Corroded rock support issues: implementation of an investigation and rehabilitation program

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Abstract

Raglan Mine site includes four underground mines extracting nickel (Katinniq, Kikialik, Qakimajurq and Mine 2). It is located at the extreme north of the province of Quebec. Due to freezing weather and the permafrost environment, the use of brine is mandatory. This brine is composed of about 10% calcium chloride and is corrosive to rock support systems. With mines extending deeper below the permafrost, brine flows more freely in the rock mass. The corrosion of support systems and the resulting loss of capacity can be a major safety and economic concern. Centred on rock support issues, this paper presents the mitigation measures implemented at Raglan Mine to ensure safety and the investigation program methodology to quantify and prioritise rehabilitation needs of long-term excavations. In corrosive environments, the selection and design of rock support should take the susceptibility of such systems to corrosion into consideration.

Keywords: corrosion, brine, capacity, fall of ground, rehabilitation, inflatable bolt, pull test

1 Introduction

The safety of workers is a primary goal in the mining industry. Ground control is a part of mining risk management and aims to reach zero occurrences of fall of ground. Despite the design and choice of material, ground control systems are subject to corrosion that leads to reduction in capacity. Inspection, quality control, and monitoring of aged rock supports are activities that can prevent a fall of ground. Restriction of access and rehabilitation are tools that can be used following inspection, quality control and monitoring. In many cases, corrosion is found to be the main contributing factor during an investigation into the mechanisms and cause of fall of ground failures (Hadjigeorgiou et al. 2012). This can have important safety and economic repercussions for underground mines. Figure 1 illustrates a fall of ground, the result of a loss of capacity attributed to corrosion. The corrosion of rock support in that case was caused by brine infiltration in the rock mass from a sump located in a level above.

Risk management associated with fall of ground is a concern at Glencore. At Raglan Mine, the goal is zero fall of ground incidents, and a detailed and specific program for managing this risk has been implemented. This program specified the causes of fall of ground (FOG), performance standards, and preventive controls (including critical controls). The inspection and rehabilitation of capital expenditure (CAPEX) excavations are critical controls. Figure 1 presents a FOG in a drawpoint attributed to corroded ground support. Figure 2 shows corroded inflatable rockbolt from that FOG.

This paper presents the investigation and rehabilitation program of long-term excavations conducted at Raglan Mine. The objective of this work is to qualify and quantify the loss of capacity of support systems based on several parameters, which include the presence of water, rock mass quality, condition of actual rock support, and corrosion state. This information is then used to determine appropriate support rehabilitation and the management of work priorities.

Raglan Mine is located in a permafrost environment, however the underground mines are not heated and the use of brine is needed for mining operations. Unfortunately, brine causes corrosion of metallic rock support. Another consideration is the warming of the rock mass with increasing depth. At a depth of roughly 500 m below surface, the permafrost zone ends. Below this depth, water and brine are thus free to infiltrate the rock mass and come into contact with rock support. Due to the aging of excavations, some locations need rehabilitation of rock support, and operational development such as main ramps and level accesses could be...
disruptive to mine production. At Katinniq mine, some historical excavations were supported according to old standards (ungalvanised rockbolts and rebar and no screen) and were a safety concern.

Figure 1  Fall of ground in a drawpoint caused by reduction of support system capacity related to corrosion

Figure 2  Heavily corroded inflatable bolts attributed to a fall of ground

2  Methodology

All infrastructures (garage, ventilation access etc.) and permanent excavations must be inspected on an annual basis to validate the integrity of their primary support and ensure that the excavations are still safe. The ultimate goal is to identify areas of potential risk, assess the level of risk, and plan rehabilitation according
to their severity. CAPEX infrastructure includes, but is not limited to: refuge, lunchrooms, access ramps, service bays, and emergency exits. Approximately 18 km of main ramp alone are inspected annually. A list of locations to inspect is maintained for each active mine. Depending on the progress of the operations, an evaluation of certain excavations is carried out to determine whether accessibility should be maintained. Mining engineering evaluates the future functions of the excavations and checks with underground operations which must remain open and which may be permanently closed.

An inspection protocol was developed to standardise the assessment of the underground sector. A rating of the quality of the rock mass, the integrity of the ground support, as well as an assessment of the level of corrosion of the ground support are undertaken. Rehabilitation priorities are then identified. Any high risk situation requiring immediate corrective action is identified as a priority and the corrective action is requested from the field supervisor. Non-destructive pull-tests are also performed on installed bolts. Following annual inspections, an action plan is established for the year. Rehabilitation plans are issued by a ground control engineer and work is planned according to the established precedence. Plans are presented every two weeks at a meeting between the mining engineering and underground mining operations departments.

The CAPEX excavation rehabilitation program is divided into several stages:

- Indication of the places to inspect on the mining plans.
- Inspection of underground areas and classification of the state of the support. The inspections are performed by walking through the various excavations.
- Identification of places where rehabilitation work is required.
- Establishment of priorities according to the risk level.
- Distribution of rehabilitation plans to underground operations.
- Follow-up and attestation of the quality of works.

The CAPEX inspections binder is located in the ground control office. The binder is divided by mine, with each division containing:

- Mine plans.
- A ‘Visual Assessment of Retaining Corrosion’ guide (Figures 3 and 4).
- A decision matrix for CAPEX Rehabilitation (Figure 5).
- A support state table.
- A ‘Summary of Rehabilitations’ table.

Each plan corresponds to one sector (Figure 6). Segments are named sequentially from the top of the mine downwards. The notation is the following by mine: first four letters represent the mine and a sequential number. For example:

- KATI #1 (Katinniq sector 1).
- QAKI #4 (Qakimajurq sector 4).
- MINE 2 #3 (Mine 2 sector 3).
- KIKI #7 (Kikialik sector 7).
Figure 3  Level of corrosion of rock support

<table>
<thead>
<tr>
<th>Corrosion Level</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
<th>C6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No or little</td>
<td>Localized</td>
<td>Surface</td>
<td>Advanced corrosion</td>
<td>Very advanced corrosion</td>
<td>Extreme corrosion</td>
</tr>
<tr>
<td>Description</td>
<td>&lt;10% of spots on the surface</td>
<td>10% à 75% of surface corrosion</td>
<td>75% of surface corrosion. No crust</td>
<td>100% of the surface is corroded. Presence of a thin crust (&lt;1mm)</td>
<td>100% of the surface is corroded. Presence of a thick flaky crust (&gt;1mm)</td>
<td>Important degradation. Breakable. Presence of holes.</td>
</tr>
<tr>
<td>#6 mesh diameter</td>
<td>&gt; 4,75mm</td>
<td>4,50 à 4,75mm</td>
<td>4,00 à 4,50 mm</td>
<td>3,50 à 4,00mm</td>
<td>2,50 à 3,50mm</td>
<td>&lt; 2,50mm</td>
</tr>
<tr>
<td>Typical corrosion rate (after 1 year of exposure)</td>
<td>&lt; 0,02 mm/yr</td>
<td>0,02 to 0,04 mm/yr</td>
<td>0,04 to 0,15 mm/yr</td>
<td>0,15 to 0,30 mm/yr</td>
<td>0,30 to 0,60 mm/yr</td>
<td>&gt; 0,60 mm/yr</td>
</tr>
<tr>
<td>Intervention required</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Close follow up Pull test</td>
<td>Rehabilitation to plan</td>
<td>Rehabilitation without any delay (closure)</td>
</tr>
<tr>
<td>Examples</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4  Chart of corrosion level and capacity of mesh #6 and corrosion rate (Dorion et al. 2015)
Figure 5  Decision matrix for the management of rehabilitation priorities
Figure 6  Example of inspection data collected on a mine plan
During inspections, several important aspects must be addressed; such as the major geological structures and water flows, as they can contain brine and cause corrosion of the support. Before inspections, four categories of items are identified on the mine plans:

- Purple: inspection not required for the current year (closed sector).
- Green: pay particular attention (sumps and underground drifts, emergency exits, ventilation, intersections etc.).
- Pink: presence of major geological structures.
- Blue: presence of water.

The inspection of CAPEX excavations is a visual inspection that must be done by walking to observe and note the state of the support and the rock mass. Each area should be inspected in more than one direction (for example, inspecting a ramp first from the top and then back up so as not to miss structures that would be visible from one direction).

When inspecting, the following information must be indicated on the aforementioned plans:

- Type of support (Swellex, split set, mesh etc.).
- Corrosion level (C1 to C6) for each type of support.
- Rating of the state of the grid and the rock mass (GS-1 to GS-4, according to the decision matrix).
- The presence of water.
- Quality of support where important geological structures are present.
- The presence of wedges, and an evaluation if the support is adequate.
- The places where rehabilitation is necessary are rated according to their condition and are named according to the name of the area.
- ‘State of Support’ and ‘Summary of Rehabilitation’ tables. If necessary, the plan is divided into smaller areas and the information for each area to be rehabilitated is indicated in the tables.
- Information previously indicated on the map during preparation is corrected, if necessary.
- Other relevant information is noted (barricades, gallery filled with ‘muck’ etc.).

A descriptive chart of corrosion levels is used. This one is divided into six categories. Figure 3 shows this chart of level of corrosion (Dorion 2013).

Figure 4 gives quantitative indications on the capabilities of the #6 mesh and corrosion rates. It helps to determine priorities for rehabilitation of mining support.

The document present in Figure 5 is used to identify needs and emergencies for rehabilitation work. This gives a certain uniformity to the work completed by the various people carrying out the inspections. This decision matrix is divided into three main sections.

Section one is for wet locations. As mentioned previously, generally the observed water flow is brine infiltration. The presence of brine promotes the corrosion of the mine support and special attention must be paid to these areas. In addition to checking the type of water flow, the age of the excavation and the quality of the state of the support and the rock mass are taken into account.

Section two is for special conditions; like places supported according to old standards, presence of shotcrete, or major geological structures (faults, shear). In the case of major geological structures, additional support may be required according to the support standard.

Section 3 is for dry excavations. In these situations, the level of support corrosion is considered (C1 to C6), as well as the general condition of the retaining wall and the rock mass (GS1 to GS4). The rating table of...
rehabilitation priorities is based on the tables used in risk management. This is easy to use and provides similar results from one person to another. The priorities (P) are indicated according to the combination of corrosion rating (C) and support state (GS).

3 Data

During inspection, all information is collected and noted on plans and files. Pictures are taken and archived. Table 1 lists the number of metres of main ramps alone that were inspected in 2017.

Table 1 Length of main ramp

<table>
<thead>
<tr>
<th>Mine</th>
<th>2017</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qakimajurq</td>
<td>3.6 km</td>
</tr>
<tr>
<td>Mine 2</td>
<td>5.6 km</td>
</tr>
<tr>
<td>Kikialik</td>
<td>3.6 km</td>
</tr>
<tr>
<td>Katinniq</td>
<td>4.0 km</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>16.8 km</strong></td>
</tr>
</tbody>
</table>

The following example presents a typical case of recorded information following an inspection. As can be seen, the excavations are divided into different sectors according to the state of the support. The level of corrosion, as well as the state of the support and rock mass is noted. Requests for rehabilitation work are indicated and entered in the form (Figure 7). In addition to information noted in forms and plans, an Excel file serves as a database.

Figure 7 Form used to indicate rehabilitation works and priorities
Depending on the inspection results, pull test on bolts may be performed. The type of bolt, its age and the corrosion level are noted. The pull test can be destructive or non-destructive. Because inflatable bolts are the main type of rock support at Raglan Mine, a camera is occasionally used to inspect the corrosion inside a given bolt after a destructive pull test. Figure 8 shows the inside of one such bolt.

![Figure 8 Picture of the inside of an inflatable bolt](image)

4 Results

The results of the inspections are all recorded in an Excel file (Figure 9). The priority management is established based on the rating of the location, but also on the risks related to the production in the event of a possible FOG. This means that the locations in the ramp would be a higher priority than similar locations in lower risk areas. The table also shows the details of the rehabilitation work to be carried out for each location. This table also makes it possible to follow if the plans are emitted as well as the progress of works for each of the working places.

According to established priorities, plans are distributed to underground operations (Figure 10). Each of the locations is indicated underground with a reference number. Priorities are also indicated on the plans. At each shift, a miner is given a work card with the plan indicating the work done, on which they describe any work completed. Thus, the field control team has the ability to follow the day-to-day rehabilitation work. As this work is carried out by a contractor, this system also facilitates the management of the budget.
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Figure 9  Inspection data compilation in Excel
Figure 10  Example of a work plan for underground operations
Table 2 is the summary of the percentages based on priorities for work requested during 2018.

Table 2  Metres of rehabilitation work in every mine and per priority

<table>
<thead>
<tr>
<th>CAPEX rehabilitation priorities</th>
<th>Metres</th>
<th>% completed (Dec 2018)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>P0 and P1</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P0 and P1 – Katinniq</td>
<td>2,207</td>
<td>100%</td>
</tr>
<tr>
<td>P0 and P1 – Kikialik</td>
<td>1,369</td>
<td>100%</td>
</tr>
<tr>
<td>P0 and P1 – Qakimajurq</td>
<td>290</td>
<td>98%</td>
</tr>
<tr>
<td>P0 and P1 – Mine 2</td>
<td>215</td>
<td>100%</td>
</tr>
<tr>
<td><strong>P2 and P3</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>P2 and P3 – Katinniq</td>
<td>1,369</td>
<td>100%</td>
</tr>
<tr>
<td>P2 and P3 – Kikialik</td>
<td>290</td>
<td>98%</td>
</tr>
<tr>
<td>P2 and P3 – Qakimajurq</td>
<td>215</td>
<td>100%</td>
</tr>
<tr>
<td>P2 and P3 – Mine 2</td>
<td>333</td>
<td>100%</td>
</tr>
<tr>
<td><strong>Total P0, P1, P2 and P3</strong></td>
<td>2,230</td>
<td>35%</td>
</tr>
<tr>
<td>Total P0, P1, P2 and P3 – Katinniq</td>
<td>1,369</td>
<td>17%</td>
</tr>
<tr>
<td>Total P0, P1, P2 and P3 – Kikialik</td>
<td>290</td>
<td>79%</td>
</tr>
<tr>
<td>Total P0, P1, P2 and P3 – Qakimajurq</td>
<td>215</td>
<td>66%</td>
</tr>
<tr>
<td>Total P0, P1, P2 and P3 – Mine 2</td>
<td>333</td>
<td>76%</td>
</tr>
</tbody>
</table>

**Extra work Katinniq P0 and P1**

| Extra work Katinniq P0 and P1 | 2,265  | 60% |

| Extra work Katinniq P0 and P1 | 458    | 100%

Figure 11 shows the progress of work on a monthly basis. It is possible to follow the metres of rehabilitation carried out compared to the planned budget. The cost overrun is associated with additional requests added during 2018.
This paper demonstrates the need for a well-structured inspection program to reduce the risks associated with deterioration of the ground support. The Raglan Mine’s CAPEX inspection program includes the characterisation of corrosion levels of ground support and a destructive pull test program on corroded bolts which helps to quantify loss of capacity. This information allows the technical department to design a rehabilitation program based on objective criteria. This in turn can be used in mine planning to improve strategies for choosing support in the future excavation. In 2018 more than 4 km of mining excavation were reconditioned. Different support materials may be used depending upon whether an area is designated for short or long-term access.

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References


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