Slope Monitoring and Back Analysis of the East Fault Failure, Bingham Canyon Mine, Utah

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Abstract

Using a multisystem monitoring program, Rio Tinto’s Bingham Canyon Mine safely operated during deformation of the pit’s northwest corner. The monitoring program provided timely data to ensure personnel safety, and for analysis of the slope movement. The zone of instability centered on the subvertical East Fault. The deformation was first detected in July of 2009 with failure, 152 meters (500 feet) wide and 305 meters (1000 feet) high, occurring on August 15, 2010. Prisms, slope stability radar, and spotter logs documented the development from low-level, localized deformation along the fault, to a growing zone of instability that culminated in an estimated 750,000 ton failure. Post failure analysis identified the mode to be a progressive wedge failure defined by the East Fault, overturned bedding striking approximately 30 degrees relative to the wall orientation, and a propagating cross joint fabric.

1 Introduction

Rio Tinto’s Bingham Canyon open pit mine, which produces copper, gold, molybdenum, and silver, is located approximately 50 kilometres (30 miles) South of Salt Lake City, UT in the Oquirrh Mountains. The 37 M.A. porphyry deposit consists of a monzonite stock, a younger quartz monzonite porphyry stock, and associated latite and quartz latite dikes which intruded quartzite, hornfels, siltstone and limestone country rock (Chesley & Ruiz 1998). The sedimentary country rocks were folded and thrust during the Mesozoic Era, prior to the emplacement of the mineralizing intrusions. The East Fault is one of the major northeast trending structures in the pit. It was along this steep fault that a zone of deformation progressed to a 750,000 ton failure in August of 2010. With a multisystem monitoring program, the mine continued to safely operate while experiencing minimal interruption to production.

2 East Fault failure setting

The East Fault slide area contains bedded quartzites, hornfels, limestone and skarn (Figs.1-2). The failure occurred between the Apex and Rood Folds which act as structural controls for the steeply dipping sediments, ranging between 66 and 85 degrees. Field strengths were estimated (Table 1) for the various rock types present in the East Fault section and included ranges in hardness (ISRM 2007), ranges in RQD and an estimate of average RQD.

Offsetting the sedimentary rocks is the East Fault, the type fault for a series of north-northeast striking, subvertical faults exposed on the west wall of the Bingham Pit. Movement along the fault has been principally sinistral strike–slip with up to 60 m (200 ft) of offset observed along the Commercial Limestone.
Figure 1. Plan map of Bingham Canyon Mine. The East Fault slide area is outlined in red.

Figure 2. Overlay showing the geology of Bingham Canyon Mine’s north wall. The East Fault slide area is outlined in red.
Table 1. Field strength estimates for rock types present in the East Fault area.

<table>
<thead>
<tr>
<th>Rock Type</th>
<th>Hardness Minimum</th>
<th>Maximum</th>
<th>RQD Minimum</th>
<th>Maximum</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartzite</td>
<td>R3</td>
<td>R4.5</td>
<td>5</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>Hornfels</td>
<td>R3</td>
<td>R4.5</td>
<td>5</td>
<td>40</td>
<td>18</td>
</tr>
<tr>
<td>Limestone</td>
<td>R3.5</td>
<td>R4</td>
<td>25</td>
<td>50</td>
<td>35</td>
</tr>
<tr>
<td>Quartz Monzonite</td>
<td>R3</td>
<td>R4.5</td>
<td>15</td>
<td>20</td>
<td>19</td>
</tr>
<tr>
<td>Porphyry</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Monzonite</td>
<td>R3.5</td>
<td>R4</td>
<td>10</td>
<td>25</td>
<td>15</td>
</tr>
</tbody>
</table>

Adjacent to the East Fault slide is the intermittently active Jordan slide. A relationship may exist between the two as the Jordan slide experienced high activity levels prior to the East Fault slope movement. Radar data supports a possible transfer and release of confining stresses from the Jordan slide to the East Fault slide area.

Slope deformation was focused along the East Fault with the zone of instability measuring roughly 152 m (500 ft) wide by 138 m (450 ft) long. The failure occurred in a sector designed with a 50 degree inter-ramp and governed by back break analysis. The design catch bench height ranged from 15 to 30 m (50 to 100 ft). The design bench width was 14 m (47.5 ft) and the design bench face angle was 70 degrees.

There were no significant rainfall events prior to the slide activity. Moreover, it is unlikely that pore water pressure played a role in the East Fault slide. The regional water table had been significantly lowered by fan drill holes drilled from the Highland Boy Drainage Gallery, a 2,286 meter (7,500 ft) drain tunnel excavated behind the pit wall between 2007 and 2009. Fan drain drilling had effectively depressurized the slope where the East Fault slide occurred.

3 Multisystem monitoring program

- Field Inspections: The geotechnical staff at Rio Tinto’s Bingham Canyon Mine conduct regular field inspections to monitor changing slope conditions in the pit.
- Robotic Total Stations: A monitoring system with automated alarms, it consists of five robotic total stations that survey over 200 prisms placed on the pit catch benches.
- Radar: At the time of the East Fault slide, two GroundProbe radars were stationed in the pit to monitor active slopes. The radar units display near real time data and will trigger an alarm if an increase in slope movement is detected.
- Spotters: Mine operations personnel are trained as spotters to record rock fall events. They assist in protecting mine personnel and inform the geotechnical team if slide activity is taking place.

Using this multi-system monitoring program, the mine safely operated during the East Fault slide events. The monitoring systems provided timely data such that as the deformation progressed from rock fall events to slope failure, all personnel and equipment were evacuated and the area of concern was isolated.

3.1 Timeline of events

Deformation of the East Fault zone in the northwest corner of the Bingham Canyon Mine began in July of 2009, at which time a radar unit detected up to 25 mm (1 in) per day of movement. Visual inspection of the area identified tension cracks along the trace of the East Fault. By June 8, 2010, rock fall sourcing from the Lower East Fault area began filling the catch benches below (Fig. 3). To ensure mine personnel safety, the area below the slide was isolated.
By mid-July, increased rock fall was visible and sourcing from the Upper East Fault area, located about 122 vertical m (400 ft) above the Lower East Fault area. The first failure occurred in the Upper East Fault area on August 5, 2010 and measured approximately 90 m (300 ft) high by 90 m (300 ft) wide. It created a talus pile that extended 137 m (450 ft) up from the working level. Slope movement increased shortly after the first event.

The only prism in the slide area was lost from view on August 13, 2010. Two days later, on August 15, 2010, a second failure occurred, measuring approximately 305 m (1,000 ft) high by 152 m (500 ft) wide. Deceleration of the East Fault area was detected immediately after the second failure, and movement had ceased by September 6, 2010.

3.2 Field inspections

The geotechnical department at Bingham Canyon Mine regularly inspects active mining cuts twice a week. These inspections ensure that the department stays current with pit operation activities and maintains awareness of any slope stability issues. Additional inspections are carried out if a monitoring system records a change in behaviour, or if a mine employee reports noticing anything out of the ordinary. Rock fall descriptions, fresh
talus, tension cracks and fresh scarps are noted and photographed. At the time of the East Fault slide activity, these observations played a critical role in determining the hazard controls as well as when to isolate the area.

### 3.3 Robotic total stations and prisms

The Bingham Canyon Mine is monitored with over 200 prisms which are surveyed by Leica theodolites. Five theodolites are positioned to provide complete and optimal coverage of all walls. By 2010, only one prism remained in the East Fault zone of deformation due to rock fall events and minor wall failures in the area. During the months of June and July 2010 the prism was moving at a constant rate of 10 mm (0.4 in) per day (Fig. 4). The prism began to accelerate August 3, 2010 with the peak velocity, 69 mm (2.7 in) per day, recorded on August 13, 2010. The prism was subsequently lost two days before the second failure that occurred August 15, 2010.

The mine prism monitoring system was set to perform a scan every hour and trigger alarms at critical thresholds. These hourly measurements of displacement became increasingly important as the prism accelerated. The point data provided by the prism corroborated the slope stability radar observations.

![Displacement chart for NW-113](image)

**Figure 4.** Displacement chart for NW-113, a prism near the East Fault slide. Outlying points represent atmospheric error in the prism data. Time period ranges from July 6, 2010 to August 11, 2010.

### 3.4 Slope stability radar

The Bingham Canyon Mine placed a GroundProbe slope stability radar unit at the base of the East Fault slide (Fig. 1). Due to the high activity, a radar unit was monitoring the slope almost constantly from May through September, 2010. The radar provided a nearly complete picture of the evolution of failure from May 2010 through August 2010 (Figs. 5-6). The radar captured the development from low-level, localized deformation along the East Fault, to a growing zone of instability that culminated in an estimated 750,000 ton failure.

A noticeable increase in deformation occurred around May 17, 2010 (Fig. 7). Rates on the Lower East Fault area remained fairly elevated through mid-June and then dropped to 127 mm (5 in) per day or less. By late July, the daily average, now encompassing the Upper East Fault area, became more erratic and the daily maximum rates increased. Before the first failure on August 5, 2010, the peak rate measured was 305 mm (12 in) per day. The peak deformation recorded for the second failure episode on August 15, 2010, was 533 mm (21 in) per day.

A radar unit remained aimed at the East Fault failure for a few weeks after the second event. Deceleration was detected almost immediately. By August 16, 2010, a day after the second collapse, the deformation measured just 76 mm (3 in) per day. The movement rate dropped to a mere 8 mm (0.3 in) by August 24, 2010. Slope movement was undetectable a month after the collapse. No further deformation has occurred as at June 2011.
Figure 5. Expansion of the deformation zone along the East Fault over the summer of 2010 (SSRX radar data). Red pixels are moving at least 25 mm (1 in) per day.

Figure 6. August 2010 progression to failure along the East Fault (SSRX radar data). Red pixels are moving at least 102 mm (4 in) per day.
3.5 Spotter logs

During the summer months of 2010, the East Fault was shedding material and rock fall activity was high. Employees acting as spotters from the mine operations group were designated to help monitor the East Fault area by recording their observations of rock fall. The spotters were provided a high-resolution photograph on which to draw the source, pathway, and resting place of each rock fall event. Additionally, they were asked to record the time and a basic description of the material shed with each event (Fig. 8). The spotter logs were critical in assessing the rock fall risk to operations and the best means to engineer and control the hazard.

Figure 7. East Fault area deformation rates (inches per day) during the summer of 2010 (SSRX radar data).

Figure 8. An example of a spotter rock fall log from August 3, 2010.
4 Failure back analysis

Back analyses were performed by geotechnical consultants Call and Nicholas, Inc. A two dimensional section through the failure (Fig. 9) was analysed using both Slope/W and FLAC software. The models indicate that while the overall slope was stable, adverse conditions had developed around the East Fault that contributed to the failure. FLAC modelling with isotropic, Mohr-Coulomb parameters illustrate that yielding developed in the weaker intrusive units at the slope toe, allowing for slip along the subvertical fault features. Strain then accumulated and concentrated along the East Fault (Figs. 10-11) in brittle quartzite.

Post failure analysis and interpretation determined the failure mode to be a kinematic block failure, defined by the subvertical East Fault, overturned bedding, and a cross joint fabric (orthogonal to bedding and dipping into the pit), and had no input from mine water. Initially, the block was undisplaced due to the semi-continuous nature of some of the structures. The accumulating strain around the East Fault is thought to have caused progressive extension of the existing structures until the rock mass failed through and below the East Fault. Progressive yielding is evident in the radar images with the moving zone propagating up and along the fault trace (Figs. 5-6) until slope failure.

Figure 9. Geotechnical cross section of East Fault failure zone (Call & Nicholas, 2010).
Figure 10. FLAC model showing yield zones on the East Fault failure zone (Call & Nicholas, 2010).

Figure 11. FLAC model depicting horizontal displacement in the East Fault failure zone (Call & Nicholas, 2010).
5 Conclusions

Three and a half years after excavation, a 750,000 ton failure occurred in the Northwest corner of the Bingham Canyon Mine. Contributing to the failure was adverse bedding orientation and the steep East Fault. Back analysis determined the failure to be a progressive kinematic block failure, with yielding in the slope toe leading to dilation and tensional failure of the more brittle units in the upper slope. With regular inspections, spotters, and monitoring equipment, the mine continued to operate safely and address risks and hazards with minimal interruption to mining activities. There was no impact to personnel or equipment as adequate warning was provided by the radar unit and controls were already in place. The radar provided a near complete picture from low-level, localized deformation along the East Fault, to a growing zone of instability.

6 References