THE REFURBISHMENT OF STOCKPILE ARMCO TUNNELS WITH CONSIDERATION TO CORROSION DEGRADATION AND STRUCTURAL INTEGRITY ISSUES

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1 INTRODUCTION

With mining facilities typically extending envisaged original service life requirements, management need to be more prudent in re evaluating assets to determine " fitness for purpose" of assets to be used beyond designed service life expectations. Waiting until the plant design life is imminent can result in costly refurbishment/replacement undertakings to reinstate asset integrity. This extension of plant and equipment beyond original design life has become a common undertaking for the majority of minesites within Western Australia, as exploration and technological advances in mineral recovery greatly increase original mine life expectancy thus requiring that some assets extend beyond original design capabilities.

Most refurbishment activities in the mining industry involving assets deteriorated through corrosion are typically refurbished during normal plant operations and/or during scheduled plant shutdowns. However, some assets are so designed and constructed that refurbishment of the asset, even under shut-down conditions, had never originally been contemplated and require novel and unique systems and procedures to be developed to reinstate asset integrity.

Keywords: Corrosion, cathodic protection, microbially influenced corrosion, hypersaline waters, fitness for purpose, safety.

1.1 The Scenario

A large nickel operation in Western Australia approached Extrin with a query regarding observed corrosion degradation to the main Ore Stockpile Emergency Escape Tunnels constructed in 1994. The original escape systems below the existing stockpile consisted of two (2) 3.3 metre diameter helical lock-seam corrugated steel pipe fifty (50) metre tunnels with a 125mm corrugation pitch and 25mm depth. Each escape tunnel had the addition of an infill concrete slab poured during construction.

Steel thickness was originally 4mm (as calculated for wall thickness based on original stockpile design height) to facilitate loadings imparted on the tunnels. With exposure to extremely hypersaline waters both internally from washdown and externally from stockpile dust suppression, the corrosion to the galvanized tunnels had resulted in a 50% loss of material thickness at "worse case" locations. This metal loss externally and internally was most pronounced at the lower third of the tunnel where externally the water would settle and saturate the backfill material and internally where washdown and splashing from process water would be most apparent. Although the remainder of the tunnels surfaces appeared reasonable despite the uniform corrosion evident, the damage had already been done, with this weakened zone now being exposed to the greatest loadings.

1.1.1 Structural issues

At the stage where the existing tunnel parent metal, predominantly at the internal concrete base, had suffered appreciable corrosion and reduction in parent metal thickness the structural condition of the existing tunnel section changed. Instead of the loads being spread around the entire structure, the upper portion of the existing tunnel from the concrete floor/tunnel wall interface upwards started to act as an arch.

The initial inspection identified that deformation in certain locations had occurred which confirmed that the original structural intent of the existing tunnels was no longer being satisfied. As the corrosion at the base continued, the upper portion of the tunnels acted as an arch, but without the restraint necessary to cater for the vertical and horizontal forces. A second inspection prior to undertaking the works revealed further deformation/movement had occurred and at this stage the tunnels were heading towards further deformation and possible local failures.

Fig I: General view of main ore stockpile. Note Emergency Escape Tunnels at base of stockpile.

Fig II: General view of Escape Tunnel prior to refurbishment. Note the corrosion degradation at the lower third of the tunnel.

2 THE APPROACH

The first step in providing the client with options to rectify the corrosion concerns was to clearly “define the problem”. Visually, it was possible to determine the extent of corrosion to the tunnels internally, yet externally, the condition of the tunnel steel was an uncertain parameter. Using ultrasonics, thickness measurements were obtained, yet the merit of the readings was questioned due to the extent of degradation and curvature of the corrugation perhaps giving ambiguous findings. For the purpose of accuracy, sections of the tunnel were removed to view the back surface of the tunnel walls. Removing 100mm diameter steel sample coupons at select locations throughout the tunnels provided several pieces of useful information. Firstly it allowed for visual assessment of the backface of the tunnels to ascertain the corrosion morphology but most importantly it allowed for accurate measurement of the remaining steel thickness. Coupon retrieval confirmed that the locations of most pronounced corrosion internally (lower third of the tunnel) were also replicated externally where backfill saturation was evident. In most instances the zinc galvanizing layer had been consumed by corrosion and the steel was actively corroding.

Additional to the coupon retrieval, potential measurements (versus Copper/Copper Sulphate reference) were taken along the length of both structures with potentials in the vicinity of –500 to -600mV indicative of that of corroding carbon steel. These potentials also verified the widespread loss of the galvanised coating.

Visually, the tunnels internally presented a substantial degradation to the lower section particularly at the tunnel wall/ concrete in fill floor interface. This location is where the majority of washdown is concentrated and the ponding and settlement of wet process material is evident. The problem was further exacerbated with the apparent movement of the wall away from the concrete floor which not only increased the extent of washdown water entering at the tunnel wall/floor interface but was also evidence of tunnel deformation. The water used for the washdown and the subsequent dust suppression of the ore is extremely saline and aggressive with chloride levels in excess of 32,000ppm as analysed. The major concern observed during the surveys was the apparent deformation of the tunnels at locations which suggested a substantial weakening of the structure.

Fig III: Close up view of corrosion degradation typical in the Escape Tunnels. Note also kink in the tunnel wall above red indicator line.

2.1 Option reviews

The brief given for the considerations of the existing stockpile Emergency Escape Tunnels was as follows:

- The Stockpile height was to be increased from original 20 metres to a new height to facilitate a 30 metre stockpile.
- The ore density was to be 1.69t/m3 with full safety factors applied
- Remaining service life expectancy of 20 years.
- All internal services (water, plant air, high voltage cable and fibre optics) are to remain for the duration of the works and can not be de-commissioned. These services were crucial and were responsible for entire plant operation.
- Zero disruption to existing plant operations 24hrs 7 days a week.
- Selected refurbishment to be long term, requiring minimal maintenance over the 20yr design life.

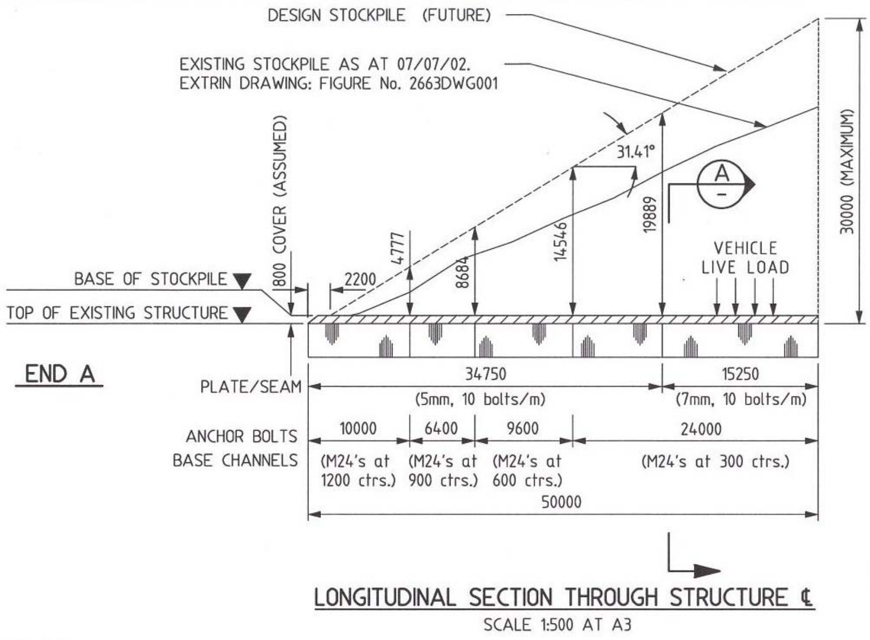


Fig IV: Tunnel design parameters showing original and future designed stockpile.

From the review of all information obtained during site surveys, and based on the results of structural calculations, it was clearly evident that the existing stockpile tunnels were not sufficient to provide the service life expectancy as required. Additionally, it was evident that the current tunnel integrity was in question and the extent of existing corrosion degradation had resulted in the tunnels deteriorating to such an extent that safety measures had to be implemented to prevent further tunnel deformation or collapse. The need to refurbish the tunnels had now become paramount as continued deformation of the tunnels may have led to the inability to refurbish the tunnels and thus result in the tunnels being condemned. The direct result of this would have meant the removal of the entire stockpile to either remove and reinstate these tunnels or resituate the stockpile. Both options held severe cost ramifications.

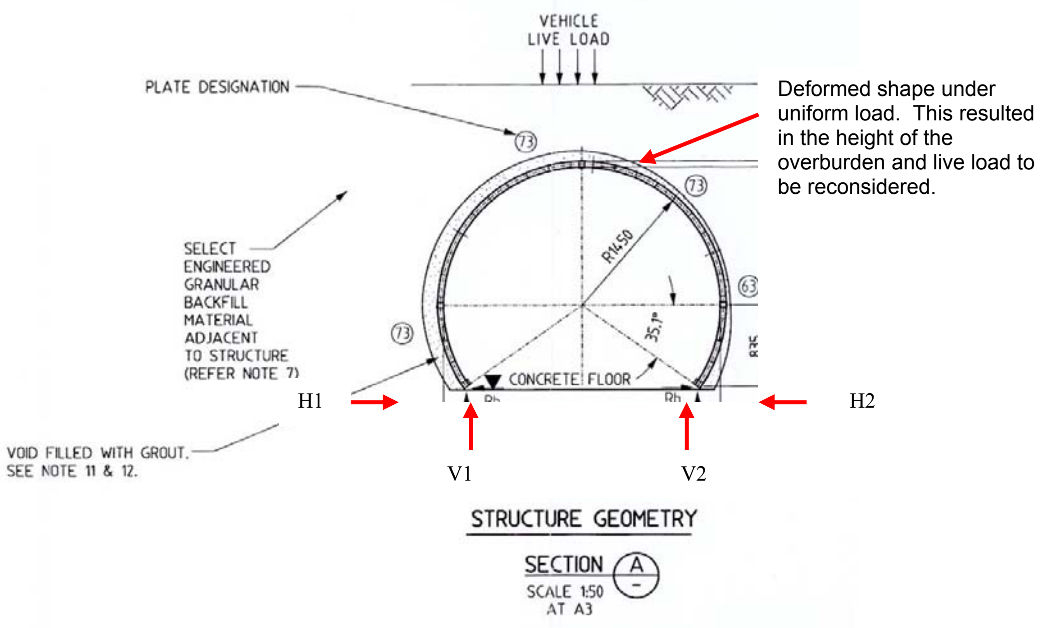
Safety measures implemented for the course of the project included:

- Restricted access to the tunnels
- Regular surveys to determine any increase in tunnel deformation
- Stockpile height was reduced significantly to reduce loadings imparted on weakened tunnels and compensate for loss of wall thickness
- No access to tunnels during loader operations on overhead stockpile

To provide the expected service life and under the governing parameters, two major options were provided for review. The first option involved the use of layered fiberglass to create an internal shell to provide internal strengthening and future corrosion resistance. Being non metallic, this option would be more corrosion resistant yet based on the structural requirements of the new stockpile, the thickness of the shell required and the extent of work required to accomplish this task did not make it a cost viable option. Additionally, it was determined that removal of the existing sound concrete base would have accelerated the deformation of the existing tunnels and likely resulted in existing tunnel failure.

The second option provided and ultimately selected for the project was the re-lining of the existing tunnels using galvanized Multiplate sections of varying thicknesses and sizes. As this type of project had not been undertaken before on such a large scale and under stringent parameters, the pre-project engineering and structural knowledge necessary to investigate, understand the previous, current and future requirements of the structures was considerable.

The new designed internal arch section took into consideration all existing and future load requirements. At the base of the new arch section the horizontal and vertical forces (see Fig V) had to be accommodated by the existing concrete base which would have a substantial compressive force.



Deformed shape under uniform load. This resulted in the height of the overburden and live load to be reconsidered.

Fig V: Section showing new tunnel liner within existing tunnel at "worse case" location of tunnel deformation. Note the offset.

Another extension to the proposed option, to protect the original tunnel structure, was that of cathodic protection. To determine the efficacy of such a system and the benefits of the same, detailed site investigations, measurements and testing were undertaken. It was determined that the extent of equipment that was inadvertently electrically connected to the tunnels made it prohibitive to undertake cathodic protection of the tunnels back surface. Hence, a hybrid cathodic protection system was designed and implemented into the multiplate tunnel option to provide some low cost corrosion management techniques to facilitate the protection of the new structure.

3 THE OUTCOMES

Providing for an extended service life, the option of re-lining the tunnels with a new metallic internal liner was selected with additional methodologies implemented to provide for both better long term corrosion protection and structural integrity of the relined tunnels.

3.1 Concrete floor reinforcement

To facilitate the placement of the new internal tunnel liner, the first undertaking was to reinforce the existing sound concrete floor to ensure its ability to handle the increase in stockpile height. Reinforcement of the existing floor was critical as removal of the floor may have resulted in the collapse of the existing (original tunnel liner). Structural calculations concluded that with considerable reinforcement placement and infill placement, the floor would handle the loads to be imparted. Design specifications specified that another 780 metres of galvanized Y20mm reinforcement bars be drilled and grouted into the existing concrete floor. Additionally, prior to any concrete placement the floor was high pressure water washed with potable quality water followed by abrasive blasting prior to the application of a bonding mortar.

Fig VI: Photograph showing existing concrete floor strengthening prior to undertaking tunnel placement.

3.2 Plate installation

As the client required a minimal loss of tunnel internal dimensions and as the existing services prevented too much movement within the tunnels, a void of approximately 200 -250mm was all that was left to work with between the tunnels for bolt fixing. As a result, a four plate closure system was incorporated which was then fixed to a modified angle section bolted to the modified concrete floor. To facilitate the forecasted increase in stockpile height, design requirements resulted in the first 15 metres of tunnel fabricated from 7mm plate with the remaining 35 metres requiring 5mm plate.

Fig VII: Photograph showing new tunnel sections and fabricated angle bases as unloaded on-site.

Lifting of the individual plate sections (100+kg) into the required position was in itself a challenge, as tunnel height and movement restrictions due to existing services prevented the use of such machinery as forklifts or bobcats. To over come this concern, a modified electric walking pallet stacker unit was utilized and provided the lift and movement required of the heavy plate sections.


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Fig VIII: Photograph showing new tunnel sections being torqued after installation.

3.3 Void grout pumping

To prevent movement between the two tunnels and to provide extra added protection of the newly placed steel liner, the void between the two tunnels was filled with a flowable grout. Placing the grout required that sockets be pre-fabricated into the new liner plates at select locations and intervals, so the grout could be added as desired to ensure that no bridges or voids were evident between the two tunnels. Design calculations required a grout strength of 5Mpa, yet at the time of placement, a mix of 15Mpa minimum was used.


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Fig IX: View of grouting truck arrangement. Concrete was batched on-site due to remoteness and pumped directly into spray unit hopper.

3.4 Internal “splash zone” coating

To facilitate extending the period of “time to first maintenance” it was determined that a “splash zone” coating to the lower sections of the newly placed galvanised sections where hypersaline wash down waters are most heavily concentrated, should be applied.

The walls were high pressure water/detergent washed prior to the surfaces to be coated receiving a whip blast to provide some profile on the galvanized wall prior to coating application. An epoxy mastic system was selected as the coating most suited to provide the protection required. All bolts, nuts and join locations were first “stripe coated” by brush to ensure the location was well coated.

Fig X: Photograph showing spray application of :splash zone” coating to tunnel wall.

3.5 Cathodic Protection

Externally, the main concern with the tunnels is the exposure to the hypersaline dust suppression water, which resulted in fitting a sacrificial anode cathodic protection system. Previous cathodic protection trial investigations showed that the tunnels were not electrically isolated from such assets as services or overhead conveyor stacker legs. As a result total protection from cathodic protection could not be assured. A partial protection cathodic protection system was designed and implemented to reduce the incidence and severity of corrosion, further extending tunnel service life. Both the existing and new tunnels were electrically bonded to ensure that the cathodic protection would initially be used to slow the corrosion process of the existing tunnel, which in turn increases the time before exposure to the hypersaline water and backfill material of the inserted tunnel.

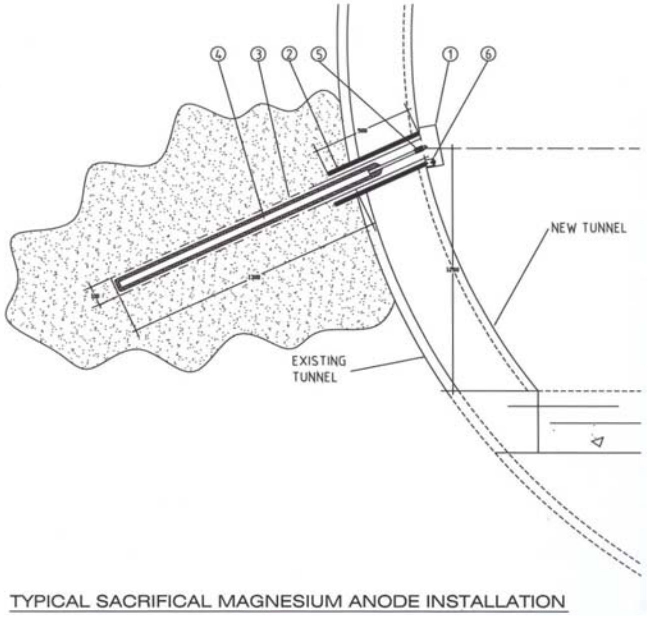

Fig XI: Figure showing sacrificial anode placement into tunnel walls.

Fig XII: Photograph showing coring activity through tunnel walls with diamond tipped core to facilitate anode placement.

4 SUMMARY

The tunnel lining option was undertaken without any disruption to mine production and was completed within the allocated schedule. The tunnel reline methodology undertaken was one of the first of this type of construction and as a result required detailed engineering and planning. The execution of the works was stringently managed with only slight variations to the originally proposed schedule. The end result was a refurbishment option implemented successfully with a cost saving of approximately 40% over other options proposed.

The tunnel relines were completed within 50 working days on site with no lost time incidents.

The installation process involved the placement of the following items in each 50 metre long escape tunnel:

- 250 individual plate sections of varying plate thickness from 5 – 7mm and weighing as much as 100kg each
- 3216 bolts and nuts for plate fixing
- 242 Ramset bolts for channel hold down to facilitate plate anchoring
- 75 cubic metres of grout to fill the void between the existing and new tunnel liner.
- Sacrificial anode system
- Internal protective coating to the “splash zone” within the new tunnel liner.

Fig XIII: General view of refurbished tunnel with all service relocated.

4.1 What next – "proactive corrosion management"

The outlay for the tunnel refurbishment project could have been prevented with some simple yet effective corrosion management techniques implemented at construction and maintained during service. The application of an internal "Splash Zone" coating to the lower 500mm of the tunnel walls would have prevented the corrosion to the internal surface as observed. Externally, a reduction in the quantity of dust suppression water that was being deposited on the stockpile would also have considerably reduced the incidence of corrosion to the back face of the existing tunnel. The dust suppression system was re-designed during the refurbishment to reduce significantly the quantity of water dumped onto the stockpile which in turn reduces the wetness of the ore and backfill down at the base of the stockpile. This will have benefits in reducing the corrosive environment behind the tunnels in the future.

With the ever increasing trend of minesites extending service lives well beyond original design life, maintenance personnel can reduce expensive refurbishment/replacement of assets that may be required to ensure the viability of the asset for the extended duration with simple corrosion management techniques.

Proactive corrosion management is still the most cost effective form of corrosion management available. Whether techniques be employed as early as the design stage when material selections or protection methodologies proven over time can be specified or during plant life when concerns are first observed, educated awareness of corrosion and the consequences will greatly limit future maintenance concerns.

In operational mines, management can consider undertaking a maintenance inspection schedule which will determine the frequency of future inspections of assets throughout facilities in an attempt to highlight possible concerns before they manifest. Such activities as Corrosion Management Audits or Risk Based Inspections that are common place in the oil and gas sectors can now be modified to cater to the mining sector to reduce significantly the costs of refurbishment or replacement particularly, in light of the likelihood of increased service life requirements.