as such. Based on examination of mapping results projected onto a vertical plane containing the tunnel, the west side of this fault is downthrown by approximately 60 m. The other steeply dipping fault is located approximately 120 m to the west of the Harmer West Normal Fault. It also strikes nearly perpendicular to the highwall and is likely a normal fault too.
The Harmer West Normal Fault cuts through the bedding sequences and the #10 coal seam and also cuts across the main access road and the coal conveyor tunnel. The lower rock mass quality and the weaker rock mass strength associated with the Harmer West Normal Fault has resulted in erosion of the highwall. Surface water running along the fault has incised a steep gully and deposited a debris fan at the base of the slope. Fault erosion has cut into the main access road to the Elkview mine. Warning signs and a monitoring station were established in 2010 where the fault intersects the road. Continued erosion from this fault zone resulted in the closure of the road in May 2011.

3 Fieldwork and photogrammetry

3.1 Equipment and software

Three-dimensional digital terrain models were built using photogrammetry software and stereo photographs taken in August 2009 and August 2010. The primary tools for the fieldwork were a high resolution digital camera and photogrammetry software plus assistance from the mine surveyors. Camera stations were established along the shoulder of access and haul roads opposite to the highwall from which overlapping photographs of the highwall were taken. The arrangement of the camera stations provided ample overlap of photographs taken from each camera station. Photographs were taken using a Canon EOS-5D Mark II camera with a fixed focus 35 mm and 85 mm EF series lenses. The 85 mm lens provides a view angle of 24° on the horizontal and 16° on the vertical, while the 35 mm lens provides a view angle of 54° on the horizontal and 38° on the vertical. The camera was mounted on a spherical panorama head that in turn was attached to a tripod. This enabled the camera lens to rotate about its nodal point ensuring that a fan of images would be captured from exactly the same location in 3D space. This panorama head facilitated distortion-free merging of multiple images.

Before taking the photographs, photogrammetric targets were placed along the edge of the access road near the top of the highwall and along the base of the highwall (Fig. 4). The locations of these targets were obtained by the mine surveyors using a differential GPS survey system. The targets were identified in the photographs and used to provide scale and to georeference the digital terrain models generated from the stereo photographs.
Figure 4. Locations of camera stations and survey control points in 2009 and 2010.

Photogrammetry software from Adam Technology (Birch 2006) was used to process the photographs. Fans of photographs taken from each camera station were merged to create an image covering an area of interest along the highwall. Digital terrain models were generated from stereo images created by merging photographs taken from a pair of camera stations.

3.2 August 2009 photography

On August 25, 2009, four camera stations were established in front of the highwall (Fig. 4). The distance between the camera stations and the base of the highwall varied from 167 m to 205 m. The ratio of the camera separation distance to the distance between the cameras and the highwall is 0.16 and 0.25 for the eastern and the western pairs of camera stations respectively. A fan of photographs was taken from each camera station to cover a portion of the highwall. Nine targets were mounted on the highwall for survey control. The locations of these target points were used in the photogrammetry software to georeference the digital terrain models created using the photographs.

3.3 August 2010 photography

On August 5, 2009, two camera stations were established in front of the highwall (Fig. 4). The fieldwork in 2010 focused only on the western portion of the highwall, especially the area containing the Harmer West Normal Fault. Five photogrammetry targets were placed on the highwall, two at the top by the edge of the mine access road and three near the pit floor (Fig. 4).

The distance between the camera stations and the fault varied from 208 m at the bottom of the highwall to 330 m at the top of the highwall (Fig. 4). The ratio of the camera separation distance and the distance between the cameras and the highwall is 0.25.
4 Analysis of DTMs

The stereo photos taken in 2009 and 2010 were used to construct Digital Terrain Models (DTMs), which in turn were used to evaluate the geological structures in the highwall and to observe the changes in the fault over a one-year period. Two DTMs were created in 2009; DTM$_{2009E}$ covers a surface area of 93,500 m$^2$ on the eastern part of the highwall and contains 173,622 points and 347,204 triangles in a triangular irregular network, and DTM$_{2009W}$ covers a surface area of 70,622 m$^2$ on the western part of the highwall and contains 125,358 points and 250,651 triangles. One DTM was created in 2010 (Fig. 5 & 6); DTM$_{2010}$ covers a surface area of 62,285 m$^2$ on the western part of the highwall with focus on the faulted zone. The DTM$_{2010}$ contains 231,107 points and 462,185 triangles. DTM$_{2009W}$ covers a common area of 19,251 m$^2$ with DTM$_{2010}$.

Figure 5. Coordinates of camera stations and randomly generated points used to create DTM$_{2010}$.

Figure 6. Portion of highwall in DTM$_{2010}$ showing triangulation and texture near the Harmer West Normal Fault.
4.1 Discontinuity orientations

The orientations of bedding planes and cross joints were measured using all three DTMs created for the Cedar pit highwall. In addition, the orientations of the larger faults in the western part of the highwall were measured (Fig. 7). Mapping within the DTM was concentrated near the base of the highwall given that this location is most relevant for overall highwall stability and for assessing potential impacts of a highwall push-back on the coal conveyor tunnel. Orientations were not measured near localized folds and some smaller faulted/sheared areas in the highwall so that the mapped orientations capture the most representative bedding plane orientations. The cross joints were easiest to observe and map in the thicker, more competent sandstone layers and hence the measured joint orientations may not be applicable to other rock types.

The ‘typical’ bedding orientation as mapped shows some variability across the highwall (Table 1, Fig. 8). In the central portion of the highwall, the bedding is nearly horizontal. On the west side of the Harmer West Normal Fault, the bedding dips 10 to 20° towards the east. In the eastern portion of the highwall, the bedding dips 5 to 15° towards the southwest. While the bedding orientations vary somewhat depending on location along the highwall, the orientations of small-scale cross joints remain fairly consistent everywhere across the highwall.

![Figure 7. Western portion of the highwall created by merging DTM$_{2010}$ and DTM$_{2009W}$ showing mapped geological structures as coloured disks.](image)

![Figure 8. Lower hemisphere equal angle stereonet plots of discontinuity orientations in the highwall.](image)
Table 1. Discontinuity set orientations (degrees) and Fisher statistics.

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4.2 Analysis of fault erosion

A comparison between DTM$_{2009E}$ and DTM$_{2010}$ showed that 9600 m$^3$ of sedimentary rock eroded from the zone of the highwall intersected by the Harmer West Normal Fault over the one-year period. The volume of the sediment observed in an alluvial/colluvial fan at the base of the highwall in August 2010 is estimated to be 5840 m$^3$. Since the volume in the fan was roughly 60% of the eroded volume, this suggests that a significant portion of the eroded rock that had been deposited on the fan had been excavated and removed from the site, probably in an effort to keep the haul road at the base of the highwall clear.

Two vertical cutting planes were created in the DTMs. One plane was on a bearing of 015.2° and positioned to cut through a coordinate (17659, 52912, 1755 Easting, Northing, Elevation) that was centred on the Harmer West Normal Fault. The other vertical plane had the same bearing but cut through a point (17665, 52941, 1740 Easting, Northing, Elevation) that was centred on relatively intact highwall benches immediate to the west of the fault. These cutting planes were used to create cross-sections through DTM$_{2009E}$ and DTM$_{2010}$. These cross-sections enable comparison of lateral (horizontal) erosion in the fault zone with the nearby highwall as shown in Figure 9.

Where the Harmer West Normal Fault intersects the highwall and the tunnel, the tunnel is roughly 45 m below the pit floor and 185 m behind the base of the highwall.

A comparison of cross-sections taken through the same location in 2009 and 2010 shows that erosion along the fault had removed as much as 13 to 15 m of rock near the top of the hangingwall (Fig. 9). In August 2010, the fault exposure was up to 24 m beyond the projection of nearby bench crests. The profiles taken along the benches near the fault showed negligible erosion over this time period.

The fault erosion caused significant incision into the main mine access road. Due to the erosion, the safety berm and a portion of the road have been washed away, leading to an unprotected and narrower road in that area. Since the erosion of the fault is ongoing, close monitoring of the fault and its effect on the road is essential. The current erosion in the fault zone will have no effect on the tunnel.
Figure 9.  Comparison between 2009 and 2010 model cross sections.

4.3  Comparison DTMs and MineSight geological models

Before mining began in the Cedar pit, on-site mapping had been performed and boreholes had been drilled to delineate the coal seams and to map the major sub-surface geology. The Elkviews’s interpretation of the borehole and geological information are recorded the MineSight model, which also contains two faults in the western portion of the Cedar pit. Since the MineSight model and the DTMs use the same mine-coordinate system, the location and orientation of the Harmer West Normal Fault could be compared between the models.

Figure 10 is obtained from combining the DTMs and the MineSight fault model in AutoCAD. The red points are the highwall coordinate point cloud in DTM$_{2010}$, whereas the blue point cloud represents the highwall in DTM$_{2009}$. The 3D model of the tunnel, showed in purple, is imported from the MineSight model. The fault orientation mapped on the DTMs is shown as a red disk, and the predicted fault orientation based on the MineSight is shown as a blue disk. The location of the predicted fault (disk centre) is approximately the same as the location of the fault identified in the DTMs, however its local orientation has a 6° difference.
Figure 10. Plan view of MineSight model and DTM point clouds and a stereonet of the Harmer West Normal Fault orientation from both models. Note, the haul road is located along the southern edge of the main point cloud cluster, and the pit floor is along the northern edge of the cluster.

4.4 Highwall push-back

There is concern about the stability of the tunnel when the highwall is eventually pushed back. Currently, the tunnel is located a safe distance away from the highwall. In plan view, the tunnel and the highwall are nearly parallel to each other (Fig. 10). Along most of the highwall, the tunnel is located at an elevation that is below the pit floor. The tunnel rises up to the elevation of the pit floor at the eastern edge of the highwall.

A vertical cross-section running perpendicular to the highwall and the tunnel was constructed to examine the geometric relationship between the highwall and the tunnel location as seen in (Fig. 11). Using this cross-section, a 2D finite element model was constructed to perform a simple elastic stress analysis of the slope to examine the influence of a future highwall push-back that removed the haul road. The highwall cross-section was taken approximately 205 m east of the Harmer West Normal Fault. This simple model used only one rock type to represent the complete stratigraphical sequence of rocks and hence is not intended to be a reliable model. The isotropic rock mass modulus in the model is 5 GPa and gravitational loading was used to establish the insitu stresses using the pre-mining topography, and a rock mass density of 2400 kg/m³. The model was only run with elastic behaviour although assumed rock mass strength parameters were used to examine over-stress regions. The rock mass strength parameters were: tensile strength = 0.1 MPa, cohesion = 1.5 MPa, friction angle = 26°.

The model consisted of 47,748 triangular 3-noded elements. The model was run in three stages: 1) pre-mining topography for stress initialization, 2) excavation of the existing pit to create the highwall, and 3) excavation of a hypothetical push-back to extract more coal at the base of the highwall.
Figure 11 shows an expected stress concentration near the base of the highwall. The major principal stresses around the tunnel and at the base of the highwall are better observed in Figure 12. The push-back, using approximately the same overall highwall slope, creates a negligible change in stresses at the base of the highwall. In contrast, the push-back increases the stresses acting around the tunnel. The impact of the increased stresses can be seen by the changes in the strength factor (analogous to safety factor) around the tunnel as shown in Figure 13. While the precise strength factor magnitudes may not be correct in this figure because assumed strength parameters were used with no calibration, there is an expectation for additional yielding and deterioration of the rock mass around the tunnel.

Figure 11. Central portion of a 2D finite element model (Phase2) of the highwall and tunnel showing major principal stress contours.

Figure 12. Major principal stresses for existing highwall compared to conditions for a highwall push-back.
Photogrammetry was used as an effective survey and geological mapping tool in the Cedar pit at the Elkview mine. The digital terrain models generated from fieldwork in 2009 and 2010 provided data to assess the impact of ground erosion at a steep fault, map the orientation of geological structures, and create as-built geometries for construction of a finite element model. Fault erosion over one year was significant with 13 to 15 m of lateral incision into the bench containing the mine’s main access road. If a highwall push-back occurs, preliminary modelling results suggest that stress conditions around the existing tunnel will become worse. Further work is needed to better assess the impact of the highwall on the tunnel and the tunnel rock support needed to mitigate these effects.

6 Acknowledgements
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Figure 13. Strength factor around the tunnel for existing highwall compared to conditions for a highwall push-back.