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INNOVATIVE REHABILITATION OF EXISTING TUNNELS UNDER MINIMUM IMPACT ON OPERATION

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ABSTRACT

The authors have successfully developed an innovative rehabilitation concept, which meets actual technical standards and minimizes the impact on the operation of a key conveyor tunnel. A flexible and stepwise ground support rehabilitation program utilized a combination of yielding steel arch sections with grout filled fabric hoses, which represents a fast and safe backfilling support system.

The system was developed and successfully installed at Bingham Canyon Mine, the world's largest open pit copper mine, which also includes numerous underground structures. The mine is owned and operated by Kennecott Utah Copper (RTKC) a fully owned subsidiary of Rio Tinto. The system was implemented at a conveyance tunnel, which was originally designed as a railroad tunnel, but was re-commissioned and is currently used as a conveyor belt tunnel to transport ore from the open pit to processing facilities outside the mine. The existing structure showed signs of overstressing due to movements in the surrounding rock mass, which had to be addressed with a yielding support system in order to provide safe access into the tunnel. However, the impact on the conveyor belt operation due to support installation was to be limited to the bare minimum.

Keywords: rehabilitation, yielding support, mining, stabilization, and grout filled fabric hose.

PROJECT DESCRIPTION

The C6 Tunnel is considered a critical asset for the operation of the Bingham Canyon mine as it comprises the standard route for transporting crushed ore from the open pit to the processing facility on a continuous conveyor belt system.

The C6 tunnel was originally built as a railroad tunnel. Construction was completed in 1959. The original horse-shoe shaped cross section of the tunnel was 18 feet wide and 24-1/2 feet high [8]. The tunnel length was approximately 18,000 feet. During its service life, the railroad tunnel has undergone several transformations.

The length of the tunnel towards the Bingham Canyon pit was shortened over the course of mining operations and the railroad tracks in the tunnel were removed. The invert was partially backfilled (3 feet typical) and a 72 inches belt conveyor was installed. Currently, the C6 Tunnel is nominally only approximately 21 feet high and 15,000 feet long.

Ground Support and Rehabilitation Measures prior to 2014

The C6 tunnel was mined mainly with conventional mining methods, using drill & blast as the typical one. However, the weak geological sections, such as those encountered in the Fortuna fault, were excavated by shaping and chipping with machine-held moils [8].

The tunnel was lined with steel sets embedded in concrete lining. A concrete lining with a minimum 4 inch coverage on the intrados of the steel support was specified. A large part of the tunnel was lined with 10, 12 or 14 inches of concrete to accommodate steel profiles of 6, 8 and 10 inches, respectively. The spacing of the steel sets varied from 2 to 6 feet according to the encountered rock conditions. The steel sets were backed with timber lagging (2 inches x 2 inches x 12 inches), which acted as a formwork at the extrados of the concrete lining. Approximately 200 board feet of lumber per foot of tunnel was used for this purpose. Voids between the lagging and rock were filled and tamped. Load distribution spreaders, consisting of 90 to 100-pound rails, were used at the bottom of the steel sets [8].

Prior to 2014, shotcrete was used as a rehabilitation support measure, predominantly towards the end section of the tunnel close to the pit. Shotcrete was sprayed presumably to strengthen the concrete liner at locations, which showed damages. The timeline of the shotcrete application is unknown.

In other sections, the tunnel was previously rehabilitated with installation of 2-inch chain link mesh to prevent spalling and block failure. The mesh was secured in place with the use of what appears to be 10" x 5/8" diameter bolts through the shotcrete and presumably embedded in the cast-in-place concrete lining underneath. The chain link mesh was installed from the portal to conveyor table #76 in 1996 and from conveyor table #110 to table #120 in 2011. Each conveyor table is approximately 20 feet long. The chain-link mesh has since been removed and replaced with welded wire fabric (WWF).

Figure 1 shows the typical geometry and support system of the C6 tunnel as completed in 1959. Figure 2 shows the C6 Tunnel in an area where it is partially unearthed by surface mining activity. Steel sets embedded in the concrete lining can be clearly seen, as well as timber lagging at the extrados of the lining. The deck shown in Figure 2 is not typical for the tunnel and just used close towards the pit portal and has no structural support function.

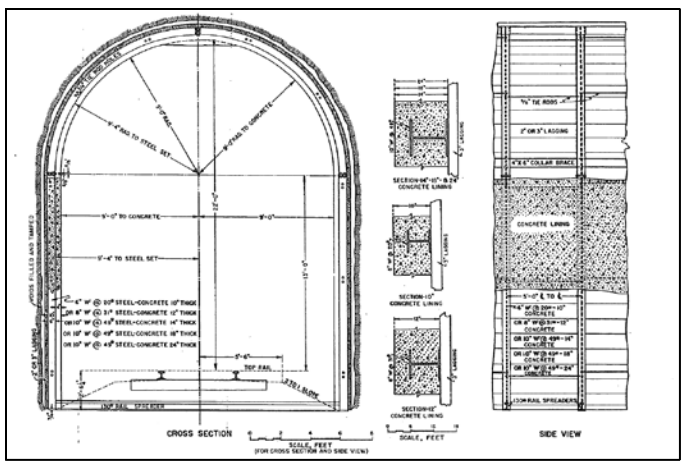

Figure 1. Typical geometry original C6 Tunnel [8].

INITIAL SITUATION

The section of the tunnel between the concentrator, located at the portal away from the mine near Copperton, UT, and the Fortuna fault was inspected and assessed to be in relatively good condition. However, the section between the pit portal and the Fortuna fault had already shown signs of deterioration in the past and was therefore subject to numerous rehabilitation campaigns prior to 2014 as described above. The existing structure showed signs of overstressing due to movements in the surrounding rock mass. Wide open cracks covering the entire circumference of the tunnel and spalled concrete and shotcrete was observed.

Figure 2. C6 Tunnel, partially unearthed during open pit mining activity

Between January and June of 2014, excessive and progressing damage was observed from the pit portal at table #56 to table #121 (Figure 3). Spalling of concrete slabs from this section of the liner led to partial closure of the tunnel to access in early June. Significant damage was reported within the approximately 200-foot tunnel section along the Fortuna fault. The remaining portion of the tunnel between the Fortuna fault and the pit portal was also reported to have increasing rates of deterioration. As a safety precaution, access to the tunnel had to be restricted between the pit portal towards the end of the Fortuna fault crossing.

Figure 3. Typical damages in the tunnel's back.

REHABILITATION APPROACH AND DESIGN

The conveyor is a critical asset for the operation of the mine and needs continuous inspection and maintenance as a precautionary measure. Since a portion of the conveyor tunnel could no longer inspected and maintained, the restricted access to the tunnel became a critical risk to the operation of the mine.

The primary purpose of the rehabilitation design was therefore to restore the access to the C6 Tunnel to allow for inspection and maintenance works on the conveyor belt to avoid a potential damage and standstill of this lifeline of the mine. Time was of the essence and Gall Zeidler Consultants (GZ) developed the subject rehabilitation design concept with the support of DSI Underground Systems (DSI), and Beton- und Monierbau Herten (BuM Herten) under enormous time pressure. Within a couple days the original design concept was completed and accepted by RTKC. GZ worked then in close cooperation with RTKC as well as DSI and BuM Herten, the key suppliers, and Cementation USA on further refinements and completion of the design.

Based on observations of the pit walls and the geological model of the mine, it was obvious that the observed damages in the underground tunnel are related to slope movements on top of the Fortuna fault system. The slope movements were concurrent with the observed damages in the first 1,200 feet of the C6 Tunnel until the Fortuna fault was crossed. However, an in-depth knowledge about the mechanisms behind the slope movements and a clear picture about subsurface movements of the slope was not available during the design phase.

The purpose of the subject design was therefore solely the restoration of access to the C6 Tunnel by providing a safe working environment. This goal was achieved by supporting the existing, deteriorating lining and providing a support system that could withstand the relatively large movements, and with this approach mitigate and slow down the ongoing deterioration of the lining. From an operational point of view, the installed support measures had to ensure sufficient clearance, while the impact on operation during the rehabilitation installation had to be minimized.

As shown in Figure 7, the conveyor was located close to the left sidewall with a nominal clearance of about 1 ½ feet between the conveyor and the wall. Providing more clearance by moving the conveyor towards the center of the tunnel was not an option, because the clearance on the right side of the conveyor was needed to provide a pathway for vehicles. In addition, a relocation of the conveyor would have required an additional shutdown of the conveyor and would have made access into the tunnel during the construction process much more difficult.

On the right side of the conveyor belt, a roadway with a minimum clearance of about 6 feet was to be maintained, which provided just 1 foot of available clearance for the width of the support system. All installation measures had to be installed from the roadway or above the conveyor, preferably while the conveyor was running.

Support measures like installation of shotcrete or a new cast-in-place lining had to be excluded from the beginning due to the lack of clearance.

Options with rock bolts as the primary rehabilitation support did not appear to be feasible. It was to be expected that relatively long rock bolts would be necessary to pass the loosened area around the original tunnel to show a sufficient structural effect. Since no detailed information about the rock mass surrounding the tunnel was available, rock bolting was considered too risky for a long term solution. In addition, installation of long rock bolts would have been a challenge considering the clearance towards the belt and potential damages of the belt due to collision and muddy drilling water.

For similar reasons shotcrete was excluded. Shotcrete appeared not attractive for another reason too, since spalling of shotcrete from previous rehabilitation measures was one of the reasons to restrict the access in the first place.

Considering the need for a relatively clean installation process and limited available clearance, as well as the advantage of pre-assembly prior to construction, steel sets appeared to be the only viable option. However, due to numerous passes of rehabilitation with rock bolts and mesh as well as shotcrete and combinations thereof, the steel sets had to provide sufficient geometrical flexibility during the installation.

Regarding the ongoing slope movements, a stiff support also appeared counterproductive. Therefore, a yielding support system had to be chosen, which allowed for movements by still providing sufficient structural support and a safe working environment. Yielding support also provides the greatest benefit to elongate the service life.

Yielding support systems in general comprise all ground control elements, which allow a considerable controlled stress release and deformation of the ground, while maintaining supporting forces. Main areas of application are squeezing and swelling ground conditions, weak ground in general combined with high overburden, and fault zones. Depending on ground conditions, magnitude of displacements, and lifetime of the excavation, different means and methods of yielding support are applied. Examples for support elements with a yielding ability are anchors and rock bolts with a free length or a deformable section, lining stress controllers (integrated in a shotcrete or concrete lining), or yielding steel support, just to mention a few [3], [4].

The developed design concept was consistent with all requirements and goals above while being extremely simple and easy to install. The design provided a yielding support system comprised of TH steel sets and prefabricated, grout filled fabric hoses, type BULLFLEX®. These grout filled fabric hoses allowed the TH steel sets to be designed with a 6-inch offset to the theoretical existing alignment, by providing continuous load transfer from the existing lining into the steel sets. The grout filled fabric hose system also allowed accommodation for geometrical imperfections by the damaged existing lining or prior rehabilitation measures. In addition, joints of the TH steel sets were laid out to allow for vertical as well as horizontal adjustments providing additional geometrical flexibility during construction. Sections of the TH steel sets were laid out with an insertion piece, a so-called dutchman, to allow for adjustments for differing invert backfill levels (Figure 7).

The yielding support system used for rehabilitation of the C6 tunnel consisted of TH steel sets with yielding locks (Figure 4). TH steel sets were originally developed by H. Toussaint and E. Heintzmann in the 1930's for mining operations in Germany, which are prone to highly squeezing ground conditions under high pressure. Due to its special shape, single interleaved TH sections are easily connected by different types of lock systems, which are defined by German standards [1], [2] (Figure 5). This allows both an easy and fast connection of single segments in underground operations. Different types of TH sections are available and classified according to their nominal weight in [kg/m], which equals 0.672 [lb/ft]). For the present application, TH-25 and TH-29 type segments have been used. The nominal weight of these profiles is 25kg/m (17 lb/ft) and 29kg/m (19.5 lb/ft), respectively.

Figure 4. TH steel sets in a storage area and principal assembly of the TH system.

The TH steel sets are produced as straight pieces. The ground control supplier cuts and bends the TH profiles according to geometrical layout in the design drawings (Figure 7). Foot plates for the connection to spreader beams or nuts are factory welded to allow for the use of spacer bars.

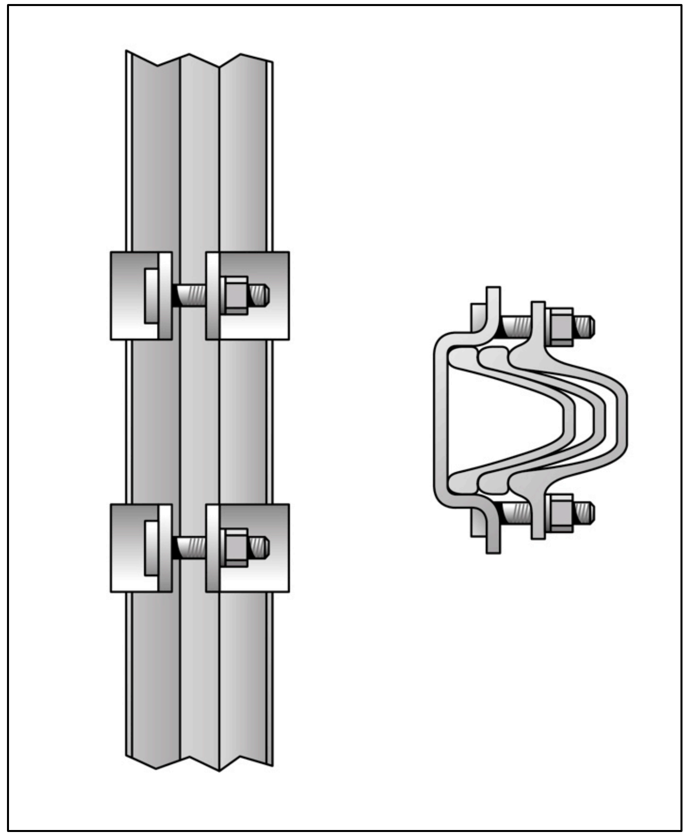

Figure 5. Principal assembly of the TH system.

Grout filled fabric hoses consist of textile encased columns made of high-strength fabric, which are subsequently filled with grout. For the current application as roof support backfilling system, grout filled fabric hoses were installed in the gap between existing lining and TH steel support to provide an immediate load transfer and form fit between the passive steel support and the lining surface (original concrete lining or rehabilitation measures, Figure 6). Due to the working mechanism of its fabric, grout filled fabric hoses allow even the introduction of an active pre-load into the excavation perimeter, while maintaining a controlled residual load. Excess water in the grout will be pressed out of the fabric by stiffening the grout. This process provides an immediate load transfer, even before the grout starts hardening. The grout filled fabric hose system has already been used previously for construction projects in the USA. Examples for applications are the Detroit River Outfall No. 2 [5] or the Northeast Interceptor Sewer in Los Angeles [6].

The German standard DIN 21530-3 (2003-05) [3] also defines and standardizes the yielding load of TH joints connected by two or more locks, which is in the range of 150 to 200 [kN] (34 to 45 [kips]). The research of the load-deformation behavior of TH profiles with yielding locks in German coal mining dates back to the 1950's [7] and provides a helpful insight into the yielding mechanism of installed TH arch sections under progressive load and deformation or respective closure of underground openings. Simplified, the TH joints provide an ideal elasto-plastic like behavior. As soon as the slipping load in the joint is reached the joint slips by holding the load. However, by slippage in the joints the diameter of the entire cross section gets smaller and depressurizes the set – the system yields.

Based on the application at Bingham Canyon, ongoing ground movements are to be expected due to the surface and subsurface slope movements along the Fortuna fault. Since the exact deformation mechanisms are unknown, the system was designed to allow for vertical as well as horizontal yielding. Yielding occurs as soon as the slippage load limit is reached. Due to the slippage the system distresses itself by yielding. Two vertical yielding joints are located at and below springline and allow for sufficient yielding capacity in vertical direction. Two yielding joints in the back of the steel sets provide for sufficient yielding capacity in horizontal direction (Figure 7).

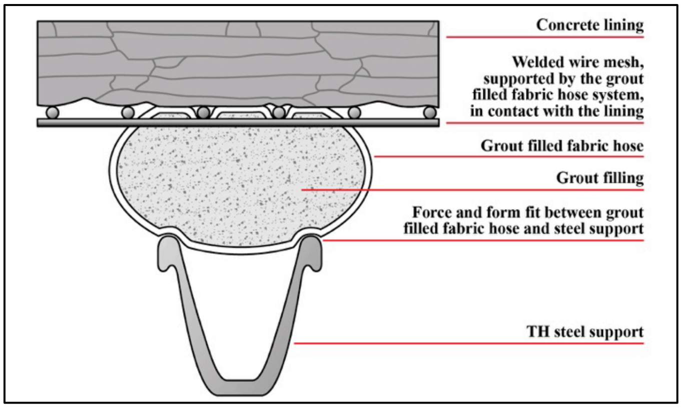

Figure 6. Schematic TH steel set and grout filled fabric hose system supporting a rock mesh.

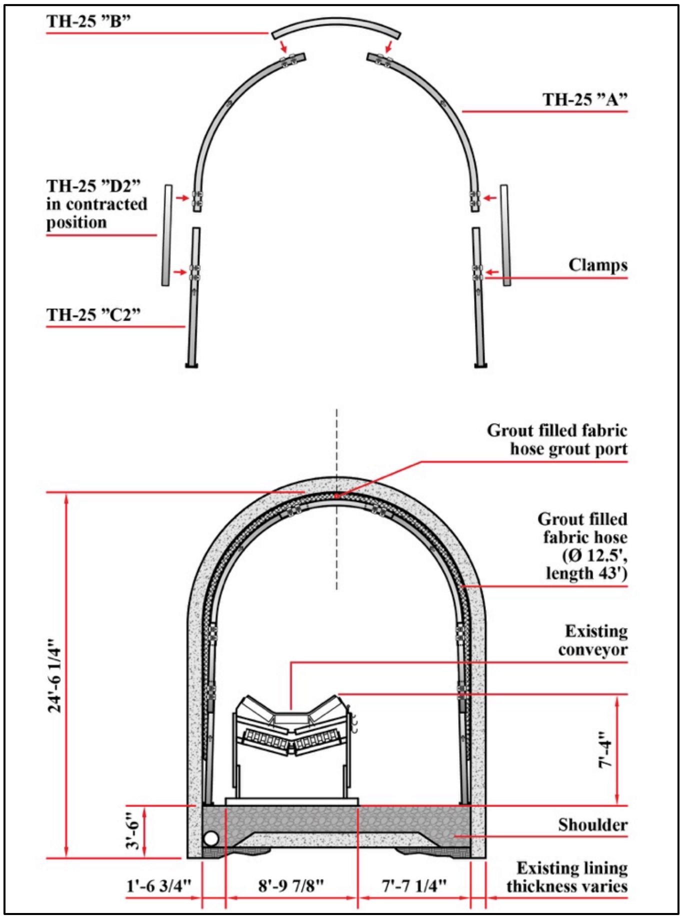

Figure 7. Typical tunnel section with TH steel sets.

During the design three different failure mechanisms were evaluated and quantified:

1. Yielding in the joints
2. Buckling of the vertical legs
3. Material failure of the steel

The system is designed in a fashion that buckling and steel failure can theoretically never occur, because the joints in the system will yield and distress the system before it can reach the buckling or steel failure load limits. In addition, the design for buckling conservatively disregarded the strutting effect of the grout filled fabric hose.

To avoid horizontal slippage of the steel set footings towards the center of the tunnel, the vertical legs are slightly sloped outwards to the concrete lining (Figure 7). A vertical load in the steel sets therefore always tends to push the footings outwards and hinders slippage of the footings towards the center, which could potentially destabilize the system. The geometrical layout locks the system in place to avoid this failure mechanism.

The open side of the TH steel sets is located towards the original lining. The grout filled fabric hose is pushed into this opening during grouting. Furthermore, the hose overlaps the sides of the steel sets as shown in Figure 6. After the grout in the grout filled fabric hose is hardened, it holds and supports the TH steel set in place and avoids a potential rolling out of the load plane of the set. A buckling of the system out of its load plane (cross section) is naturally avoided by the system.

The design is therefore in principal laid out as a “self-protecting” system against numerous failure mechanisms. Buckling and overstressing of the cross section is avoided by yielding joints; buckling either in the cross section or out of plane is sidestepped by continuous support of the grout filled fabric hose. The potential for slippage of the footings is prevented by the geometrical layout.

Theoretically it is also possible to conduct an active stress relief of the steel sets. During this procedure, the sections of the sets have to be distressed by temporary support measures. This allows to loosen and de-stress the joints. After the distressing the joints the load will be transferred back into the original set.

Another design parameter is the spacing of the steel sets. The design allows for a spacing of the steel sets between 3 to 6 feet. A 6 feet spacing allows to place additional steel sets in future rehabilitation campaigns on an as-needed basis.

Figure 7 provides the typical tunnel cross-section with the yielding support system.

Another element of the design is a so-called Trigger Action Response Plan (TARP), which is part of the Ground Control Management Plan for the C6 Tunnel. A TARP is a proactive management tool that defines pre-planned responses to escalating levels of risk. The scope and intent of the TARP is to ensure the health and safety of employees working in the tunnel by developing a mechanism for monitoring the tunnel against potential tunnel instability or failures and provide an action plan in case of any unwanted movement or instabilities while the tunnel is still in service. The TARP serves as an integral component of risk management and works in conjunction with the Rio Tinto Underground Performance Safety Standard D1.1.

The TARP is a structured mode of addressing likely scenarios pertaining to the condition of the tunnel lining and provides suitable responses to mitigate and prevent health and safety as well as structural risks. Furthermore, the TARP defines the baseline level as a point of reference and two trigger levels, namely the warning level and the action level. The baseline level meets acceptable health and safety and stability requirements and has been developed for each of the five Support Performance Categories (SPC), reflecting the installed typical support and rehabilitation measures for the entire C6 Tunnel.

IMPLEMENTATION AND CONSTRUCTION

The installation of the described rehabilitation support measures was started in May 2014 and completed in November 2014. The installation of the TH steel sets was complicated by the business need of the conveyor tunnel. The conveyor carries all production from the mine to the mill, and due to outstanding customer commitments the operation of the belt could neither be impacted for extended periods of time nor shut down on a daily basis.

To develop efficient installation means and methods a work stream was started immediately and in parallel with the structural design. The goal was the development of a construction method that minimizes the impact on operation of the conveyor and in addition allows working in close proximity to the running belt while minimizing personal exposure to meet the stringent safety requirements of Rio Tinto. The team was comprised with a multidisciplinary team from RTKC, GZ, BuM Herten, DSI, and Cementation USA.

The developed system evolved in an elevated work platform suspended off of two monorails located in the arched profile of the tunnel (Figure 8). The work deck included a crane and jig for assembling the steel sets and placing the completed sets. In addition, it provided access for grouting of the grout filled fabric hoses and prevented contact with the operating belt (Figure 9).

This work was scoped, reviewed, and released for fabrication within 2 weeks of the initial brainstorming session.

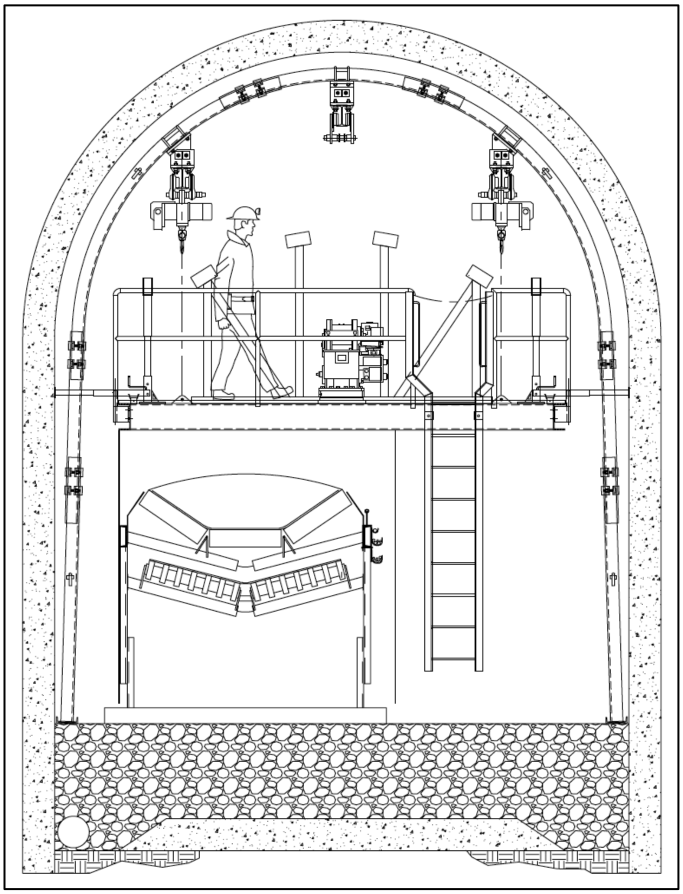

Figure 8. Cross section of work deck in tunnel.

While the elevated work platform was fabricated an opportunity arose to begin a targeted rehabilitation program, focusing on the most damaged section of the tunnel in the Fortuna fault zone.

This initial phase of the repair project focused on an approximately 250 feet section of the tunnel, which sustained the most severe damage, starting 1,100 feet from the new mine side portal and ending approximately 13,000 feet from the Copperton portal.

The timing of this repair was scheduled to capitalize on a planned shutdown of the conveyor and had a very short lead time for planning. Again the same multidisciplinary team created a solution utilizing a jig attached to a mini-excavator (Figure 10) to stand the steel sets and grouting the bags using a standard grout pump. To meet the project timeframe this scope of work was staffed to support advance from both the Bingham Mine side and the Copperton side. The work required careful logistical handling as all supplies on the Copperton side had to be moved 13,000 feet to the work area and assembled underground, while the Bingham side could pre assemble arch profiles above ground. Work on this 250 foot section began on May 26th and was completed on June 10th.

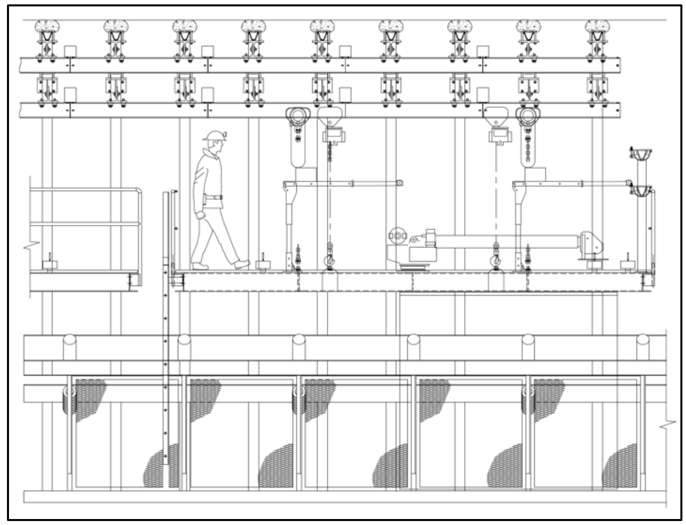

Figure 9. Longitudinal section of work deck in tunnel.

Figure 10. Mini-excavator and jig, at fabrication shop.

Upon completion of the rehabilitation in this section, additional inspections of the tunnel revealed significantly larger areas requiring varying degrees of rehabilitation. After the belt was restarted the preparations for the next phase of repair had already begun.

Due to the requirement of minimizing impact to the operation of the belt while securing the tunnel as quickly and safely as possible, a second approach was derived. The Bingham side would utilize the elevated work deck to install steel sets as originally planned. A second crew would repurpose an existing work deck located in the tunnel to install wire mesh and rock bolts using jacklegs over the running belt (Figure 11). This measure would secure the tunnel temporarily and provided access until the steel set installation from the mine side could proceed to the section previously supported.

A team of structural engineers re-designed the bolting deck. Reinforcements and additional guarding were fabricated and installed before the deck was commissioned. The services for this deck were supplied from the mine side of the tunnel. Air and water was supplied by hoses, pulled through the damaged sections of the tunnel using a 1 yd^3 LHD fitted with a tele-remote package. Split Set Bolts and OMEGA-BOLTs were used with bolt selection dictated by the required longevity of each system. The installation was complicated, because the embedded steel sets of the original lining were fully encapsulated in the existing concrete tunnel liner. The lagging material and cribbing located behind the liner provided additional challenges. The bolting deck was commissioned on July 22nd and was decommissioned on August 19th after securing approximately 926 feet of tunnel.

Figure 11. Bolting work deck.

The elevated work deck was commissioned in the same time period as the bolting deck. A construction platform was erected at the Bingham Portal and after initial construction and commissioning steel set installation began on July 22nd. The TH steel sets were transported to the work area using custom-built baskets suspended from the walkway monorail. TH steel sets were assembled in an assembly jig located on the deck. In the next step the legs were slid into place and stood from ground level. After the legs were placed and the arch was assembled in the jig a crane lifted the arch section into place and the legs were connected. Monorail brackets were installed on the profile before the groutable hose was secured.

The groutable hoses were inflated using a grout mix supplied by a local ready mix supplier. The grout was pumped via a 2 inch slick line to the work deck to eliminate the need for bag handling and grout machine maintenance underground. Monorail sections 6 feet in length were suspended off of the brackets and affixed to the stood and grouted steel sets and attached to the end of each existing monorail section. After the extension was installed, the stops were moved forward onto the newly installed monorail section and the deck can advance forward. This extension of the monorail occurs after two sets are stood and fully grouted, with each section aligned and plumbed to insure the work platform can advance efficiently.

Figure 12. Elevated work deck over the running conveyor belt.

Men installing legs were protected on both the walkway side and the one aligned immediately next to the conveyor by guarding affixed to the work deck. The guards protect workers from contact with moving rollers the fast moving belt. Due to load requirements on the monorail set spacing is fixed to 3 foot centers for all repair work using the work deck. The monorail system has allowed set installation over the running belt with work continuing at a rate of 6 sets per day or 18 feet per day.

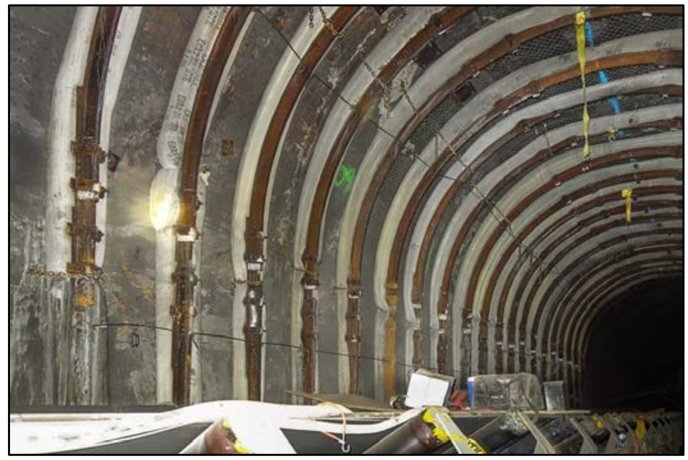

Figure 13. Completed tunnel section with TH steel sets.

CONCLUSIONS

The authors have successfully developed an innovative rehabilitation concept, which meets actual technical standards and minimized the impact on operation of a key conveyor tunnel. The flexible and stepwise ground support rehabilitation program utilized a combination of yielding steel arch sections with grout filled fabric hoses, a fast and safe backfilling support system.

The design allowed for sufficient geometrical tolerance to accommodate the variations of cross section geometry and supported a quick installation process. The installed yielding support system provides for long term mitigation of the expected movements and elongates the service life of the existing asset.

Hence, the best value demonstrated by this installation method is the fact that the installation of the TH profiles could be undertaken while minimizing the impact on critical operations within the tunnel. Similar work platform systems have been utilized in civil applications for quite some time, but have not been executed in earnest in a mining application until now.

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