CASE STUDY OF THE REHABILITATION OF THE HISTORICAL CONIAGAS NO. 4 SHAFT IN COBALT, ONTARIO

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The Town of Cobalt, located in northeastern Ontario, Canada was incorporated in 1906 following the construction of the Temiskaming & Northern Ontario Railway and the subsequent discovery of silver in 1903. The Cobalt mining camp produced over 460 million ounces of silver in the half century that followed the discovery. The Coniagas deposit was discovered by W. G. Trethewey in 1904 and sold to Coniagas Mines Limited shortly thereafter. Coniagas Mines operated the claim from 1905 to 1924 when a fire destroyed the concentrator and the No. 2 Shaft headframe. Other small operators mined the Coniagas property sporadically until 1943. The Coniagas property yielded nearly 34 million ounces of silver (Sabina, 1974). The No. 4 Shaft headframe was built in 1914 and the shaft was sunk to a depth of approximately 350 ft. Workings extend as deep as 375 ft near the No. 4 Shaft and are the deepest workings on the Coniagas property.

Following the closure of the No. 4 Shaft, a grocer named Anthony Giachino purchased the building and constructed Giachino's Grocery, enclosing the headframe with the store building in 1926 (Brown, 1999). Figure 1 shows the building in what is estimated to be the 1940's. Giachino used the No. 4 Shaft and the cold air from the mine as a cold storage for produce and meats. Several businesses have since occupied the building including multiple restaurants (Figure 2 and Figure 3), and it is currently in use as a residential apartment and a publisher (Figure 4).

Figure 1: Giachino's Grocery Store – Looking down Prospect Avenue (c.1940's) (Cobalt, 2016)

Figure 2: Coniagas No. 4 Shaft (c.1960's) (Sabina, 1974)

Figure 3: Cornmeals Restaurant (2008)

Figure 4: White Mountain Publishing - Current Tenant (2015)

Investigation

Golder Associates Ltd. (Golder) completed a preliminary investigation with Agnico Eagle Mines Ltd (Agnico Eagle) that consisted of reviewing historical records, and completing a site visit to locate and record the status of the shaft before a detailed investigation was completed. Historical records from previous investigations suggest that the cap was constructed of 18” thick concrete reinforced with 16 lb mine rail and 6-inch square wire mesh, and also indicated that an access port in the top of the cap was left open and covered with planks. The shaft cap was located under the ground level floor of the building inside a storage closet (Figure 5).

Figure 5: Location of shaft cap access port under plywood floor

After removing the plywood floor inside the storage closet, the access port was found to be covered with wood boards. The boards were removed and cool air could be felt coming from the exposed shaft. A light was lowered into the shaft along with a borehole camera. All of the timber shaft guides had deteriorated and fallen into the shaft. At approximately 15 m depth, a significant amount of wood and debris was blocking the shaft (Figure 6). It was not known if the debris was hung up in the shaft with void extending below the debris, or if the shaft was filled from the bottom to the level of the debris.

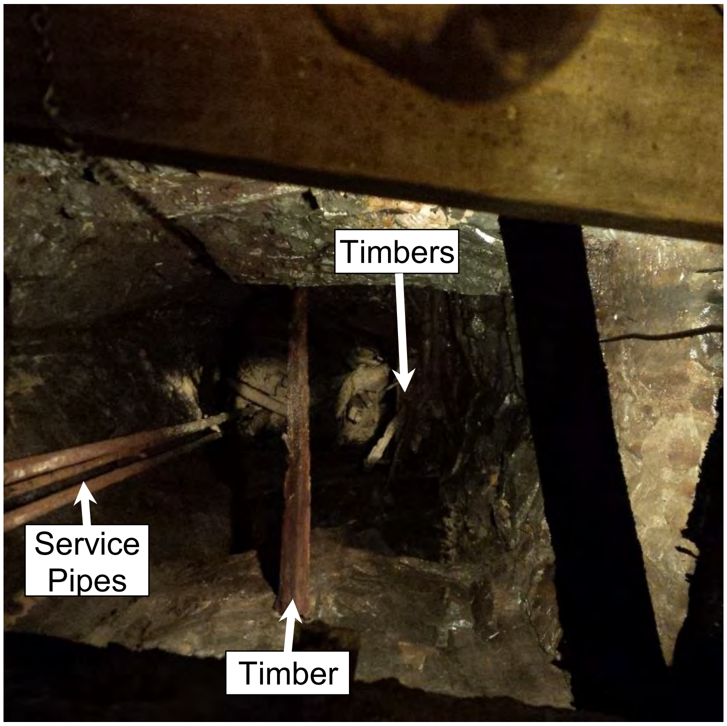

Figure 6: Looking down the shaft from access port. Timbers and other debris are visible at approximately 15 m depth

A cavity monitoring survey (CMS) was completed using a C-ALS borehole deployable laser scanner. The C-ALS probe was lowered 3 m below the building floor into the shaft void on carbon fiber rods designed to keep the probe aligned. The C-ALS creates a point cloud of the void space at assigned degree intervals. Multiple scans were completed of the shaft at different elevations to minimize the portion of the shaft wall which could not be scanned due to blocked line of sight from the scanner. The CMS result confirmed that the shaft was blocked at 15 m depth. The shaft measured approximately 2.5 m by 4.2 m directly below the cap, and narrowed to approximately 2.5 by 3.5 m starting at approximately 1 m depth, from which point, the opening size remained nearly the same to the debris blockage at 15 m. The void space above the obstruction was estimated to be approximately 116 m^3 by creating a wireframe from the point cloud, shown in Figure 7.

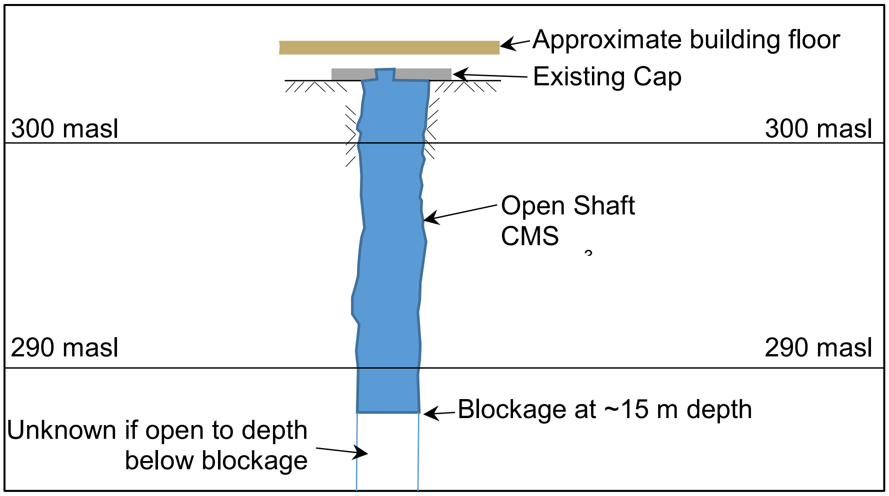

Figure 7: Longitudinal Drawing of Coniagas No. 4 Shaft

Rehabilitation Options

Three rehabilitation options were developed based on the assumption that the shaft void was open below the debris blockage, and are outlined as follows:

Option 1: Spray polyurethane foam on top of the debris blockage to 3 m thick. After the foam cures, pour a 1 to 2 m thick 30 MPa strength concrete layer on top of the foam. Allowing the 30 MPa concrete to gain strength for seven days, fill the remaining void with lower strength concrete designed to be self-supporting

Option 2: Spray 3 m of polyurethane foam on top of a form lowered 6 m into the shaft. After the foam cures, pour 1 m of 30 MPa concrete. Allowing the 30 MPa concrete to gain strength for 7 days, fill the remaining void with lower strength concrete designed to be self-supporting.

Option 3: Place granular backfill on the debris blockage and fill the shaft to 3 m below the existing cap. Pour a self-supporting concrete plug on top of the granular backfill.

The three options vary in their degree of risk versus potential cost savings. Option 1 is the lowest risk as the debris blockage is only used to support the initial spray foam before it cures and serves as the form for the initial concrete plug pour. Option 2 was discussed as a method to reduce the volume and cost of the final concrete plug while maintaining the use of spray foam as the form for the concrete plug. Option 3, identified as the highest risk, would replace the high cost foam with granular backfill and significantly reduce the volume of concrete.

The options were discussed with the Ministry of Northern Development and Mines (MNDM) and the MNDM indicated that all of the proposed options would be acceptable if successful. The high risk of using the debris blockage to support the granular backfill and the logistical problems created by the delivery of backfill into the building and void was not acceptable. It was determined that because of the location of the shaft and marginal cost difference of the rehabilitation between Options 1 and 2, the lowest risk (Option 1) was selected as the rehabilitation.

Rehabilitation Design

The concrete design was completed using the equations outlined in *Analysis and Modelling of Sill Pillars* (Mitchell and Roetteger, 1989) and *Sill Mat Evaluation Using Centrifuge Models* (Mitchell, 1991), referred to as the Mitchell equations. The equations examine several failure mechanisms commonly encountered in the creation of cemented sill pillars in mining. The failure modes considered include flexural (bending), caving, sill shear, and rotational failure.

The failure mechanisms are a function of the geometry of the concrete and void, the weight of the potential load being applied, the strength of the concrete, and other design factors such as friction angle and cohesion. Conservative assumptions were made for parameters that were unknown. The design of the concrete was completed for each of the filling stages; the initial layer of high strength concrete poured on the foam and the lower strength concrete poured on top of the one week old high strength plug. Additionally, the design included consideration of the full column of concrete acting as one unit.

The design of the initial concrete layer was completed to determine the minimum required strength necessary to achieve a minimum Factory of Safety (FOS) of 3 for the potential failure mechanisms considered, and also support the weight of concrete during the second pour. Using the span and width of the shaft obtained from the CMS scans, and assuming a plug height of 1.5 m, the limiting failure mode was identified as rotational failure. The rotational failure mechanism which normally develops in situations with shallow dipping walls was identified as the limiting failure mechanism for the initial plug given the variability in the shaft walls and the relative thickness of the initial plug to the span of the opening. The analysis conservatively assumes that the foam layer will add no support to the initial pour once it has cured and that the initial layer must support the load applied by the concrete during the final stage of backfilling. The analysis showed that the concrete would need to have a minimum required strength of 14 MPa to achieve a FOS of 3. A 35 MPa concrete mix was selected to ensure that the desired strength was met after one week of curing time.

The second concrete layer was designed to consider the strength and thickness of both concrete pour, such that the full column would be self supporting and meet the regulatory requirements for loading. The limiting failure mode was identified as the sliding failure mechanism, which indicated that the cemented backfill would have a FOS of 13 based on a weighted average backfill strength of 10.3 MPa (i.e., 1.5 m of 35 MPa concrete plus 7.1 m of 5 MPa concrete).

Construction of the Rehabilitation

The rehabilitation of the Coniagas No.4 Shaft was completed over three phases; Phase 1 – Polyurethane foam, Phase 2 – High strength concrete plug, and Phase 3 – Final concrete plug.

Phase 1: Polyurethane Foam

The first phase of backfilling consisted of spraying an expanding polyurethane foam on the timber obstruction in the shaft, using the obstruction as a form. The objective of phase one was to build a foam plug in the shaft which would act as a form for the higher strength concrete plug. The foam plug was constructed using three sets of 55 gallon drums of Part A and Part B of 2 lb. medium density closed cell polyurethane foam, which is typically applied as residential insulation. The foam was sprayed from surface through the opening in the shaft using a nozzle that would ensure that the liquid stream could reach the timber obstruction and not hit the walls of the shaft. The foam was applied evenly across obstruction and around the edges of the shaft walls to minimize the risk of concrete leaking around the foam during the next phase. A CMS was completed after the foam had set, and indicated that a foam plug thickness of 7 m had been achieved. This was approximately twice as thick as originally anticipated, likely due to the expansion rate being under estimated during the planning stage. The CMS showed that the surface profile of the foam was not flat (i.e., it was mounded in the center of the shaft). Figure 8 shows the application of the spray foam and the subsequent CMS. The foam was allowed to set for 24 hours before commencing Phase 2.

Figure 8: Application of Polyurethane Foam Plug and Cavity Monitoring Survey Using the C-ALS System

Phase 2 – High Strength Concrete Plug

The second phase of backfilling consisted of pouring a high strength, 35 MPa, fibre reinforced concrete on top of the polyurethane foam. The objective of Phase 2 was to build a concrete layer which could support the load of the final concrete layer before it had cured and became self-supporting.

A total of 12.5 m^3 of 35 MPa concrete was pumped into the shaft void using a positive displacement pump with a slick line through a window in the building into the shaft, as shown on Figure 9. A CMS was completed after the Phase 2 concrete was pumped into the shaft and indicated that high strength plug was approximately 1 m higher than the surface of the foam plug after Phase 1. Based on the shaft area from the CMS and the volume of concrete delivered, it was estimated that the foam had compressed 0.5 m, resulting in a concrete plug that was 1.5 m thick, as planned. It was anticipated that compression of the foam plug would occur between 20% and 30% based on some rudimentary lab testing of foam cores completed at another project location leading up to this work. Observations of the concrete pour showed no evidence of the concrete leaking through the foam plug.

Figure 9: Concrete pump truck and slick line used to pump concrete into shaft void

A sample cylinder of the high strength plug was broken after 6 days curing time in order to confirm that the concrete had achieved the strength necessary to support the second concrete pour. The uniaxial compressive strength test indicated that the initial concrete pour had reached a strength of 22.7 MPa, which represented a FOS of 4.9 based on the Mitchell equations when considering the load of the second pour. Figure 10 shows the shaft after placement of the high strength concrete plug.

Figure 10: Specified 35 MPa fibre reinforced concrete for initial plug

Phase 3 – Final Concrete Plug

The objective of Phase 3 was to fill the remaining void volume and have the final plug be in contact with the historical cap. The minimum concrete strength planned for this phase in the design was 5 MPa; however, 25 MPa concrete was ordered from the supplier to maintain pumping ability through, also considering the differential cost was minimal. Approximately 104 m^3 of 25 MPa strength concrete was pumped into the shaft void. Pumping was ceased when the concrete level had risen into the opening in the historical cap.

Figure 11 shows the delivery of the final concrete plug and the location of the plug surface inside the historical cap.

Figure 11: Pumping specified 25 MPa concrete for final plug

Conclusion

Cemented backfill was placed inside the Coniagas No. 4 Shaft that meets the requirements for rehabilitation of mine openings to surface as outlined in the *Mining Act* O.Reg.240/00. The concrete for the top 7.1 m of the shaft (i.e., Phase 3 pour) had an average 28-day UCS strength of 32.0 MPa (Adbel-Aty, 2014), and the next 1.5 m (i.e., Phase 2 pour) had an average equivalent 28-day UCS strength of 28.4 MPa. The weighted average equivalent 28-day UCS of the concrete backfill placed in the shaft is 31.4 MPa, which represents a FOS of approximately 13 for the limiting failure mechanism using the Mitchell equations.

Figure 12 shows a longitudinal projection of the Coniagas No. 4 shaft with the rehabilitation phases superimposed on the initial void model from the investigation.

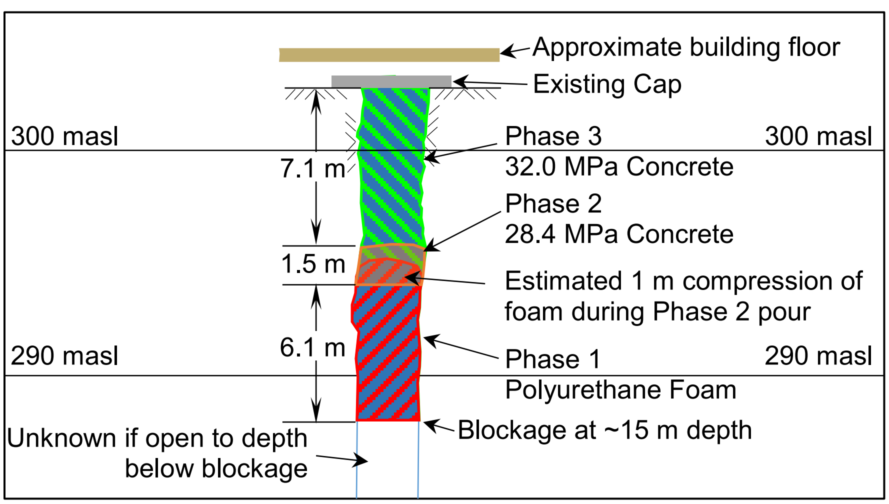

Figure 12: Longitudinal Drawing of Coniagas No. 4 Shaft

Experience on this rehabilitation has shown that cemented backfilling of mine openings to surface using a remotely constructed foam barricade is appropriate when infrastructure is present above the mine opening, or minimal disturbance of the surface/infrastructure is desired. The cost is comparable to constructing a monolithic cap above the mine opening, and concrete backfill should be considered as an alternative where possible. Application of the initial foam barricade is the greatest challenge, and the Coniagas No. 4 Shaft had favorable conditions of a vertical void with an obstruction at a reasonably shallow depth. Alternative methods of constructing a temporary barricade to build the foam plug, or incrementally building the foam plug from off of the rock walls, may be necessary depending on site and void geometry.

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