Queensbury Tunnel Study

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Highways England - Historical Railways Estate

HQU/3D

Major Works Framework

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Contents

Executive Summary

This report presents the outline proposals for making Queensbury Tunnel structurally safe for public use. It does not include the following: any infrastructure relating to constructing a cycleway through the tunnel e.g. lighting, surfacing, drainage works, security, signage etc; any work to the existing drainage channels beneath the track bed; any work to track bed itself; any external/ access works required outside of the tunnel portals and shafts.

No analysis or design calculations have been undertaken as part of this study and the proposed repairs have been based upon existing information available and assumptions as outlined. Any works within the tunnel will be subject to detailed design prior to construction.

The costs of the construction have been prepared by AMCO-Giffen based upon the proposed repairs as outlined in the report and their proposed preferred solutions for Shafts 2 and 3.

Total Cost Estimate for repair works:	£26,382,087.00 (+/- 30%)
Estimated annual running costs:	£24,090.00

The following assumptions have been made in the production of the proposed repairs and cost estimates:

- Access will be available at both tunnel portals and shafts for the duration of the construction works.
- The tunnel will be de-watered prior to construction works and the water level maintained throughout by the existing pump at the south portal.
- The proposed repairs have been based upon the condition of the tunnel as outlined in the report and no deterioration has been allowed for.

The following costs have been omitted from the estimate:

- Any costs associated with gaining access to the tunnel for the works.
- Any costs associated with de-watering prior to construction start.
- Any repairs that may be required to the sump and pump at the south portal.

The following gaps in information have been identified as part of this study and will require further investigations prior to detailed design:

- Current condition of the tunnel lining between Shaft 3 and the south portal.
- Current condition of the shaft linings.
- Condition and extent of the granular fill at the base of shaft 2.
- Current condition of the drainage channels.
- Extent of any overbreak between tunnel lining and rock face.
- Current condition of the pump at the south portal.

The repair methods selected are anticipated to be the most economical methods available to address the current condition of the tunnel and utilise all of the safety works already undertaken by Amco-Giffen to date. It is assumed that any heritage value of the tunnel fabric held by interested parties is a secondary consideration relative to economic repair methods facilitating transfer and opening of the tunnel. It is proposed to use multiple repair options throughout the length of the tunnel. The method of repair will be chosen based upon the lining condition and the presence of previous remedial works within the tunnel. The proposed repairs outlined in the report are: spray applied concrete (shotcrete); colliery arches; traditional brickwork / stonework repairs; grouting assumed voids due to overbreak and corrugated steel pipe.

1. Introduction

Highways England – Historical Railways Estate (HE-HRE) have commissioned Jacobs to undertake a study to determine what would be required to make structure HQU/3D, Queensbury Tunnel, structurally safe for public use. A cost estimate and programme have been provided by HRE Framework Contractor, Amco-Giffen.

This report contains: a brief background on the structure; a summary of the existing condition; a review of available existing information; gaps in the existing information and recommended investigations; the proposed repair works; estimates and a programme for the proposed works and a risk register with associated cost.

The following items were not included as part this study and report: any infrastructure relating to constructing a cycleway through the tunnel e.g. lighting, surfacing, drainage works, security, signage etc; any work to the existing drainage channels beneath the track bed; any work to track bed itself; any external/ access works required outside of the tunnel portals and shafts.

The following assumptions have been made for the production of the proposed repairs and cost estimates:

- Access will be available at both tunnel portals and shafts for the duration of the construction works. (No access costs have therefore been included).

- The tunnel will be de-watered prior to construction works and the water levels maintained throughout by the existing pump at the south portal. (No de-watering costs have therefore been included).

- The proposed repairs have been based upon the condition of the tunnel as outlined in this report and no deterioration has been allowed for.

No analysis or design calculations have been undertaken as part of this study and the proposed repairs have been based upon assumptions as outlined. Any works within the tunnel will be subject to detailed design prior to construction. An estimate for the cost of design, development and supervision has been included as part of the estimates.

2. Background Information

2.1 Structure Description

Queensbury tunnel is a disused railway tunnel situated between Bradford and Halifax running directly under the town of Queensbury. The tunnel is 2502 yards (2287.8m) in length, with a span of 26ft (7.9m) and is situated up to a maximum depth of 115m below the ground surface. There is a fall of 1:100 from the north to south portal.

The tunnel was constructed over four years and completed in July 1878. It was opened in October 1878 and closed to all traffic in 1956. Excavation of the tunnel was carried out using "drill and blast" techniques through Coal Measures and Millstone Grit. The tunnel is generally horseshoe in profile and the lining comprises of brickwork and stone masonry. The sidewalls are constructed from stone blocks throughout. The arch haunches and crown are predominantly brick with the exception of approximately 120m at the south portal, 75m at the north portal and at the locations of the shafts, where they have been constructed from stone. This excludes below shaft 8, where brick was still used.

A total of eight shafts were originally planned, only five were sunk to the depth of the tunnel, shafts 1, 2, 3, 4 and 8. Two were abandoned during construction, shafts 5 and 6, and shaft 7 was never commenced. All of the shafts have been capped at ground level. Shafts 1 and 8 are located within fields away from residential areas. Shaft 2 is located adjacent to a track south west of Queensbury which provides the only access to several residential properties and businesses. Shafts 3 to 6 are all located within the town of Queensbury close to housing.

The tunnel was originally drained via a 24" wide, 18" high culvert which was located under the centre of the tunnel between the tracks. Most of the tunnel was drained via this culvert with gravity taking the water towards the south portal. However, from shaft 8 to the north portal, the tunnel was drained via an 18" square culvert taking the water north.

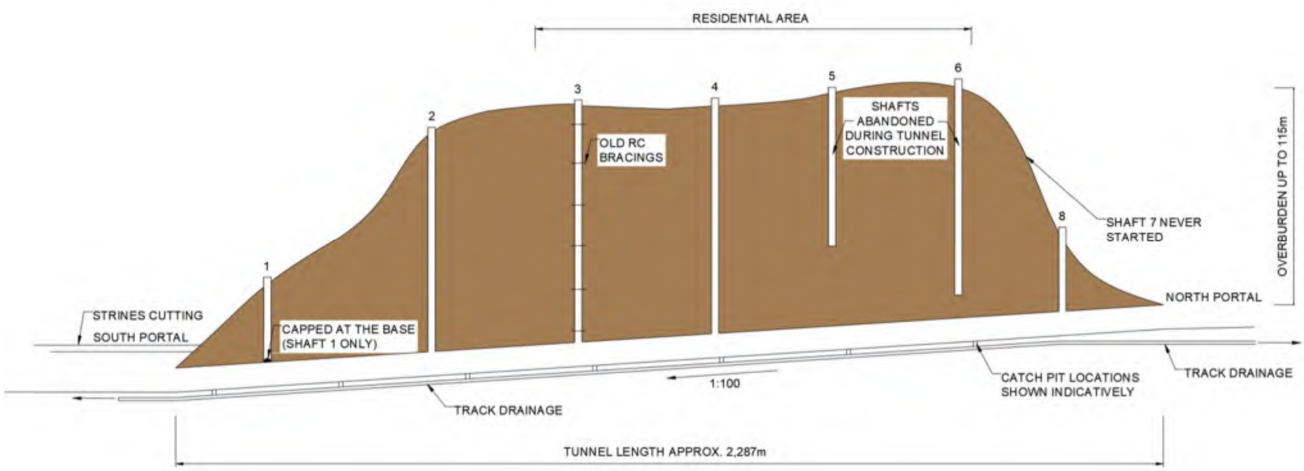


Figure 1: Schematic Long Section Through Tunnel (Prior to Closure)

The tunnel has been split into sections 50 feet (15.24m) long, starting at the north portal, which is noted as tablet 0 and reaching tablet 150, just inside the south portal.

2.2 Existing Information

The following key documents have been reviewed for the purpose of determining the existing condition of the tunnel and identifying gaps in available information:

- Jacobs – Progress reports on ongoing safety works from October 2018 to date

- Amco Giffen – Design information relating to the ongoing safety works from October 2018 to date
- Aecom – Queensbury Tunnel Phase 1
    - Literature Review
- Aecom – Queensbury Tunnel Phase 2
    - Baseline Assessment
    - Examination Report
    - GPR Report
    - Intrusive Report
    - Post examination Assessment Report
    - Technical Summary Report
- Jacobs – Queensbury Tunnel Options Report (2016)
- Detailed examination reports dated between 2015 and 2017 covering:
    - South portal to approximate tab 98 (collapse location)
    - All shafts

3. Information Review

3.1 Current Tunnel Condition

This section of the report outlines the current condition of the tunnel. It has been taken from a combination of the following:

- information from HRE's Framework Contractor Amco-Giffen on recent remedial works within the tunnel to make it safe for works access;
- progress reports from Jacobs site supervision visits;
- Aecom – Queensbury Tunnel Phase 2 Reports noted in Section 2.2;
- and previous examination reports for the parts of the tunnel not inspected during the remedial works.

The 1:100 gradient of the tunnel and the infilling of Strines cutting south of the Southern portal has caused the south end of the tunnel to flood. Groundwater ponds in the short length of the cutting remaining open and backs up into the tunnel, generally to between tablets 92 and 87 but is known to have reached as far as tablet 77 (1,112m from the south portal).

During 2013 and 2014, there were two major collapses in the tunnel lining, between Shafts 3 and 4. On both occasions the brick lining and rock behind collapsed into the tunnel. The force of the collapses crushed the temporary scaffold platforms, that had been placed there in 2012, to prevent falling brickwork hitting anyone walking underneath, making the areas virtually impassable. The platforms were not designed to contain localised ground collapses.

Figure 2: Collapses at tablets 90 (left) & 98 (right)

Between June 2015 and August 2016, HRE Framework Contractor Hammond (ECS) Ltd dewatered the tunnel and installed a semi-permanent pump just inside the south portal.

During, and subsequent to, the installation of the pump various tunnel examinations were undertaken. HRE's Examination Contractor for the area at that time, Carillion, undertook detailed examinations of the shaft linings and the southern portion of the tunnel, previously subject to flooding. No entry was made to the area between the two collapses noted above.

Aecom undertook examinations of the tunnel during July and August 2018, including investigating the lining using Ground Probing Radar (GPR) at 1.5m and 3.0m above track level on each side wall. Their analysis of the results had the following key findings:

- Tunnel lining thickness is in line with historic drawings, circa 24” (0.6m).
- Highly reflective boundary at an average depth of 0.25m and 0.35 behind the tunnel intrados for the brick and stone lined section respectively. This may indicate a difference in either or both of:
  - Material quality and form (competent facing with less competent material behind);
  - Material placement for the stone sections (structured placement with a regular pattern with unstructured placement behind).
- Micro-voiding within the rock mass – likely as a result of the use of explosives.
- Limited or no apparent voiding behind the extrados of the sections surveyed.

They undertook a point cloud survey and extracted cores in addition to the GPR survey but the cores were only undertaken within the stone sidewalls and no cores were undertaken within the brick lined sections.

Analyses undertaken by Aecom indicate that the tunnel lining is overstressed in some areas, particularly in the deeper sections of the tunnel, brick lined sections and where the profile has deformed. A point cloud survey was undertaken as part of their investigations to identify the sections of the tunnel which were out of profile. These were defined as those areas where the deformation of the lining exceeded 100mm.

The following is a summary of the deformations and cracking identified by the point cloud survey. Their survey did not cover the potentially unstable length (“exclusion zone”) of tunnel between tablets 82 and 102. Chainage is from 0m at the north portal to 2288m at the south portal.

Chainage	Tablet	Lining Type	Length out of profile (m)	Observations
58-72	4 – 5	Stone	13	Asymmetrical bulging of up haunch. Open joints / missing bricks.
76-86	5 – 6	Brick	10	Flattening of haunches. Missing brickwork in both haunches.
289-310	19 – 20	Brick	21	Flattening of haunches. Missing brickwork in both haunches.
502-548	33 – 34	Brick	46	Flattening of haunches. Localised bulging of down sidewall. Longitudinal hinge fracture in both haunches. Drummy brickwork.
690-700	45 – 46	Brick	10	Asymmetrical bulging of down haunch. Longitudinal fracture in down haunch. Missing brickwork in down haunch.
777-791	51 – 52	Brick	14	Flattening of haunches. Longitudinal hinge fractures in both haunches.
1010-1020	66 – 67	Brick	10	Bulging of down sidewall. Drummy brickwork.
1030-1051	68 – 69	Brick	21	Bulging of down sidewall. Drummy brickwork.

1082-1257	71 – 82	Brick	175	Localised bulging. Drummy brickwork. Longitudinal hinge fracture.
1605-1643	105 – 106	Stone	15	Asymmetrical bulging of up haunch. Drummy brickwork.
1874-1890	123 – 124	Brick	10	Asymmetrical bulging of up haunch. Longitudinal hinge fracture.
1890-1955	124 – 127	Stone	45	Bulging of up sidewall. Collapsed refuge.
1995-2040	127 – 130	Brick	45	Flattening of haunches. Longitudinal hinge fracture on both haunches.

3.1.1 Tunnel lining between North Portal and Shaft 3

Since October 2018, HREs Framework Contractor, Amco-Giffen, have been undertaking safety works within the tunnel for the purpose of enabling safe access for operatives. The safety works within the tunnel extend from the north portal up to Shaft 3. Works to date include installation of appropriate temporary ventilation and lighting, reinstatement of previously defunct drainage at the north end of the tunnel, clearance of the tunnel solum to improve underfoot conditions, installation of RAM Arch steel reinforcement to the construction shaft support structures of Shaft nos. 8, 6, 4 and partial installation at Shaft no. 3, installation of RAM Arch to areas of poor and / or unstable brickwork in the lining at numerous locations along the length of the tunnel, clearance of debris from the two collapse areas and erection of colliery arches through the collapse zones to provide safe access for operatives, plant and equipment. These works are discussed in more detail below.

At commencement of the current safety works, the pumps at the south end of the tunnel were switched off by the landowner. It was therefore only possible to access the tunnel from the north portal. As noted above, the flooding to the tunnel is generally confined to the southern half, allowing work to proceed in the northern half of the tunnel without the need for pumping the water out. However, it was deemed necessary to create safe access from the north portal to Shaft 1 (tablet 143), secure the shaft base, and work back towards the north portal from there, securing the remaining shaft bases.

The shorth length of original drainage which runs north from approximately shaft 8 (tablet 8) was investigated and found to be blocked and silted up. A new concrete manhole to the drainage channel was constructed just inside the north portal and the drainage channel was flushed through to allow the discharge of water being pumped from the southern end of the tunnel.

For the safety of operatives working in the tunnel, RAM Arch has been utilised to temporarily secure areas of suspected poor brickwork in the lining, particularly between Shafts 3 and 4 where the two major collapses have occurred. It has also been installed to the shaft support structures of Shaft nos. 8, 6, 4 and partial installation at Shaft no. 3, to temporarily secure the base of the shaft and to protect the workforce from any falling materials from the shaft linings. In its basic form it is galvanised steel bars forming a mesh, bent to a radius and fixed to the tunnel lining. The spacing of the bars is sufficiently tight to prevent loose bricks falling from the lining on to operatives working or passing below. During the installation of RAM Arch, operatives remain safely underneath the mesh so are protected from the risk of collapsing brickwork. The RAM Arch comes in 2.2m long panels with a 1.3m width and subsequent panels are fixed on top of the existing with a 300mm overlap. Each advance is therefore 1m and using this method the tunnel can be safely secured. Each joint going around the curve of the RAM Arch has an expandable joint. The RAM Arch is therefore jacked outwards to ensure that the mesh is in intimate contact with the lining. RAM Arch is resin fixed to the masonry lining using 450mm long, 25mm diameter steel bars, generally at 1m centres both horizontally and vertically.

Figure 3: RAM Arch Installed at Queensbury Tunnel

In order for the Contractor to safely navigate through the two major collapse areas, more substantial temporary works were required. Amco-Giffen proposed the use of 'colliery arches' to achieve safe passage through the collapse areas. The colliery arches were formed using Universal Beams, with a 4m long roof beam and 5m high splayed legs, the frames are set at 0.6m centres with connecting Circular Hollow Section struts. Mesh panels were then used on the outside of the frames to prevent smaller debris from falling through the gaps.

A total of 72no. colliery arch frames were utilised between tablets 90 and 99. 28no. at tablet 90, the location of the first collapse, 14no. at tablet 93 where a significant bulge in the upper haunch of the lining rendered RAM arch impractical and potentially unsafe to install, and 30no. at tablet 98, the location of the second collapse.

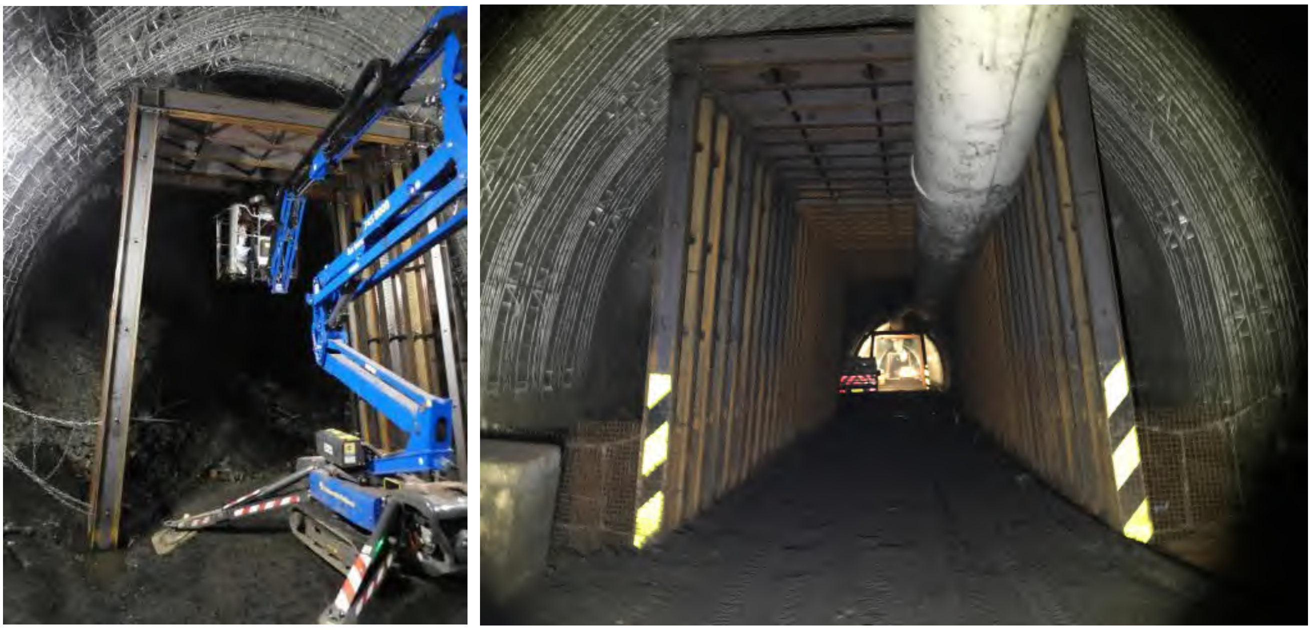


Figure 4: Colliery Arches Being Installed at Queensbury Tunnel

During late December 2018 and early January 2019, a culvert was constructed by the landowner between Strines Beck and the cutting close to the south end of the tunnel. This allowed for a significant increase in the volume of water entering the tunnel, overwhelming the capacity of the temporary pumps Amco-Giffen had brought in to clear the tunnel of flood water.

Two further significant inundations of water during 2019 eventually led to works inside the tunnel being temporarily halted, principally on Health and Safety grounds.

Just prior to the last significant influx of water and the temporary halting of the works inside the tunnel, there was a brief opportunity to inspect the tunnel lining up to Shaft 2. The lining in the vicinity of the base of Shaft 2 was found to be in poor condition. The shaft cap at the top of Shaft 2 is adjacent to a bridleway forming the only access to several businesses and residential properties and it was therefore deemed necessary to undertake works to secure the shaft as a matter of urgency. As no access to the base of the shaft was possible due to water levels in the tunnel, the shaft was filled from the shaft cap at ground surface level. A well graded, quarried limestone was deposited into the shaft via a conveyor belt. This will have formed a 'cone' of granular fill inside the tunnel and then subsequently filled the shaft.

Subsequent to the works to secure Shaft 2, Amco-Giffen were asked to submit proposals for securing the base of Shaft 3 while also applying a spray applied concrete to the RAM Arch already installed below Shafts 8, 6 and 4, to provide additional support to those shafts. A 250mm thick spray applied concrete (shotcrete) was applied to the RAM Arch at the base of each shaft. As part of these works, the RAM Arch covering the shaft openings has been cut away to allow for temporary installation of 'ring dams' and application of the shotcrete at the shaft eyes.

The design of the shaft plug to secure the base of Shaft 3 is ongoing. Amco-Giffen propose to form a 'pyramid' support structure utilising Gabion type baskets. The gabion baskets will be constructed of 50 x 50 x 10 gauge galvanised steel mesh, secured with galvanised hog rings. The baskets contain bespoke bags that will be filled with a 2 part high strength resin product that will be pumped into the bags once submerged and placed by the divers. The bags are designed such that they will leach water, but not resin. The top layer of resin filled bags will not be contained within baskets and will be allowed to form a fluid shape to fit the profile of the tunnel lining, ensuring a good contact fit and fully supporting the shaft eye.

The following table summarises the current condition of the tunnel lining for the currently accessible section from the north portal to Shaft 3.

Tablet	Condition
0 – 5	Minor patches of spalling stonework which has been dressed back.
5 – 6	Missing brickwork dressed back and RAM Arch installed to haunches and crown.
6 – 8	Few defects.
8 – 9	Location of Shaft 8. Missing brickwork dressed back with RAM Arch installed and 250mm of spray applied concrete added later.
9 – 26	Missing and spalled brickwork dressed back with RAM Arch installed to crown at tablet 11 for approx. 3.0m.
26 – 27	Location of Shaft 6 (which did not reach the tunnel). RAM Arch installed and 250mm of spray applied concrete added later.
27 – 42	Few defects. Missing and spalled brickwork dressed back.
42 – 71	Missing and spalled brickwork starts to become more extensive with fractures in the haunches and crown.
71	Existing crash deck present with bulge to down haunch.
71 – 77	Several areas of spalled brickwork, deformation of the arch profile and fractures to the haunches and crown.
77	Existing crash deck in place with bulge to up sidewall and haunch.
77 – 80	Deformation of the arch profile. Bulge and fracture to up haunch at tablet 79.
80 – 81	Location of Shaft 4. RAM Arch installed and 250mm of spray applied concrete added later.
81 – 90	Potentially unstable zone of tunnel. Areas of spalling and missing brickwork have been dressed back. Majority of the tunnel lining has had RAM Arch installed.
90 – 91	Location of collapse. Colliery arches installed with mesh panels on the outside.

91 – 93	Potentially unstable zone of tunnel. Areas of spalling and missing brickwork have been dressed back and RAM Arch installed.
93 – 94	Location of significant bulge to up haunch. Colliery arches installed with wooden packing beneath the bulge.
94 – 98	Potentially unstable zone of tunnel. Areas of spalling and missing brickwork have been dressed back and RAM Arch installed.
98 – 99	Location of collapse. Colliery arches installed with mesh panels on the outside.
99 – 100	Potentially unstable zone of tunnel. Areas of spalling and missing brickwork have been dressed back and RAM Arch installed.
100 – 105	Few defects. Missing and spalled brickwork to crown dressed back.
105 – 106	Location of Shaft 3. See section 3.1.3 for details.

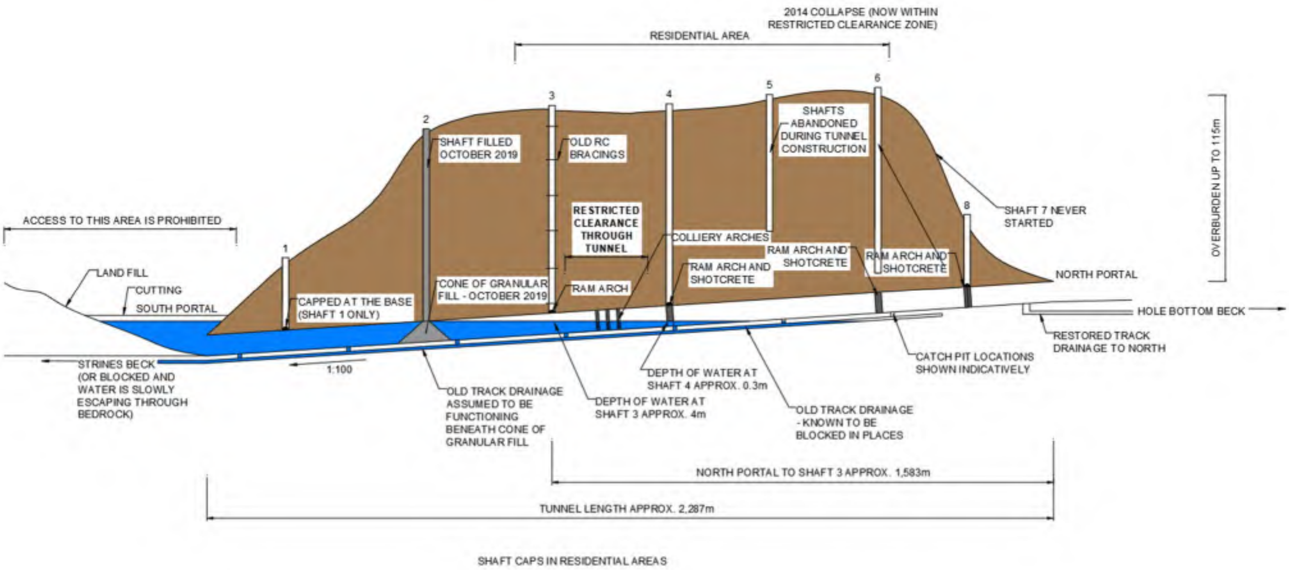


Figure 5: Schematic Long Section Through Tunnel (Current Arrangement)

Refer to the schematic drawings contained within Appendix A for full details of defects and remedial works undertaken.

3.1.2 Tunnel lining between Shaft 3 and the south portal

The current condition of the tunnel lining between Shaft 3 and the south portal is not known. This is due to flooding in the tunnel preventing safe access. The following table is a summary of the condition based on the Carillion Detailed Examination report for the examination completed on 13/02/2017.

Tablet	Condition
106 – 142	Extensive areas of missing and spalled brickwork and open joints in both haunches. See section 3.1.3 for details of Shaft 2.
142 – 147	Few defects.
147 – 150	Missing blocks and spalled stonework particularly to the up haunch.
150 – 150.5	Lining repaired in 2016.

In addition to the above noted defects, access to the lining between Shafts 2 and 3 was briefly available in September 2019, prior to Amco-Giffen's temporary pumps being overwhelmed. During this brief period, tactile inspections were undertaken to discrete locations of the lining to ascertain the general condition. This was undertaken predominantly to assess if any further temporary works would be required to reduce risks to the operatives working in the tunnel at that time. The most notable observation from the inspection was that the mortar in the brickwork joints was found to be saturated and very soft (could be scraped out with a pen or finger in places) throughout.

3.1.3 Shafts

The condition of the shafts has been based upon available examination reports. The following table is a summary of the shaft conditions where known.

Shaft	Examination Date	Condition
Shaft 1	26/10/2015	Fair with high levels of water ingress. Shaft 1 is capped at top and bottom.
Shaft 2	11/02/2016	Shaft 2 has been filled with Class 6N granular fill.
Shaft 3	12/02/2016	Fair with high levels of water ingress and heavily spalled, retrofitted reinforced concrete beams.
Shaft 4	26/10/2015	Fair with high levels of water ingress.
Shaft 5	26/10/2015	Shaft was terminated above tunnel. It was not backfilled and water is present. Condition of lining is unknown.
Shaft 6	30/03/2016	Shaft was terminated above tunnel and is not backfilled. Condition is unknown.
Shaft 8	26/10/2015	Fair with high levels of water ingress.

3.1.4 Refuges

There are fourteen refuges sporadically spaced along the sidewalls in the tunnel. They are constructed from brick and are generally in fair condition with some exceptions.

- There is a fracture in the back of the refuge located in the up sidewall at tablet 78.
- The refuge located at tablet 105 in the down sidewall had spalling to the back of the refuge and a circumferential fracture approximately ½ brick in from the face.
- The refuge located in the up sidewall at tablet 127 was in very poor condition with bulging present. It is expected to be buried by the granular material plug now at the base of shaft 2, though this has not been confirmed.

3.1.5 Drainage

In 2016 a sump and pumping system was installed at the south portal to manage water levels within the tunnel. It has not been in operation since late 2018 and the condition of the pumping system is currently unknown.

As part of the recent works for safe access for the Contractor’s operatives, sections of the existing track drainage have undergone minor repairs to aid with pumping water from the tunnel towards the north portal. This has included: exposing and clearing out sections of the drainage channel to maintain water flow from the tunnel towards the south; and the installation of a manhole inside the tunnel, close to the north portal tied into the drainage channel which carries water from the tunnel to the north. Full details of the condition of the former track drainage are not known.

3.2 Gaps in Information

The proposed repairs outlined within this report are based on a desktop review of limited available information. The following have been identified as gaps in the current information, which will require further surveys and investigations prior to the detailed design of the works being undertaken.

- Current condition of the tunnel lining between Shaft 3 and the south portal – due to current water levels in the tunnel, a complete detailed inspection of the tunnel lining between these points has not been undertaken since 2017. It is anticipated that there will be some deterioration to the lining since the last inspection.

- Current condition of the shaft linings (last inspected in 2015/16).

- Condition and extent of granular fill at base of Shaft 2 – works to fill the shaft were completed from ground level above the tunnel with the tunnel in a flooded condition. There has been no access to the base of Shaft 2 since completion of the works, therefore the level of compaction achieved and extent of the base of the fill is not known.

- Current condition of existing drainage channels – some of which were restored to help with pumping during works but not all and hasn't been in operation for some time.

- Extent of any overbreak between tunnel lining and rock face – The GPR survey undertaken by Aecom appeared to show that there is likely little to no overbreak but the survey covered discrete sections of the tunnel lining and the findings in the brick section were not confirmed with investigatory cores.

- Current condition of pump at south portal which was installed circa 2016 and has not been operational since late 2018.

3.3 Recommended Surveys and Investigations

Prior to detailed design of the proposed repairs outlined in this report, it is recommended that the following surveys and investigations are undertaken:

- Detailed examination of the tunnel and shafts (including between Shafts 2 and 3, however, no access will be available to this area until works are underway).

- Investigations to determine extent of expected overbreak and nature and condition of the strata behind (An estimated cost for this has been included in the overall cost estimate for the works).

- Trial pits to determine the form of the footings to the tunnel sidewalls.

- Point cloud survey of the entire tunnel and cross-referencing the previous AECOM point cloud survey to check for any recent movement in the lining.

- Investigations into the condition of the existing drainage channel within the tunnel.

- Confirmation of the extent and condition of the granular material plug at the base of shaft 2.

- Analyses to determine which sections of the tunnel are overstressed to determine which areas need strengthening and which would require remedial repairs to the existing lining only.

- Sampling and testing of existing bricks and mortar throughout the tunnel to allow for the selection of appropriate replacement materials.

- A Coal Mining Risk Assessment in relation to opening the tunnel for public use.

4. Proposed Repairs

4.1 Assumptions

The proposed repairs have been based upon the assumed condition of the tunnel lining and shafts as outlined above. The proposed repairs to the tunnel lining have not allowed for expected deterioration of sections of the tunnel which have not been accessible due to flooding since 2018.

At this stage, no detailed analysis of stresses in the tunnel lining has been undertaken by Jacobs. However, analysis of assumed typical tunnel conditions undertaken by Aecom suggests that through the deepest section of the tunnel, the 'as-built' lining is sufficient to carry the compressive stresses where the tunnel passes through sandstone. However, where the tunnel passes through mudstone it is likely to be overstressed. The results suggest that maintaining full thickness of the lining is imperative for stability of the tunnel where it passes through sandstone and strengthening of the lining beyond the 'as-built' thickness is necessary where it passes through mudstone. Therefore, in developing the repair strategy, and due to the age and condition of the tunnel, very few areas of the lining are to be left in their current condition. Furthermore, as the extent to which the tunnel passes through these different materials is unknown, it is proposed to include strengthening the tunnel over the majority of its length to ensure the estimate provided by Amco-Giffen is the upper bound cost estimate sufficient to cover actual costs to provide a tunnel that is structurally safe for public use. However, as stated above no detailed analyses of these sections of tunnel have been undertaken by Jacobs and as such the proposed repair methods should be considered as preliminary.

It is assumed that any heritage value of the tunnel fabric held by interested parties is a secondary consideration relative to economic repair methods facilitating transfer and opening of the tunnel. The repair methods selected and briefly described below are anticipated to be the most economical methods available to address the current condition of the tunnel and utilise all of the safety works already undertaken by Amco-Giffen to date.

4.2 Proposed Lining Repairs (Including refuges)

It is proposed to use multiple repair options throughout the length of the tunnel. The method of repair will be chosen based upon the lining condition and the presence of previous remedial works within the tunnel. The proposed repairs are outlined below.

4.2.1 Spray Applied Concrete (Shotcrete)

Two forms of shotcrete repairs are proposed: an unreinforced shotcrete will be used in areas where RAM Arch has already been installed, which will form the reinforcement for the spray applied concrete, and fibre reinforced shotcrete for identified sections where RAM Arch has not been installed. The exception to this approach is between the south portal and tablet 142, where the condition of the mortar joints for this stonework section of the tunnel is known to be particularly poor. RAM Arch will be installed throughout this section, to stabilise the lining and prevent any individual stones falling in advance of remotely (there are a number of remote-controlled shotcrete sprayer units available) applying the shotcrete. This will reduce the risks the operatives would otherwise be exposed to and will also prevent any localised collapses in the lining. Alternatively, a fibre reinforced shotcrete could be applied remotely. This would further reduce risks to operatives, as no RAM Arch would be installed, but may induce a collapse in the areas of particularly loose stonework, which would incur potentially significant additional time and costs to remediate.

<u>Areas of the tunnel lining where RAM Arch has already been installed</u>

RAM Arch has been installed in various sections of the tunnel as part of temporary works to facilitate safe access through the tunnel. The bare RAM Arch has been installed as protection to operatives from falling elements only and not as a permanent support solution for the tunnel lining. At the locations of shafts 8, 6 and 4, spray applied concrete has also been installed. It is proposed to add a 250mm layer of spray applied concrete at all remaining locations where RAM Arch has been installed. At this stage it is assumed that the existing resin anchors used to fix the RAM Arch to the tunnel lining are likely to be sufficient to tie the shotcrete to the lining and no foundations or additional dowels into the masonry are required. This would be confirmed during any future detailed design of remedial repairs to the tunnel.

An appropriate drainage system would be required to prevent any build-up of hydrostatic pressure behind the shotcrete lining. Where RAM Arch has already been installed, this may include the provision of weep holes and the fixing of downpipes or similar to the face of the shotcrete, which would then need to be tied into the overall tunnel drainage system.

Fibre reinforced

There are sections of the tunnel lining which have not had RAM Arch installed but the tunnel will require permanent support to allow opening for public access. At these locations a 300mm layer of fibre reinforced spray applied concrete will be installed.

It is proposed to install a fibre reinforced, spray applied concrete lining at the following locations: tabs 27-32 & 42-70, tabs 81, 84 & 85, tabs 102-104, 109-117, 123-125 & 127-137 and 139 & 140. The total length of the tunnel lining requiring fibre reinforced concrete is 975m.

The shotcrete shall comprise a layer containing 35mm long steel fibres with hooked ends, 280mm thick, and a 20mm regulating layer (no fibres) to cover any protruding fibres from the structural layer. The regulating layer will only be applied to a height of 3m on each sidewall. The shotcrete lining shall become an integral part of the tunnel lining due to the (albeit relatively weak) bond between the shotcrete and masonry substrate and the provision of 25mm diameter steel dowels, 600mm long and resin fixed or grouted into the linings. The dowels will be provided at 1m centres both vertically and horizontally.

As above, an appropriate drainage system would need to be incorporated into the design. This may include the provision of drainage strips behind the shotcrete at 5m centres along the tunnel, which would then need to be tied into the overall tunnel drainage system.

An alternative, thinner shotcrete and rock bolts option was considered but has been discounted on cost and Health and Safety grounds (refer to the assumptions provided with the estimate from Amco-Giffen in Appendix C).

4.2.2 Colliery Arches

Colliery arches have been installed at three locations in the tunnel: at the two collapses and below the significant bulge in the up haunch with a hinge forming between the collapses. These were erected as temporary works to afford access through the former exclusion zone. It is not considered safe or cost-effective to remove these colliery arches to install an alternative, they will therefore be left in place.

It is proposed that formwork is erected to the inside face of the arches (through the passage) and concrete pumped between the steel frames and tunnel lining. The exposed concrete at the ends of each set of colliery arches would then be faced with brickwork.

The concrete would need to be pumpable, self-compacting, self-levelling and of adequate strength to cater for the anticipated loading. It may also be necessary to provide struts at invert level to restrain the splayed legs of the arches in the event of anticipated high lateral or heaving forces. This, and any other modifications would be determined during the detailed design.

4.2.3 Traditional Brickwork/Stonework Repairs

Traditional brickwork repairs are required for sections of the tunnel where there are few defects of a relatively minor nature and the lining does not require additional strengthening. Further surveys and analysis is required prior to identifying the true extent to which these repairs could be applied to the tunnel. The proposed repair methods are well known in industry and are briefly summarised below:

Open Joints – brickwork and stonework mortar joints that have become recessed, friable or are soft, shall be raked out by hand back to sound material. The joint shall be cleaned of dust, loose particles and any residues and mechanically re-mortared with a mortar to match the properties of the existing. Sodium Silicate additive to be used when re-mortaring joints in wet areas of masonry.

Spalling / Missing Brickwork – spalled brickwork shall be cut out and replaced in panels not exceeding one square metre by half brick (or one ring) thick. The replacement bricks shall have properties that match the existing. Areas of replacement brickwork greater than half a square metre shall be pinned back into the existing brickwork behind. Relatively substantial temporary support works are required for cutting out and replacing brickwork in arches.

Spalling to Stonework – the above method may also be applied to spalled stones but additionally where the spalling is of a shallow nature, 'plastic' repair methods, using proprietary repair mortars can be used to reinstate the appearance of the original stone. This repair method is comparable in cost to replacing masonry blocks and is usually reserved for structures with some perceived heritage value, such as listed buildings.

4.2.4 Grouting voids due to brickwork delamination and / or overbreak

The extent of any delamination of leaves of brickwork or overbreak behind the tunnel lining is currently unknown. The cost estimate provided includes for undertaking 450no. 5m long investigatory cores through the lining and strata behind but does not include for grouting any overbreak.

4.2.5 Corrugated Steel Pipe

Where there is significant deformation to the profile of the tunnel arch, a spray applied concrete lining may not be appropriate. It is therefore proposed to install a corrugated steel pipe within the tunnel. The steel pipe will have a diameter circa 5.0m and the void between the pipe and tunnel will be filled with concrete. See figure below for an example of a corrugated steel pipe installed within a tunnel.

Figure 6: Corrugated steel pipe installed in Merthyr Tunnel.

A layer of concrete will be placed in the invert of the pipe to create a level surface. A structural invert may be required, subject to further surveys and analysis. Small ramps will be built up from granular fill at each end of the pipe for access. Exposed concrete faces can be clad with bricks or stone as appropriate. It is proposed to install a corrugated steel pipe at the following locations:

Chainage	Tablet	Lining Type	Length out of profile (m)	Proposed length of pipe (m)	Notes

502-548	33 – 35	Brick	46	46	Full length of deformed section to have pipe installed.
1082-1257	71 – 82	Brick	175	135*	Shaft 4 is located between tablets 80 and 81 with ramarch and spray applied concrete in place already. Proposed pipe is between tablets 71 and 80.

Amco-Giffen have proposed and priced an alternative approach that is slightly less expensive, which involves the installation of RAM Arch and spray applied concrete. As this has also been included in Amco-Giffen's programme of works, it has also been carried through into the cost estimate for the works. The adequacy of this approach and any additional temporary or permanent works requirements cannot be fully assessed until further surveys, investigations and analysis has been undertaken.

4.3 Proposed Shaft Repairs / Works

There were originally intended to be 8 shafts but Shaft 7 was never commenced. Shaft 1 is currently capped just above the tunnel and also just below ground level, Shafts 2 and 3 have been backfilled/sealed, Shaft 4 is open, Shafts 5 and 6 do not penetrate the tunnel, and Shaft 8 is open.

Shaft 2 has been backfilled from the surface and was not sealed at the tunnel shaft eye prior to this taking place. As such the shaft backfill will have spread out into a "cone" within the tunnel. This cone of potentially unstable fill material is currently blocking the tunnel and will need to be removed or adapted in order to bring the tunnel into use. Shaft 3 has been stabilised from within the tunnel with the stabilisation material providing a seal from invert to crown around the shaft eye, blocking the tunnel from within. Further details on the suggested remedial works for all shafts is provided in the following sections.

4.3.1 Shaft 2

Shaft 2 is a masonry lined shaft 2.75m in diameter and approximately 34m in depth. The shaft top is located in open ground adjacent to a minor road south west of Queensbury. Shaft 2 has been backfilled, as an emergency measure to prevent collapse, with 6N granular fill that has been poured in from the ground surface with no provision to restrict its flow into the tunnel, or provide any compaction as the backfilling progressed up the shaft. It is therefore thought that a cone of material as depicted in the following figure will be forming a blockage within the tunnel that will need to be removed before the tunnel can be used. This presents obvious health and safety risks in that removal of the granular infill from within the tunnel would leave the shaft and tunnel linings unsupported and would subsequently loosen the backfill within the shaft, potentially resulting in an uncontrolled ingress of the backfill and potentially the shaft lining too.

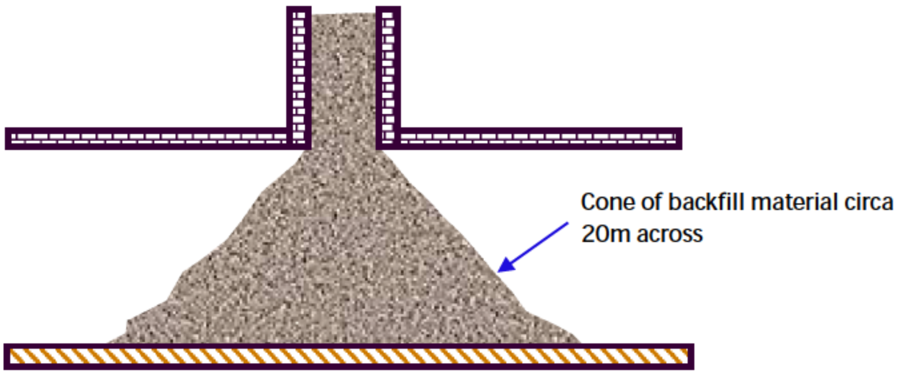


Figure 7: Presumed cone of 6N fill below Shaft No.2

The characteristics of the 6N fill are somewhat understood. Table 6/1 of Series 600 of the Manual of Contract Documents for Highway Works, Volume 1, Specification for Highway Works describes 6N fill as "Selected well graded granular fill":

Natural gravel, natural sand, crushed gravel, crushed rock, crushed concrete, slag, well burnt colliery spoil or any combination thereof. None of these constituents shall include any argillaceous rock. Recycled aggregate except recycled asphalt.

Where material is imported onto site which is not 'as dug' it shall be aggregate conforming to BS EN 13242 from one or more of the following source codes, see Notes 8, 9 and 10:

P (natural aggregates – except shale, siltstone or slate, see Note 7);

A2 (crushed concrete)

A3 (crushed bricks, masonry)

D2 (air cooled blast furnace slag)

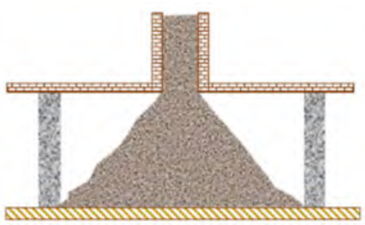
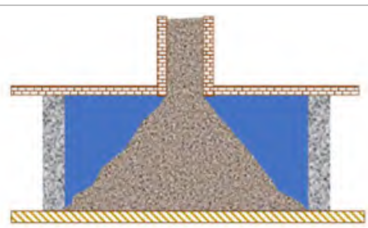
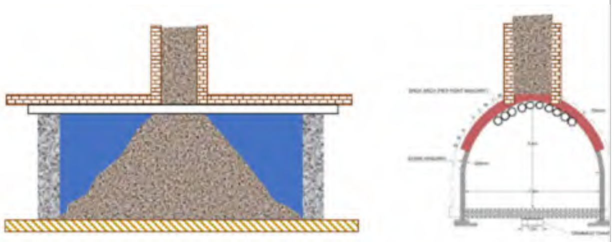
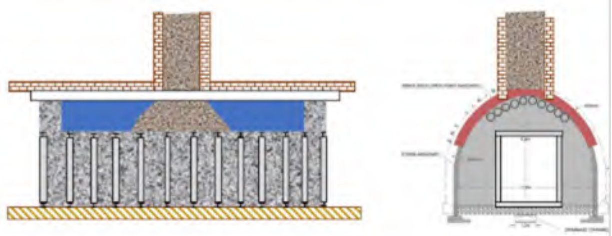
G1 (red coal shale).

The material used is believed to be limestone and it is understood that this does become cemented to a certain degree when exposed to damp. The tunnel was completely flooded when Shaft 2 was infilled and it is therefore possible that the backfill has become quite solidified and stable.

However, without further investigation, the stability of the fill cannot be relied upon. Therefore, three different options have been identified for the creation of a passage through the backfill. i) creation of a pipe arch through the backfill to allow for safe removal beneath and the creation of an inner tunnel lining. ii) excavation through the backfill with a mini open-face boring machine or iii) grouting of the backfill cone, removal by excavator and installation of a sprayed concrete lining around the shaft eye.

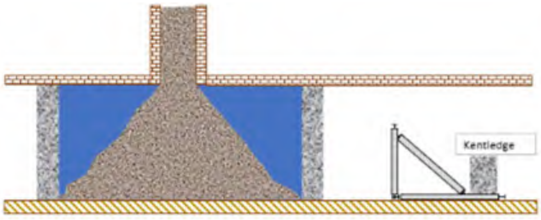
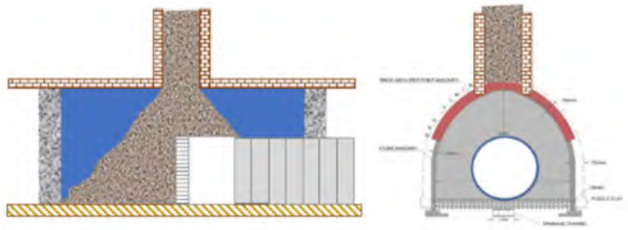
4.3.1.1 Option 1 – Pipe Arch

Initially bulkheads would be cast either side of the backfill cone to act as support for the pipes. The void between the bulkheads and the backfill would be grouted or filled with foam concrete. A pipe arch would then be installed against the crown of the tunnel across the shaft eye opening with the pipes supported by the bulkheads. This would provide restraint against the inundation of the backfill into the tunnel and would allow a steel frame and concrete heading of appropriate size for the final tunnel use to be driven through the backfill and concrete.

	
Stage 1 - install concrete bulkhead either side of uncompacted backfill cone. (may involve breakout of the tunnel invert to form a solid foundation)	Stage 2 - fill void with foam concrete or similar
	
Stage 3 - drive pipe arch in crown over extents of shaft eye	Stage 4 - excavate aperture through backfill/foam concrete and install steel frame / insitu concrete

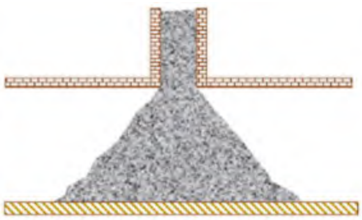
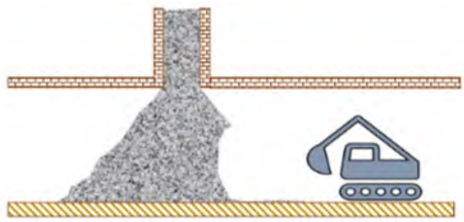
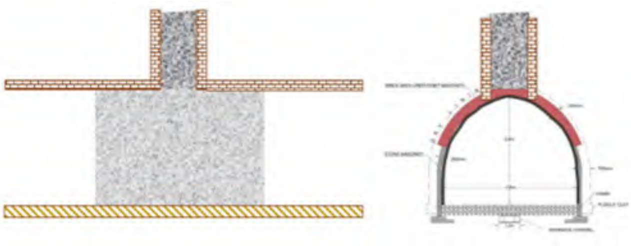
4.3.1.2 Option 2 – Open-face Mini Shield

The first two stages are the same as for the pipe arch proposal. In stage 3, a reaction frame is installed close to one of the new bulkheads and held in place with kentledge (concrete blocks). The shield is then positioned between the reaction frame and the bulkhead and then used to drive a short tunnel through the backfill and foam concrete.

STAGE 1	STAGE 2
Stage 1 – As per Option 1	Stage 2 – As per Option 1
	
Stage 3 – erect reaction frame for mini-shield	Stage 4 - drive through backfill with open face mini-shield and excavator erecting precast concrete or cast iron lining

4.3.1.3 Option 3 – Grout Backfill and Excavate

In this option there is an assumption that the backfill is capable of being grouted into a stable, self-supporting block. Using a long reach excavator, the cone is then removed and the lining in the vicinity of the shaft eye is strengthened with a layer of fibre reinforced sprayed concrete. It is expected that this would need to extend for somewhere in the region of 5m either side of the centre line of the shaft, the full extents would be determined upon examination of the condition of the lining as it is exposed.

	
Stage 1 – Grout backfill with an appropriate grout to cement it together	Stage 2 – Excavate with a long reach excavator
	

Stage 3 – As excavation progresses, apply sprayed concrete lining across the shaft eye to prevent future movement of the backfill within the shaft above.	

4.3.1.4 Preferred Option – Shaft 2

The preferred option is Option 1 as it is felt that this provides the best all round solution in terms of operative safety and cost. Once installed the pipearch will provide a safe working zone from within which the new tunnel configuration can be constructed.

The grouting of the backfill option is not considered further at this stage as the ability to successfully cement the backfill is unknown. The mini-shield is not considered further due to the high relative cost of the machine for the length of the drive, the complex establishment requirements and costs, providing necessary power and the fact that the open nature of the shield will not necessarily protect the operatives from sudden inundation of the backfill.

4.3.1.5 Shaft 2 Option Carried through to Estimate

Amco-Giffen have proposed and priced an alternative approach that is their preference, which involves strengthening the tunnel lining with RAM Arch and shotcrete on the southern approach to Shaft 2 and then carefully excavating the fill, allowing the material in the shaft to migrate down to the cone as excavation progresses. Once the fill has been removed from the shaft, Amco-Giffen propose to continue to install RAM Arch to secure the area. Refer to Appendix C for further details.

The adequacy of this approach and any additional temporary or permanent works requirements cannot be fully assessed until the extent and condition of the cone of granular fill at the base of Shaft 2 is known. However, it is considered likely that additional permanent works would be required to secure the defective refuge and sidewall in close proximity to Shaft 2.

4.3.2 Shaft 3

Shaft 3 is a masonry lined shaft 3.2m in diameter and at approximately 116m in depth, the deepest shaft on the tunnel. At intervals the shaft lining is propped with reinforced concrete frames. The shaft top is located in a garden in High Bury Close in Queensbury and the shaft is understood to be subject to a great deal of water ingress. The tunnel lining around the shaft eye (masonry) is subject to significant defects – spalling and open joints, and so in order to prevent further acceleration and propagation of these defects, the tunnel has been backfilled in the eye zone with gabion baskets. Different size baskets have been used to seal the tunnel and these are filled with dense foam.

Given its heterogenous nature, this backfill will be difficult to remove and it is also unclear how tight up against the shaft eye it has been placed. Had it been formed purely from foam then any number of excavation methods could have been employed. However, the inclusion of heavy gauge wire on the gabion baskets will cause some restrictions, for example:

- Certain rotary methods of excavation will not be possible as the rotating bit will get tangled up in the wire
- The use of mechanical excavators will not be able to make a clean-cut excavation, running the risk of catastrophic overbreak.

Therefore, three different options have been identified for the creation of a passage through the backfill. i) creation of a hand mined timber/steel framed heading through the backfill and the creation of an inner tunnel lining. ii) excavation through the backfill with a mini closed-face boring machine or iii) installation of a stitch-drilled steel section reinforced soffit under which an inner lining is formed. All of these options are preceded by a stage to grout and stabilise the baskets as necessary.

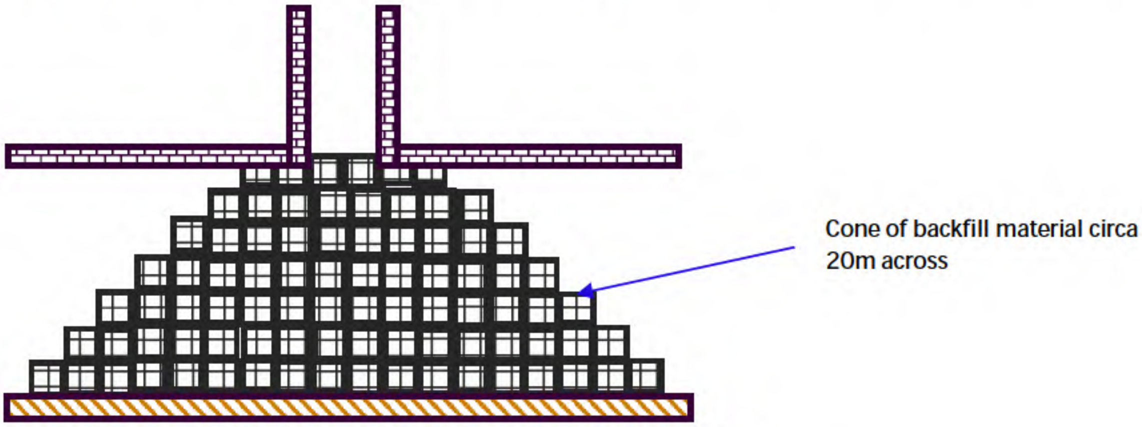
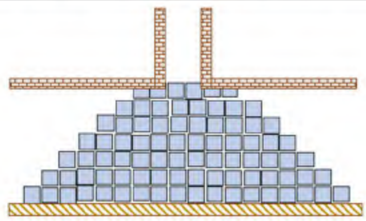
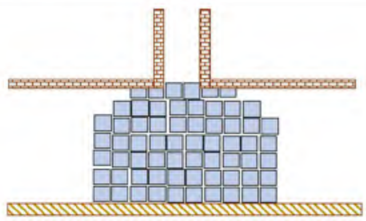
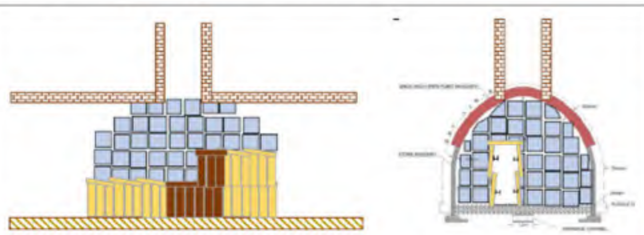
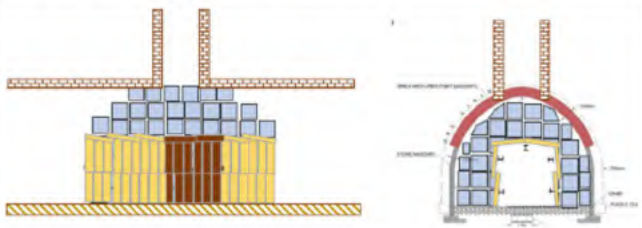
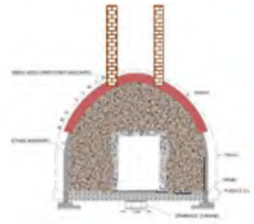


Figure 8: Indicative detail of proposed backfill below Shaft No.3

4.3.2.1 Option 1 – Timber/Steel Heading

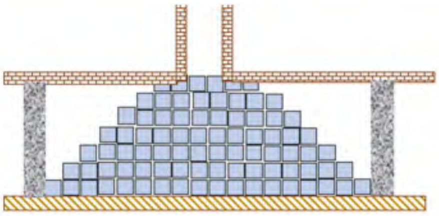
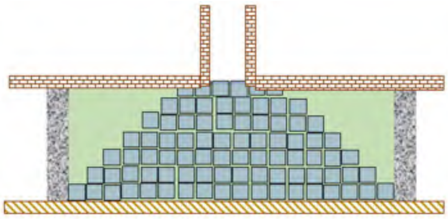
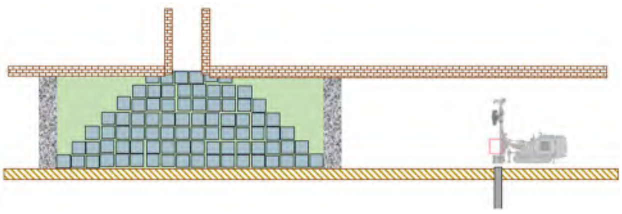
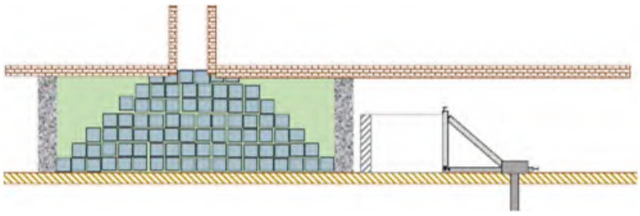
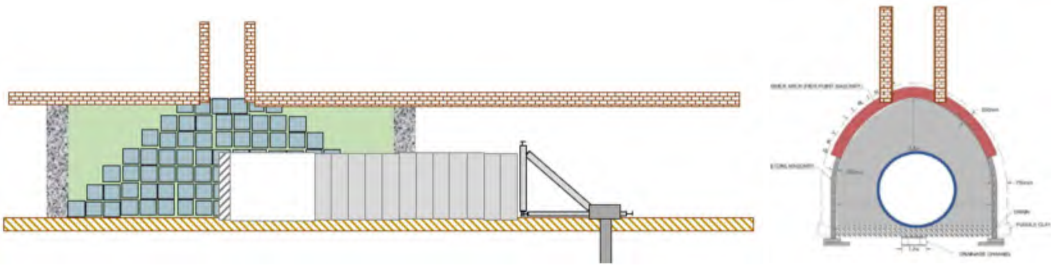
Following grout stabilisation of the gabion baskets, a number are removed from either end to create a "face" to drive the heading through. The new tunnel opening is created with a number of smaller headings formed from steel or timber sets. It is anticipated that four interconnected headings will be required in the region of 2m wide x 2m tall. Upon completion of the heading, a permanent inner cast insitu concrete lining is installed. The exposed gabion basket headwalls would then be sealed with a layer of sprayed concrete.

	
Stage 1 – grout gabion basket to stabilise	Stage 2 – trim ends to form a face
	
Stage 3 - breakthrough to form new tunnel in series of timbered/steel lined headings	Stage 4 - excavate aperture through grouted gabion baskets and install steel frame / insitu concrete support

	
Stage 5 - install cast insitu permanent lining and stabilise gabion basket headwall with sprayed concrete	

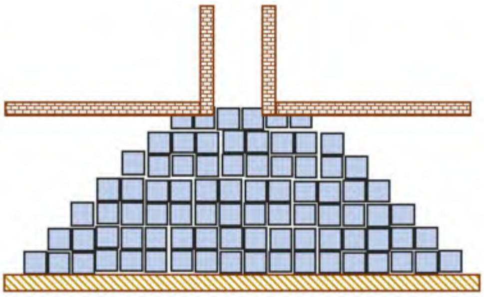
4.3.2.2 Option 2 – Mini closed faced TBM

Upon grouting of the gabion baskets, bulkheads would be cast either side of the backfill. The void between the bulkheads and the backfill would be grouted or filled with foam concrete. In stage 3, a low headroom piling rig is used to drive a pile to hold down the TBM reaction frame which is installed in stage 4 close to one of the new bulkheads. The machine is then positioned between the reaction frame and the bulkhead and used to drive a short tunnel through the backfill and foam concrete.

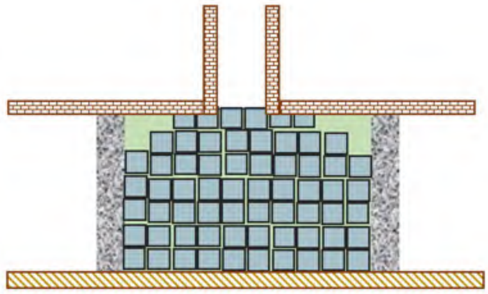
	
Stage 1 – grout gabion baskets to stabilise and install concrete bulkhead either side of backfill cone	Stage 2 – fill void with foam concrete or similar
	
Stage 3 – drive pile for TBM shove frame reaction	Stage 4 – erect reaction frame and prepare mini-TBM
	
Stage 5 - drive through backfill with closed face mini-TBM erecting precast concrete or cast iron segmental lining	

4.3.2.3 Option 3 – Steel frame

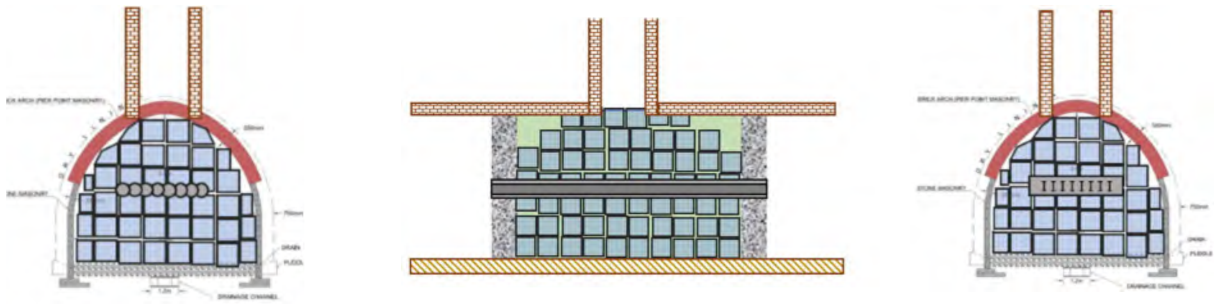
Upon grouting of the gabion baskets, the backfill is trimmed to form a face and two bulkheads are cast either side of the backfill. The void between the bulkheads and the backfill is grouted or filled with foam concrete. A “letter box" is then stitch-drilled through from bulkhead to bulkhead and a series of steel sections are inserted to form a steel reinforced concrete soffit (in practice, this may be completed in sections across the tunnel for stability). A hole is then made in the bulkhead and the gabion baskets removed in sections to form the cast in place inner tunnel lining.



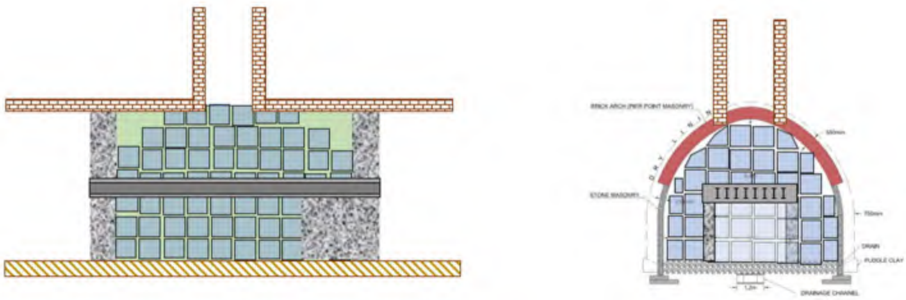
Stage 1 – grout gabion baskets to stabilise



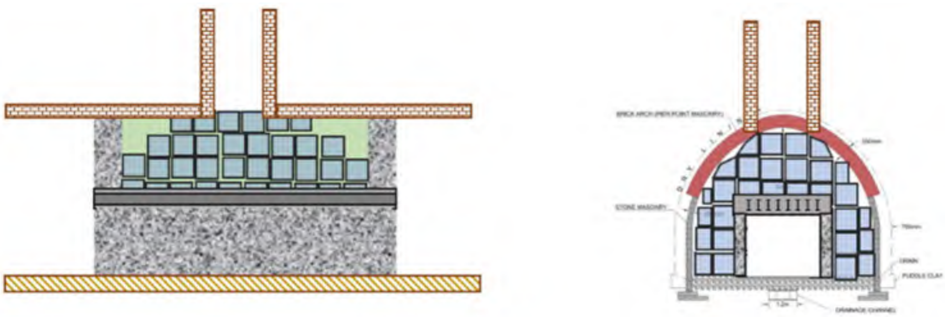
Stage 2 – trim ends to form a face, install concrete bulkhead either side of backfill cone and fill void with foam concrete or similar



Stage 3 - stitch drill through gabion baskets, install UC sections, and cast soffit.



Stage 4 – excavate new heading in suitable advances, casting sidewalls in bays



Stage 4 – completed tunnel

4.3.2.4 Preferred Option - Shaft 3

The preferred option is Option 3 as it is felt that this provides the safest, most practical solution. Given the degree of hand work required for Option 1 it is not considered that this option is suitable given the potential instability of the gabion basket stack. In the final condition it is also considered that the spraying of the headwall may not provide for long term stability or sealing against water ingress.

The mini-shield is not considered further due to the cost of the machine for the length of the drive, the complex establishment requirements including the mini-pile, and the cost associated with providing the necessary power. Option 3 provides the simplest and safest way to provide stability to the gabion basket whilst maintaining operative safety.

4.3.2.5 Shaft 3 Option Carried through to Estimate

Amco-Giffen have proposed and priced an alternative approach that is their preference, which simply involves dismantling the shaft support plug. As full details of the design of the shaft support plug are not yet available the adequacy of this approach cannot be fully assessed. However, given this alternative proposal is provided by the Contractor charged with designing and constructing the plug, it is assumed to be adequate at this time.

4.3.3 Remaining Shafts

Of the remaining 6 shafts, two (shafts 5 and 6) never reached the tunnel horizon and were terminated well above the tunnel. So, whereas they may represent a hazard at the surface they do not represent a risk to the use of the tunnel and are not further considered.

4.3.3.1 Shaft 1

Shaft 1 is 34m deep, masonry lined and 2.74m in diameter. At the surface it is located in open countryside. At the top it has a reinforced concrete cap, raised above ground level and it has a water management dome in the shaft eye at tunnel level.

It is recommended that the water management dome at the shaft eye is surveyed and reconditioned/replaced as required.

4.3.3.2 Shaft 4

Shaft 4 is 110m deep, masonry lined and 3.66m in diameter. At the surface it is located in the garden of 28 Moor Close Road, Queensbury. At the top it has a reinforced concrete cap, raised above ground level and is an open shaft eye at tunnel level. Water ingress is significant and the shaft is reported to be very wet below 40m depth.

It is recommended that a water management dome is installed at the shaft eye. Given the potential use of the tunnel as a cycleway, it is suggested that the design of the dome is sufficient to accommodate isolated falling masonry should that occur in the future.

4.3.3.3 Shaft 8

Shaft 8 is 38m deep, masonry lined and 2.74m in diameter. At the surface it is located in open countryside. At the top it has a reinforced concrete cap, raised above ground level and is an open shaft eye at tunnel level. This shaft experiences significant water inflows.

It is recommended that a water management dome is installed at the shaft eye. Given the potential use of the tunnel as a cycleway, it is suggested that the design of the dome is sufficient to accommodate isolated falling masonry should that occur in the future.

4.4 Water Management

Improvements to, or replacement of the existing pumping equipment at the south end of the tunnel is not included within the scope of this study. However, annual running costs for the existing pump (once operational) are approximately £1,350 per annum (electricity supply + servicing), excluding any fees associated with infrastructure on third party land.

4.5 Ventilation

This outline analysis has been undertaken on the assumption that none of the existing ventilation shafts are open.

When the tunnel is rehabilitated as a cycle way, it will effectively become an indoor sports space (albeit with open ends). As such it has been assessed that to provide adequate ventilation, 2 air changes per hour will be required. It is noted that the 1:100 gradient in the tunnel will mean that the elevation difference in the portals will create a difference in pressure/temperature and hence an air flow within the tunnel.

However, considering external factors such as prevailing wind conditions at the portals, analysis has shown that this induced air flow alone will not be sufficient to provide the required number of air changes per hour. Following analysis, it is therefore proposed the mechanical ventilation is provided along with air quality monitors to detect carbon monoxide, carbon dioxide, sulphur dioxide and nitrous oxides. It is also recommended that anemometers are installed at each portal.

The following table lists the equipment required.

Item No.	Description	Estimated Cost	Power (kW)
1	4-6 No Axial Fan at 1.2m diameter to achieve 60m3/s airflow at each portals (500 Pa ESP)	£50,000	100
2	4-6 No Transition Pieces from Fans to Silencer	£8,000	N/A
3	4-6 No Sound Attenuators at 5m/s face velocity	£40,000	N/A
4	14 No mechanically adjusted opposed blade airflow dampers	£50,000	10
5	2 No Weather Louvres	£7,500	N/A
6	Airflow sensors (3 in tunnel) NO2, SO2, CO, CO2	£15,000	
7	Associated Power Supplies for above (connection only)	£30,000	
8	Redundant Generator or redundant Power	-	

Annual running costs for the ventilation (once operational) are expected to be commensurate with that of the pumping equipment at £1,350 per annum (electricity supply + servicing).

5. Estimates

An estimate and programme for the construction works has been provided by Amco-Giffen, predominantly based on the repairs described within this report.

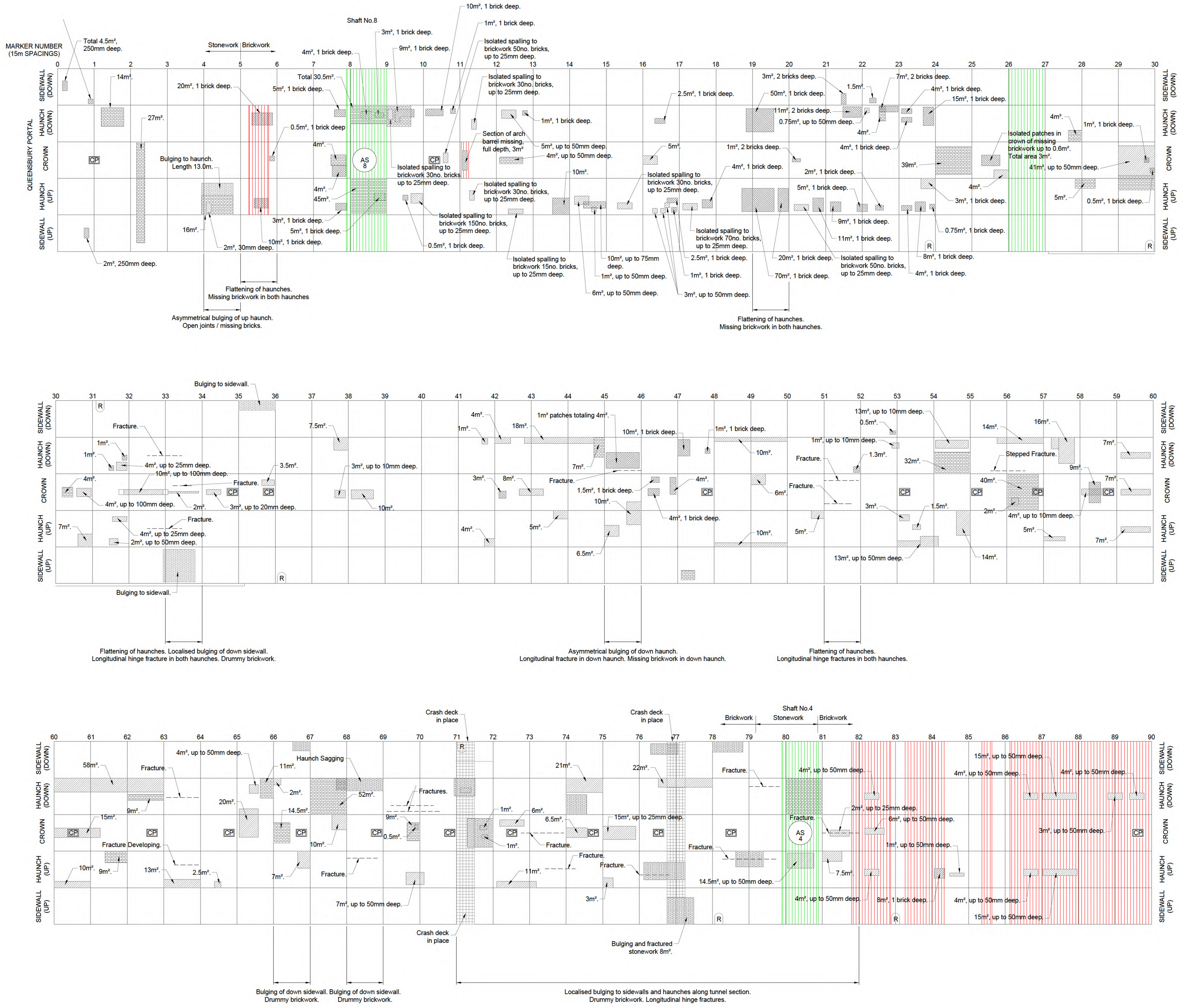
Amco-Giffen have provided a construction cost estimate based on a construction programme of 74 weeks (Refer to Appendix C for further details).

Cost estimate for works (Amco-Giffen):	£21,415,264.00
Ventilation costs - procure and install (Jacobs):	£195,500.00
Design, Development and Supervision costs @3% (Jacobs):	£648,323.00
Risk - 90% Confidence Level Maximum value from Probabilistic	
Assessment of risks listed in Appendix D	£4,123,000.00
Optimism Bias:	Not Included
Inflation:	Not Included
Total cost estimate:	£26,382,087.00
Estimate Tolerance:	+/-30%

Annual Inspection and Maintenance Costs (excluding inflation)

Structure Examinations (aggregate of visual and detailed examinations on a three year cycle):	£7,890.00/year
Pumps:	£1,350.00/year
Ventilation:	£1,350.00/year
Drainage maintenance:	£2,500.00/year
Periodic repairs (aggregate of ten year cycle):	£11,000.00/year
Total running cost estimate:	£24,090.00/year

Appendix A. Schematic of Current Defects and Works to Date



Notes

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3. Defects noted on this drawing have been identified through visual examination only. Additional defects within the tunnel lining are considered likely to be present.
4. Locations of defects are shown indicatively and are considered to be within 5m of their actual location within the tunnel.

KEY

- Missing brickwork.
- Spalled brickwork.
- Open Joints.
- Bare Ramarch.
- Ramarch Reinforced Shotcrete.
- Colliery Arches.
- AS Air Shaft.
- CP Catch pit.
- R Refuge.

FOR INFORMATION

REV	REVISION DATE	PURPOSE OF REVISION	DRAWN	CHECKED	APPROVED
3	Mar-21	Repair Estimate	[redacted]	[redacted]	[redacted]
2	15/05/2018	Updated Defects	[redacted]	[redacted]	[redacted]
1	08/11/12	Form B	[redacted]	[redacted]	[redacted]
0	28/08/12	Form A	[redacted]	[redacted]	[redacted]

JACOBS

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WEBSITE: WWW.JACOBS.COM

CLIENT
Historical Railways Estate on behalf of the DfT

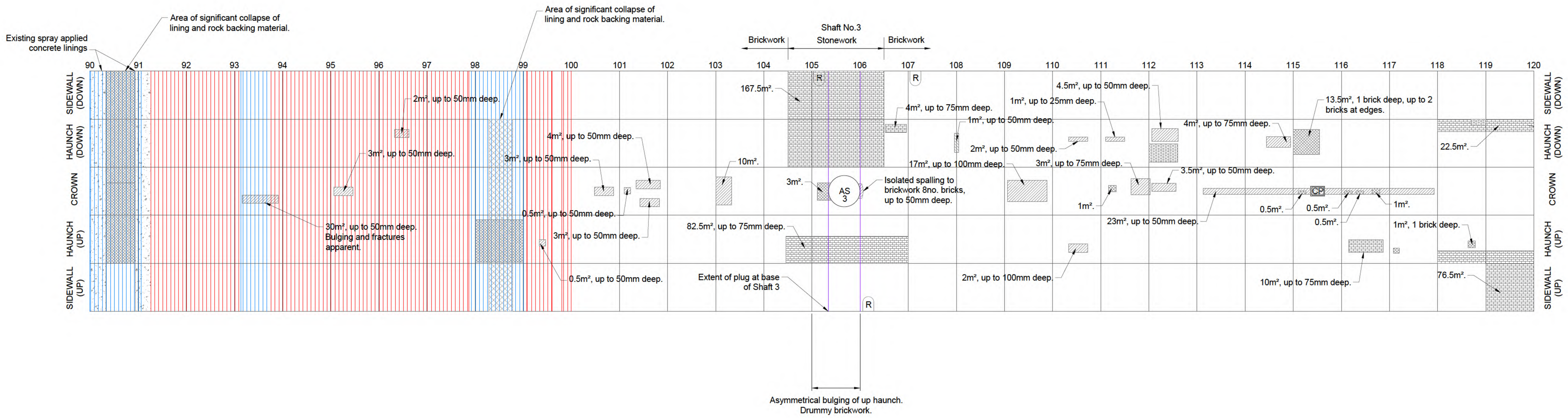
PROJECT
HRE WORKS FRAMEWORK

DRAWING TITLE
STRUCTURE HQU/3D
EXISTING DEFECTS
SHEET 1 OF 2

DRAWING STATUS
FOR INFORMATION

SCALE: NOT TO SCALE — DO NOT SCALE
JACOBS No. B38380
CLIENT No. HQU/3D

DRAWING NUMBER B18280-AH-0001
REV 3



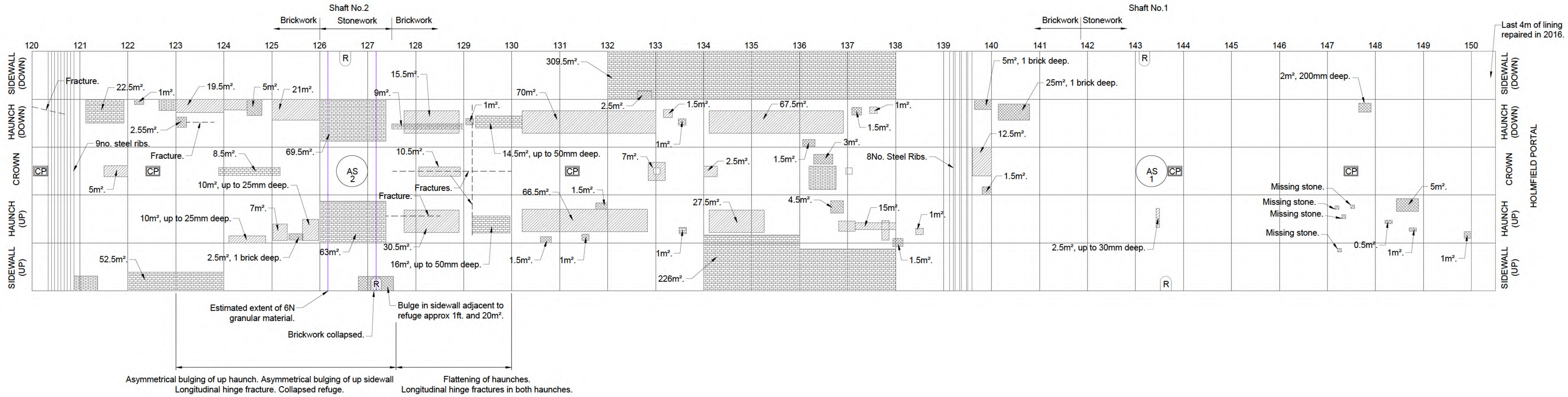


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Photo 1: Typical example of spray applied concrete lining at shafts (Shaft 4)

Photo 2: Example of Ramarch (between markers 99 and 100 shown)

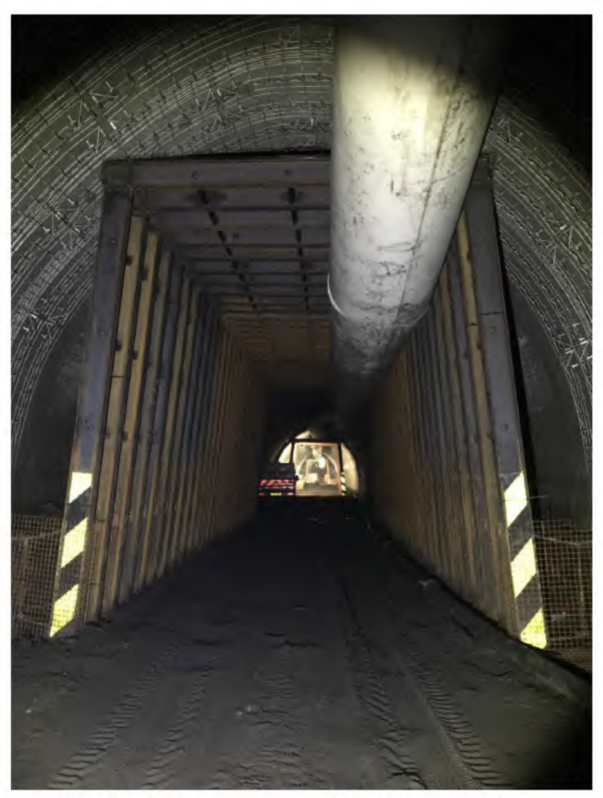

Photo 3: Example of Colliery Arches

FOR INFORMATION

REV	REVISION DATE	PURPOSE OF REVISION	DRAWN	CHECKED	APPROVED
3	Mar-21	Repair Estimate	[redacted]	[redacted]	[redacted]
2	15/05/2018	Updated Defects	[redacted]	[redacted]	[redacted]
1	08/11/12	Form B	[redacted]	[redacted]	[redacted]
0	28/08/12	Form A	[redacted]	[redacted]	[redacted]

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DRAWING TITLE
STRUCTURE HQU/3D
EXISTING DEFECTS
SHEET 2 OF 2

DRAWING STATUS
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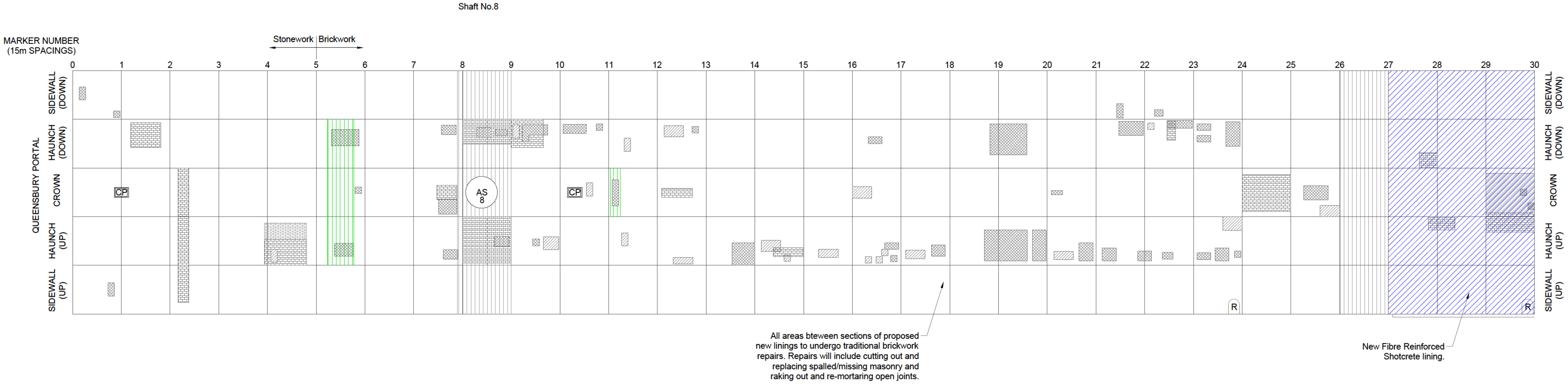
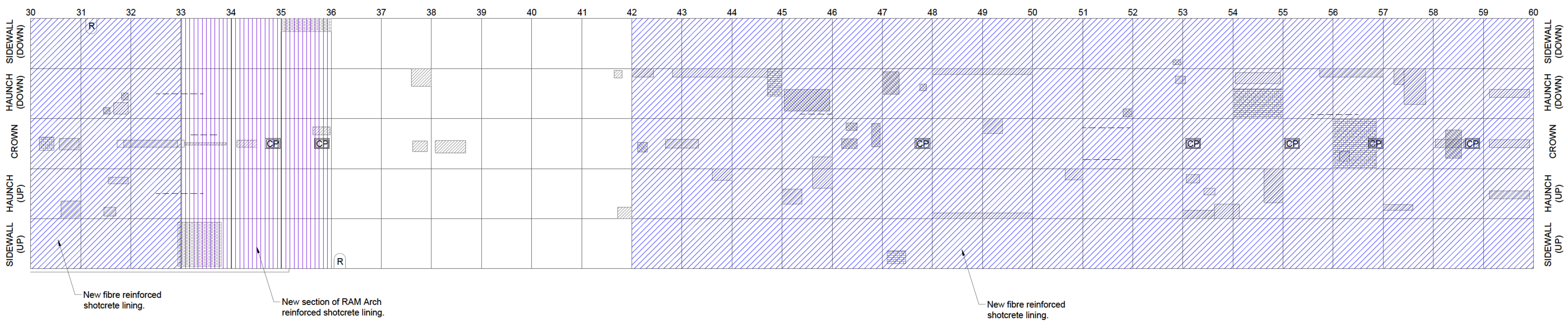
SCALE: NOT TO SCALE — DO NOT SCALE
JACOBS No. B38380
CLIENT No. HQU/3D

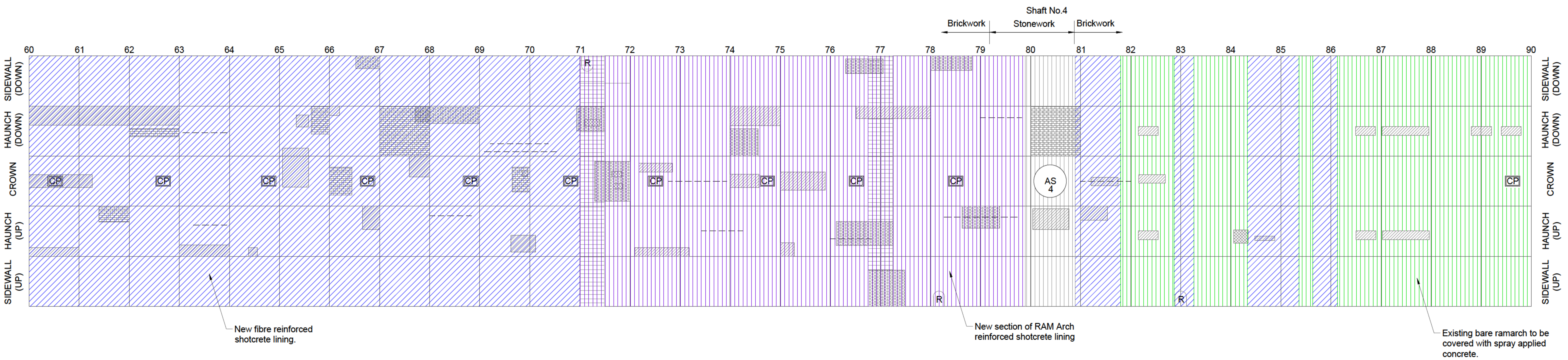
DRAWING NUMBER
B18280-AH-0002

REV
3

Appendix B. Schematic of Proposed Repairs







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5. Locations and extent of the suggested repairs are indicative only and will be subject to additional surveys and investigations, structural analyses and detailed design.

KEY

- Missing brickwork. Areas to be dressed back and replaced where not covered by new lining.
- Spalled brickwork. Areas to be cut out and replaced where not covered by new lining.
- Open joints to be raked out and re-morated where not covered by new lining.
- Existing bare RAM Arch to have spray applied concrete layer installed.
- Existing sections with RAM Arch reinforced shotcrete.
- Colliery arches to be shuttered and void between the arches and tunnel to be backfilled with concrete.
- New sections of RAM Arch and shotcrete lining.
- New sections of fibre reinforced shotcrete lining.
- AS — Air Shaft.
- CP — Catch pit.
- R — Refuge.

FOR INFORMATION

REV	REVISION DATE	PURPOSE OF REVISION	DRAWN	CHECKED	APPROVED
0	Mar-21	Repair Estimate	[redacted]	[redacted]	[redacted]

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CL ENT
Historical Railways Estate on behalf of the DfT

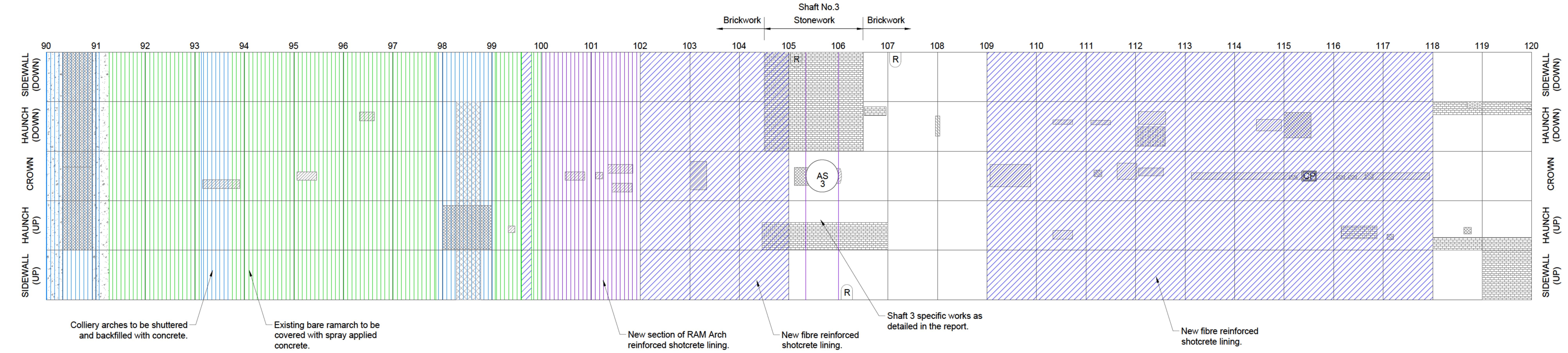
PROJECT
HRE WORKS FRAMEWORK

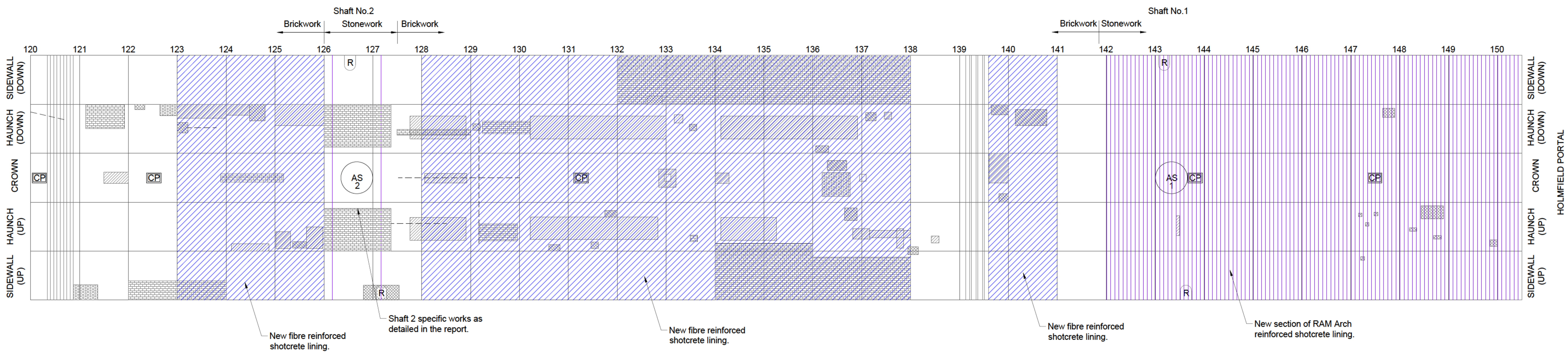
DRAWING TITLE
STRUCTURE HQU/3D
PROPOSED REPAIRS
SHEET 1 OF 2

DRAWING STATUS
FOR INFORMATION

SCALE:	NOT TO SCALE	DO NOT SCALE
JACOBS No.	B38380	
CLIENT No.	HQU/3D	

DRAWING NUMBER
B18280-AH-0003
REV 0





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0	Mar-21	Repair Estimate	[redacted]	[redacted]	[redacted]

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PROJECT
HRE WORKS FRAMEWORK

DRAWING TITLE
STRUCTURE HQU/3D
PROPOSED REPAIRS
SHEET 2 OF 2

DRAWING STATUS
FOR INFORMATION

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JACOBS No.	B38380	
CLIENT No.	HQU/3D	

DRAWING NUMBER
B18280-AH-0004
REV
0

Appendix C. Amco-Giffen Estimate and Programme

AMCO·GIFFEN

Our Reference: QT/01

Our budget estimate of cost for the repairs at Queensbury Tunnel is based upon the methods and quantities detailed within the Jacobs email dated 20/01/2021.

When reviewing the budget estimate please refer to the conditions below;

- Please note that due to the similarity of the repair required Items 10 and 12 have been grouped together has have items 11 and 13.
- The Preliminary Item includes all staffing and costs associated with the running of two individual compounds, one at the North Portal and one at the South Portal for a period of 74 weeks, including full mobilisation and demobilisation of both compounds.
- Item 5 has not been included as an alternative to Item 4 due to Health and Safety grounds, although the cost has been included in the submission. The HAVS impact with the installation of high quantities of Rock Bolts using pneumatic hand held bolters would be considered unacceptable. The cost and programme have been estimated with six teams of men using 'Turbo Gopher' type machines and in order to mitigate the HAVS element of the operation, but still maintain programme, would require the design and construction of three or four bespoke engineered drill rig platforms at considerable expense.
- Removal of the infill at Shaft 2 and Shaft 3 is considered a far more economically viable alternative to any proposed tunnelling through the infill
- Item 7 shows 'New Ramarch and Sprayed Concrete 250mm thick' as being more economically viable than the 'Installation of a Multi-plate Arch and Grouting into the Annulus' due to programme implications of the original proposal.

Yours faithfully

For and on behalf of AmcoGiffen

AMCO·GIFFEN

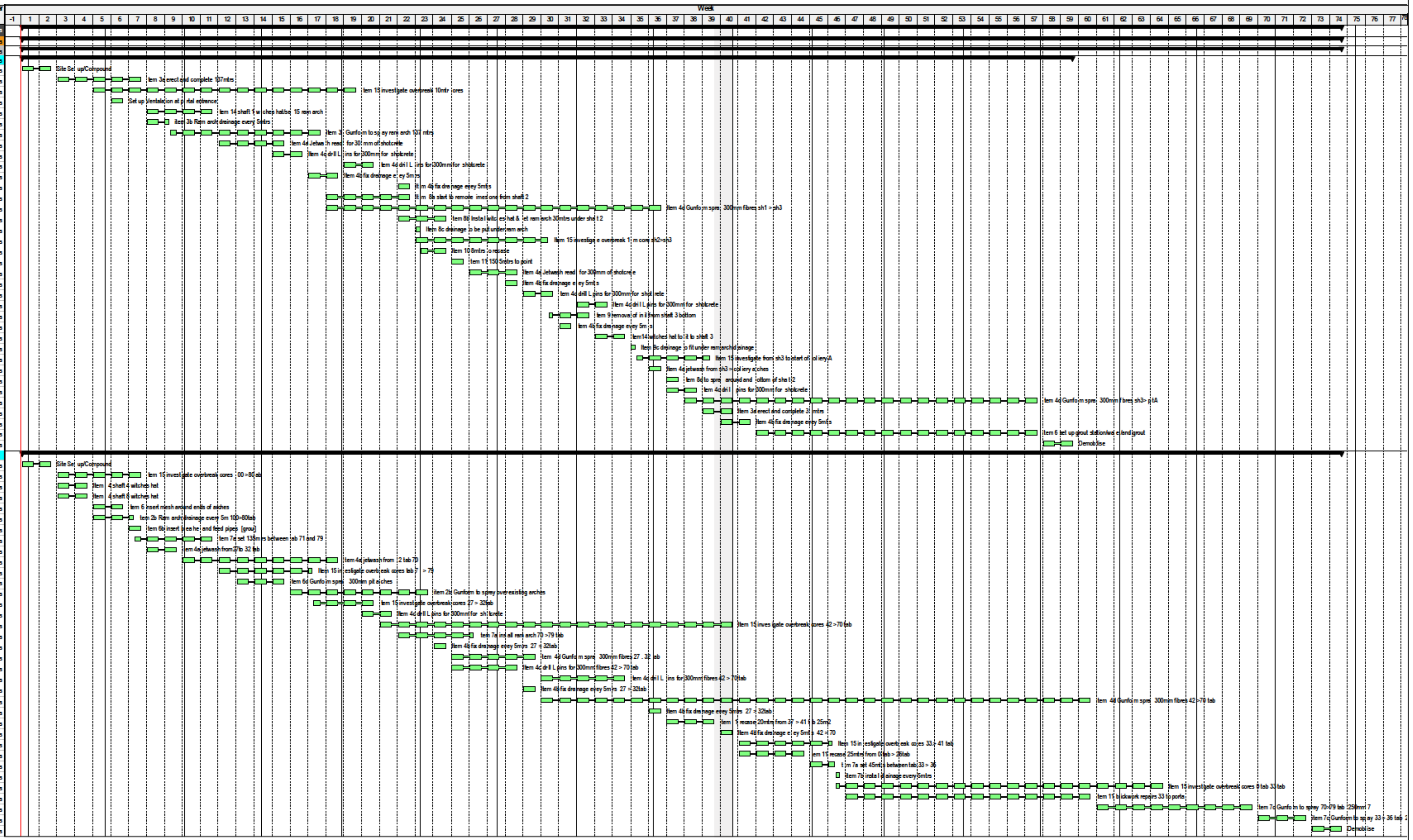
Our Reference: QT/01

Item No.	Quantity	Brief description	Cost	Alternate Methodology	Alternate Cost
1	74 week	Preliminary costs as detailed on previous page	£6,015,595.91		N/A
2	199m	250mm of shotcrete to areas with Ram Arch already installed.	£1,259,609.67		N/A
3	157m	New Ram Arch and shotcrete 250mm thick	£1,671,842.87		N/A
4	975m	Fibre reinforced shotcrete (300mm thick) to areas of tunnel with no Ramarch installed.	£6,486,711.80		N/A
5	364m	Fibre reinforced shotcrete (300mm thick) to areas of tunnel with no Ramarch installed. Price included in Item 4 above		Rock bolts and fibre reinforced shotcrete (100mm thick) to areas of tunnel with no ramarch installed.	£1.566,236.16
6	43.2m	Shuttering and backfilling around colliery arches using foamed concrete.	£920,774.56		N/A
7	180m	New Ram Arch and shotcrete 250mm thick	£1,807,930.96	Installation of Multi-plate Pipe Arch and Grouting as proposed by Jacobs	£2,000,894.61
8	2,000t	Remove Infill at Shaft 2 and Ramarch and Spray Concrete to 15m area	£298,482.52		N/A
9	300m^3	Remove Infill at Shaft 3 and Ramarch and Spray Concrete to 15m area	£298,964.82		N/A
10+12	261.5m^2	Rake out and repoint joints	£58,759.97		N/A
11+13	363.5m^2	Remove and Recase	£656,141.64		N/A
14	5 Nr.	Installation of 'witches hats' to bases of all remaining shafts - to be suitable for catching potential brick fall from shaft.	£308,065.26		N/A
15	450 Nr.	Investigations into overbreak (cores in crown and haunches)	£1,632,383.57		N/A
Total			£21,415,263.55		

Project Name : Queensbury
Project ID & Version : Queensbury

Print Date : 24-Feb-21 15:27
Data Date : 29-Mar-21

Activity ID	Activity Name	Original Duration	Start	Finish	Calendar
Queensbury		370	29-Mar-21	26-Aug-22	#GC - 5 day Working No Bank Holidays
Implementation		370	29-Mar-21	26-Aug-22	#GC - 5 day Working No Bank Holidays
Site Works		370	29-Mar-21	26-Aug-22	#GC - 5 day Working No Bank Holidays
South Programme		295	29-Mar-21	13-May-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1090	Site Set up/Compound	10	29-Mar-21	09-Apr-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1100	Item 3a erect and complete 137mtrs	25	12-Apr-21	14-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1110	Item 15 investigate overbreak 10mtr cores	75	26-Apr-21	06-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1120	Set up Ventalation at portal entrance	5	03-May-21	07-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1130	Item 14 shaft 1 witches hat/set 15 ram arch	20	17-May-21	11-Jun-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1140	item 3b Ram arch drainage every 5mtrs	7	17-May-21	25-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1150	Item 3c Gunform to spray ram arch 137 mtrs	43	26-May-21	23-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1160	Item 4a Jetwash ready for 300mm of shotcrete	20	14-Jun-21	09-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1170	Item 4c dri l L pins for 300mm for shotcrete	10	05-Jul-21	16-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1175	Item 4c dri l L pins for 300mm for shotcrete	10	02-Aug-21	13-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1180	Item 4b fix drainage evey 5mtrs	10	19-Jul-21	30-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1185	Item 4b fix drainage evey 5mtrs	5	23-Aug-21	27-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1190	Item 8a start to remove limestone from shaft 2	25	26-Jul-21	27-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1200	Item 4d Gunform spray 300mm f bres sh1 > sh3	95	26-Jul-21	03-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1210	item 8b Install witches hat & set ram arch 30mtrs	15	23-Aug-21	10-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1220	Item 8c drainage to be put under ram arch	2	30-Aug-21	31-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1240	Item 15 investigate overbreak 10m core sh2>sh3	38	30-Aug-21	20-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1250	Item 10 8mtrs to recase	8	01-Sep-21	10-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1260	item 11 150 5mtrs to point	5	13-Sep-21	17-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1270	Item 4a Jetwash ready for 300mm of shotcrete	15	20-Sep-21	08-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1280	Item 4b fix drainage evey 5mtrs	5	04-Oct-21	08-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1290	Item 4c dri l L pins for 300mm for shotcrete	10	11-Oct-21	22-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1295	Item 4c dri l L pins for 300mm for shotcrete	10	01-Nov-21	12-Nov-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1300	Item 9 removal of infil from sha t 3 bottom	12	21-Oct-21	05-Nov-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1310	Item 4b fix drainage evey 5mtrs	5	25-Oct-21	29-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1320	Item14 w tches hat to it to shaft 3	10	08-Nov-21	19-Nov-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1330	Item 9c drainage to fit under ram arch/drainage	2	22-Nov-21	23-Nov-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1340	Item 15 investigate from sh3 to start of colliery A	21	24-Nov-21	22-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1350	Item 4a jetwash from sh3 > co liery arches	5	29-Nov-21	03-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1360	Item 8d to spray around and bottom of sha t 2	5	06-Dec-21	10-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1370	Item 4c dri l L pins for 300mm for shotcrete	10	06-Dec-21	17-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1380	Item 4d Gunform spray 300mm f bres sh3> p tA	100	13-Dec-21	29-Apr-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1390	Item 3a erect and complete 30 mtrs	10	20-Dec-21	31-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1400	Item 4b fix drainage evey 5mtrs	10	27-Dec-21	07-Jan-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1410	item 6 set up grout station/waterland grout	80	10-Jan-22	29-Apr-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-1420	Demob lise	10	02-May-22	13-May-22	#GC - 5 day Working No Bank Holidays
North Programme		370	29-Mar-21	26-Aug-22	
AMCO-IMP-1990	Site Set up/Compound	10	29-Mar-21	09-Apr-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2000	Item 15 investigate overbreak cores 100 >80tab	25	12-Apr-21	14-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2010	Item 14 shaft 4 witches hat	10	12-Apr-21	23-Apr-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2020	Item 14 shaft 8 witches hat	10	12-Apr-21	23-Apr-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2030	Item 6 insert mesh around ends of arches	10	26-Apr-21	07-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2040	item 2b Ram arch drainage every 5m 100>80tab	12	26-Apr-21	11-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2050	item 6b insert brea her and feed pipes [grout]	5	10-May-21	14-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2060	item 7a set 135mtrs between tab 71 and 79	23	12-May-21	11-Jun-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2070	item 4a jetwash from27to 32 tab	10	17-May-21	28-May-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2080	item 4a jetwash from 42 tab 70	45	31-May-21	30-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2090	Item 15 investigate overbreak cores tab 71 > 79	27	14-Jun-21	20-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2100	Item 6c Gunform spray 300mm p t arches	15	21-Jun-21	09-Jul-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2110	item 2b Gunform to spray over exis ing arches	40	12-Jul-21	03-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2120	Item 15 investigate overbreak cores 27 > 32tab	18	21-Jul-21	13-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2130	Item 4c dri l L pins for 300mm for shotcrete	10	09-Aug-21	20-Aug-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2140	Item 15 investigate overbreak cores 42.>70 tab	100	16-Aug-21	31-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2150	item 7a install ram arch 70 >79 tab	22	23-Aug-21	21-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2160	Item 4b fix drainage evey 5mtrs 27 > 32tab	5	06-Sep-21	10-Sep-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2170	item 4d Gunform spray 300mm fibres 27 . 32 tab	25	13-Sep-21	15-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2180	Item 4c dri l L pins for 300mm f bres 42 > 70 tab	20	13-Sep-21	08-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2185	Item 4c dri l L pins for 300mm f bres 42 > 70 tab	25	18-Oct-21	19-Nov-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2190	Item 4b fix drainage evey 5mtrs 27 > 32tab	5	11-Oct-21	15-Oct-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2200	item 4d Gunform spray 300mm fibres 42 >70 tab	155	18-Oct-21	20-May-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2210	Item 4b fix drainage evey 5mtrs 27 > 32tab	5	29-Nov-21	03-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2220	item 11 recase 20mtrs from 37 > 41 tab 25m2	15	06-Dec-21	24-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2230	Item 4b fix drainage evey 5mtrs 42 > 70	5	27-Dec-21	31-Dec-21	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2240	Item 15 investigate overbreak cores 33.> 41 tab	27	03-Jan-22	08-Feb-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2250	item 11 recase 25mtrs from 0 tab > 26tab	20	03-Jan-22	28-Jan-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2260	item 7a set 45mtrs between tab 33 > 36	8	31-Jan-22	09-Feb-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2270	item 7b install drainage every 5mtrs	2	10-Feb-22	11-Feb-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2280	Item 15 investigate overbreak cores 0 tab 33 tab	92	10-Feb-22	17-Jun-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2290	item 11 brickwork repairs 33 to portal	70	14-Feb-22	20-May-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2300	item 7c Gunform to spray 70>79 tab 250mm 7	45	23-May-22	22-Jul-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2310	item 7c Gunform to spray 33 > 36 tab 250mm	15	25-Jul-22	12-Aug-22	#GC - 5 day Working No Bank Holidays
AMCO-IMP-2330	Demob lise	10	15-Aug-22	26-Aug-22	#GC - 5 day Working No Bank Holidays



User Name : [redacted]

- Current Milestone
- Summary
- Remaining Level of Effort
- Actual Level of Effort
- Actual Work
- Remaining Work
- Critical Remaining Work
- Start Constraint
- Finish Constraint

Date	Revision	Checked	Approved

Alternate approach for removal of type 1 infill at Shaft 2.

The general agreement is that the angle of repose for crushed stone granular fill with medium to low flow properties is 45°. With this in mind we can assume that the fill at shaft 2 will have an appearance similar to that shown in fig1+2 below:

It has been assumed that the top of the cone will have extended slightly beyond the width of the base of the shaft and offered some support to the shaft eye, however this has been omitted for clarity.

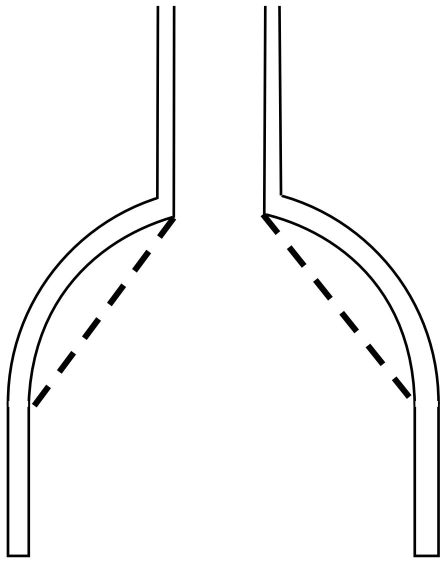


Figure 1: Cross section of tunnel showing base of fill at full width of tunnel but not filling the haunches

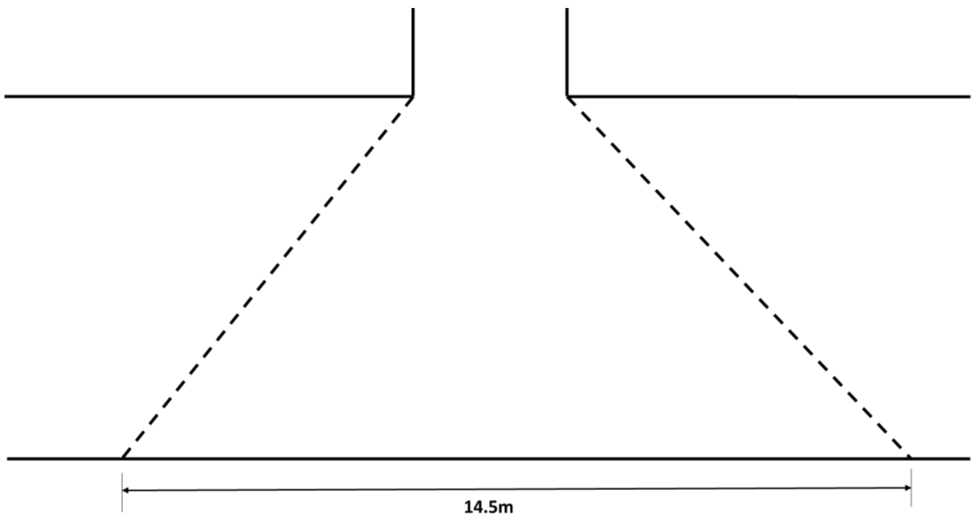
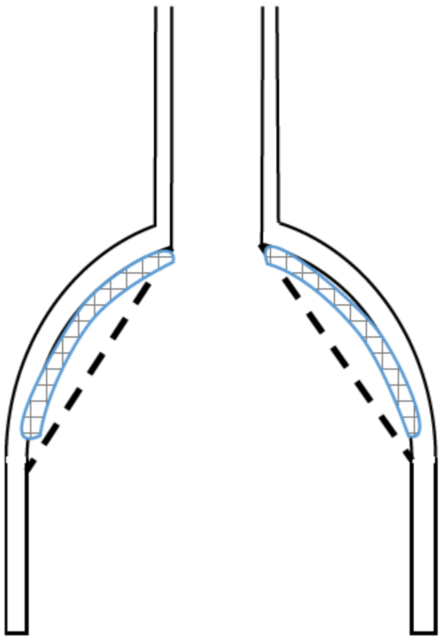
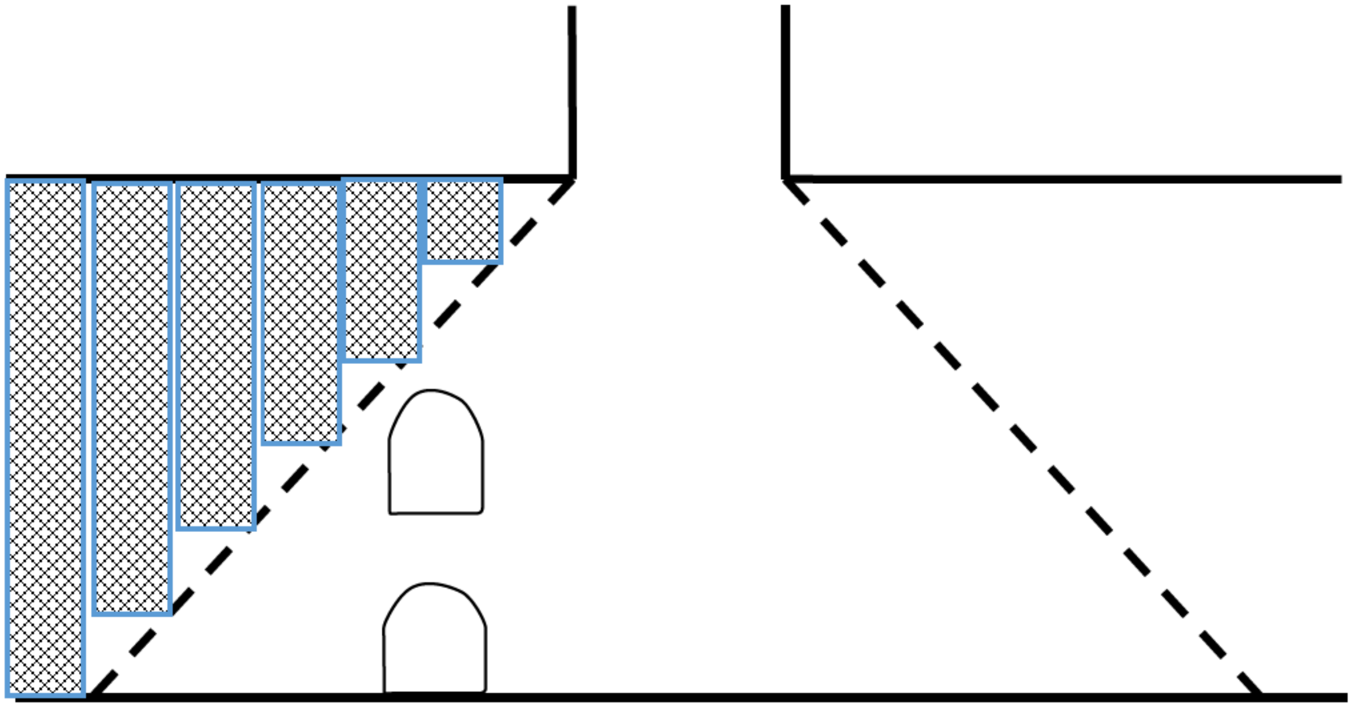


Figure 2: Longitudinal section of tunnel showing base of the fill extending to approximately 14.5m along the tunnel based on an angle of repose of 45° and a shaft diameter of 2.5m

The proposal involves the following steps:

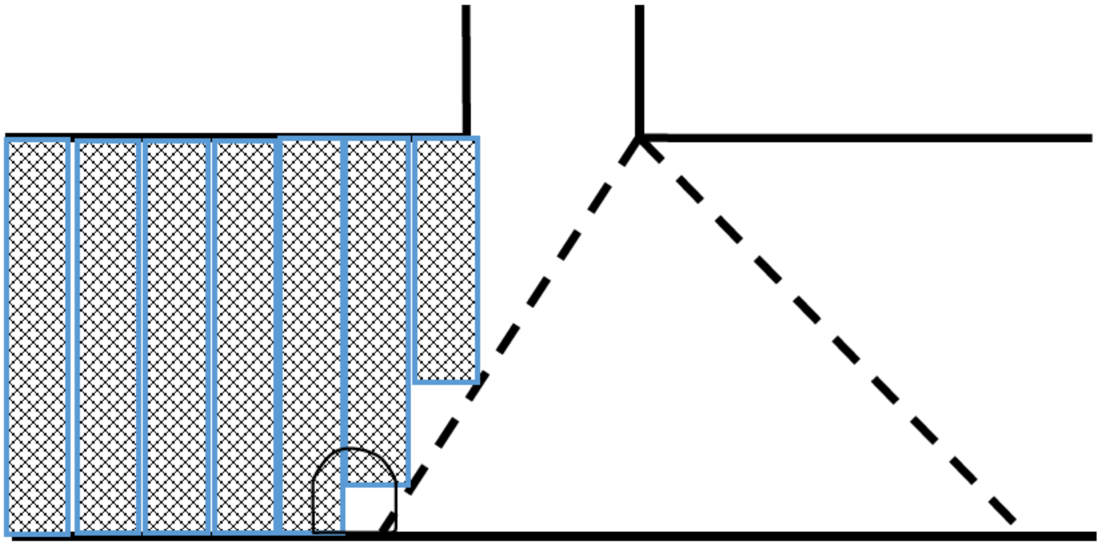
1. Erect Ramarch to all exposed areas of the tunnel lining starting as close as possible to the shaft eye to the South of the shaft as shown below:



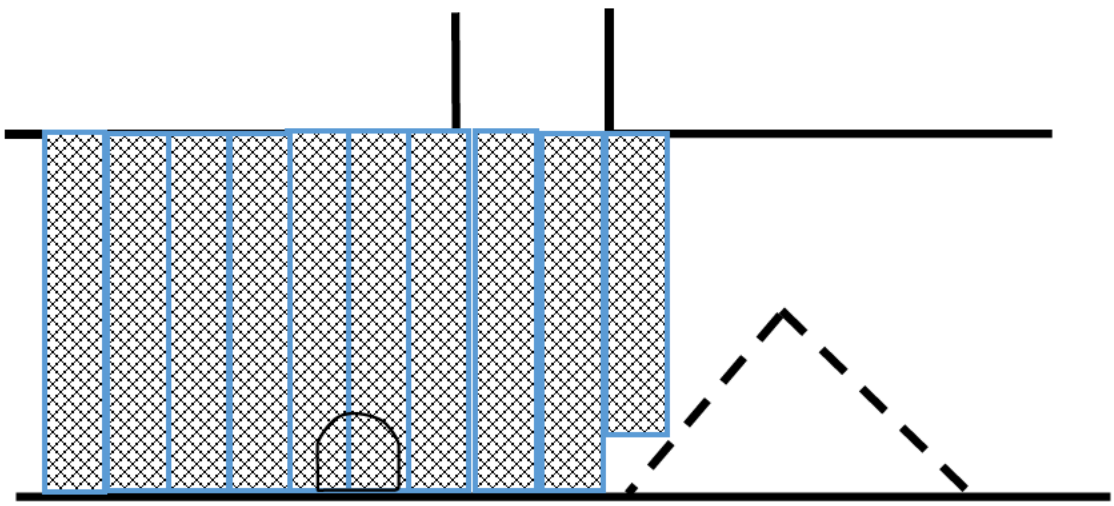


2. The installed Ramarch would then be sprayed with concrete to a depth of 250mm only in areas where it would not impede the addition of extra segments of Ramarch.

3. The Type 1 would then be systematically removed using an excavator and dumper and spread along the length of the tunnel appropriately. The excavator does not need to be a long reach, as the granular fill cannot exceed the original footprint. The excavation would only take place from the South end of the tunnel thus allowing for the critical southern point of the tunnel to be immediately supported.



4. As the removal of the granular infill progresses and the shaft is emptied and at each available opportunity the available tunnel lining will be Ramarched. These additional sections would not be sprayed until the tunnel section was complete. In order to expedite the reinforcement of the tunnel lining in the safest manner, the usual 2.2m length of Ramarch would be redesigned to accommodate 1.1m panels. This would make erection easier in the tight confines around the fill.



5. Once all the fill has been removed the whole of the Ramarch would be sprayed with 250mm deep non fibre concrete, including the defective refuge, which would be sprayed flush to the remainder of the concrete.

Appendix D. Risk Register and Probabilistic Risk Assessment

The Risk Register below has been developed by the Project Team to capture those risks that could impact on the project before and during the works required to repair Queensbury Tunnel and convert it into a cycleway. The risk register has been used as the basis for a probabilistic risk assessment to estimate the range of possible risk costs that should be allowed for in the project cost estimate.

Each of the eleven risks in the register has been assigned a probability (reflecting its likelihood) and a potential cost impact (triangular distribution defined by a minimum, most likely and a maximum value). All risks were assigned probabilities ranging between Low (>10% and <=25%) and High (>50% and <=75%). None of the risks were considered to have probabilities less than 10% or greater than 75%. All the assigned probability and impact values were reviewed by Amco-Giffen.

The Probabilistic Risk Assessment was carried out using Palisade @Risk software to run a "Monte Carlo" simulation on the risks in the register, using the probability and potential impact data described above. The Monte Carlo simulation compounded the outcomes from 10,000 iterations and the results showed a 90% confidence range of £0.387M to £4.123M for the risk cost that should be added to the base cost estimate for the works. The Project Team has taken the most pessimistic figure of £4.123M forward to the estimated total cost.

The Risk Assessment assumes that works to repair the tunnel will commence no later than 24 months from delivery of this report, and the works will be completed in line with Amco-Giffen's outline programme.

1. Risk Register

Risk No.	Hazard / Risk Description	Cause	Consequence	Mitigation / Control Measure
1	Further deterioration of the tunnel lining leading to additional collapses prior to, or during works.	Condition and age of the tunnel including: - Areas of spalling brickwork. - Missing panels of brickwork reducing the lining thickness. - Mortar loss, open and soft / saturated joints. - Already deformed sections of the tunnel. Geological and hydrological conditions including: - The presence of a coal seam adjacent to the tunnel. - The presence of mudstone surrounding sections of the tunnel. - Drill & Blast construction method fracturing surrounding rock. - Ground water levels around the tunnel.	Further lining deterioration will ultimately result in a major tunnel collapse which will then increase the remedial works duration, costs and related hazards. Further collapse in the tunnel may result in serious injury or death. 3rd party claims could also result. Additional obstacles / debris in the tunnel requiring safe removal and installation of further colliery arches (or alternatives) to facilitate the works.	Works to either restore or abandon the tunnel to commence as soon as reasonably practicable, assumed to be in FY23/24. Public access to the tunnel prior to and during construction works to be prevented at all times and restricted for essential personnel. Investigative works required, including but not limited to: - Condition survey of all parts of the tunnel. - Investigative cores throughout the length of the tunnel. - Point cloud survey of the full length of the tunnel to inform structural assessment of the lining and cross-reference against the Aecom point cloud survey to check for recent movements in the lining. Structural assessment of the lining throughout the tunnel. Install remedial strengthening measures as appropriate.
2	Further deterioration of the tunnel lining at locations of existing collapses causing irreparable damage to the existing safety measures.	Condition and age of the tunnel including: - Areas of spalling brickwork. - Missing sections of lining reducing the thickness. - Mortar loss and open joints. Geological and hydrological conditions including: - The presence of a coal seam adjacent to the tunnel. - Drill & Blast construction method fracturing surrounding rock. - Ground water levels around the tunnel.	Further collapse in the tunnel could result in serious injury or even death. 3rd party claims could also result. Further deterioration at the collapses will ultimately require further remedial works to make the sections safe both during and on completion of the works. Additional obstacles / debris in the tunnel requiring safe removal to facilitate the works. Alternative to colliery arches and concrete would be required.	Works to either restore or abandon the tunnel to commence as soon as reasonably practicable, assumed to be in FY23/24. Public access to the tunnel prior to and during construction works to be prevented at all times and restricted for essential personnel. Investigative works required, including but not limited to: - Condition survey of all parts of the tunnel. - Investigative cores throughout the length of the tunnel. - Point cloud survey of the full length of the tunnel to inform structural assessment of the lining and cross-reference against the Aecom point cloud survey to check for recent movements. Structural assessment of the lining throughout the tunnel. Install remedial strengthening measures as appropriate.
3	Hydraulic pressure behind the tunnel lining following de-watering, leading to collapse of the tunnel lining.	De-watering of the flooded tunnel section.	It is anticipated that despite the relatively low in-situ stress in the tunnel lining at the southern end, it could collapse due to the current condition, formation of hydraulic pressure and flow of water through the masonry. Additional obstacles / debris in the tunnel requiring safe removal and installation of further colliery arches (or alternatives) to facilitate the works.	Tunnel to be de-watered at an appropriate rate prior to works and condition of the flooded length of the tunnel assessed. Proposals to strengthen the southern end of the tunnel include the installation of further RAM Arches to stabilise the masonry in advance of applying the spray applied concrete. Proposed repairs to incorporate appropriate water management systems to relieve hydrostatic pressures.

				Pumping system at the south portal to be maintained and operated on a continual basis during, and on completion of the works.
4	Long standing fracturing of rock mass adjacent to tunnel causing instability in lining, necessitating additional stabilisation works.	Drill & Blast construction method adopted when tunnel was constructed.	Fracturing of the surrounding rock mass results in increase in the loading and stresses in the tunnel lining.	Grouting of rock mass behind lining may be beneficial in areas with significant fracturing. The grout would fill the fractures and stabilise the rock mass. Investigative works required, including but not limited to: - Investigative cores throughout the length of the tunnel. Structural assessment of the lining throughout the tunnel. Install ground improvement measures as appropriate. Install remedial strengthening measures as appropriate.
5	Major groundwater inflow into tunnel.	The fracturing of the surrounding rock creates flow paths through the ground resulting in increased water ingress into the tunnel. Probably related to adjacent mine working, fault or fracturing from drill & blast construction technique.	Increased water ingress results in higher rates of deterioration, including mortar washout.	Grout to be injected from within the tunnel in those areas where water ingress is excessive. Grout should fill any cavities around the lining and reduce future seepage into tunnel. Pressure pointing of masonry and blockwork. Sodium Silicate additive to be used where appropriate for pointing wet areas of masonry. Proposed repairs to incorporate appropriate water management systems to relieve hydrostatic pressures. Installation of controlled water paths through the drilling of weep holes through the lining.
6	Collapse of shaft linings	The constant water inflows at all shafts have contributed to deterioration of the linings, which are currently considered to be in fair condition. Without future maintenance a collapse may occur. Lack of firm support strata at the top of the shaft linings. Lack of systematic maintenance and lack of recent inspection data. Failure of the tunnel lining below shaft(s).	Rock mass surrounding shaft(s) may collapse (if not competent) following a shaft lining collapse. Following a shaft and/or surrounding rock mass collapse, a serious injury or death of a member of the public could occur. 3rd party claims could also result. Settlement at the ground surface. Additional obstacles / debris in the tunnel requiring safe removal and installation of further colliery arches (or alternatives) to facilitate the works.	Ground investigation to obtain information on the rock mass surrounding the shafts. A monitoring strategy to be developed and operated. Undertake condition surveys and structural assessment of the shaft linings and shaft caps. Undertake remedial works as appropriate.
7	Unforeseen problems with reinstatement of tunnel below Shaft 2.	The condition and extent of the fill at the base of the shaft is not known. The condition of the tunnel lining around shaft 2 is not known and there is a known defective refuge (and adjacent sidewalls) in the vicinity of the shaft.	Collapse in the tunnel or shaft lining could result in serious injury or death. 3rd party claims could also result. Additional measures required to clear a safe passage beneath Shaft 2 which will then increase the remedial works duration, costs and related hazards.	Public access to the tunnel prior to and during construction works to be prevented at all times and restricted for essential personnel. Investigative works required, including but not limited to: - Condition survey of tunnel in vicinity of Shaft 2. Install remedial strengthening measures as appropriate.

8	Unforeseen problems with reinstatement of tunnel below Shaft 3.	The condition of the tunnel lining around Shaft 3 is not known.	Collapse in the tunnel or shaft lining could result in serious injury or death. 3rd party claims could also result. Additional measures required to clear a safe passage beneath Shaft 3 which will then increase the remedial works duration, costs and related hazards.	Public access to the tunnel prior to and during construction works to be prevented at all times and restricted for essential personnel. Investigative works required, including but not limited to: - Condition survey of tunnel in vicinity of Shaft 3. Install remedial strengthening measures as appropriate.
9	Hazardous materials	A large quantity of rubbish/fly-tipped materials are known to be present in the flooded section of the tunnel, as was evident on previous occasions when it was dewatered.	Hazard to operatives entering the tunnel. Potential delays to construction/remediation works. Specialists may be required to remove material prior to any other works commencing, potentially extending the construction programme.	Undertake material hazard assessment within the tunnel.
10	RAM Arch and shotcrete solution not sufficient for bulges at tablets 71 & 77.	No analysis has been undertaken to determine the adequacy of proposed repairs.	Following investigation and analysis of the deformed tunnel lining at Tablet 77, the proposed RAM Arch and shotcrete lining is deemed unsuitable. Further collapse in the tunnel could result in serious injury or death. 3rd party claims could also result.	Investigative works required, including but not limited to: - Condition survey of all parts of the tunnel. - Investigative cores through lining for the length of the tunnel. - Point cloud survey of the full length of the tunnel to inform structural assessment of the lining. Structural assessment of the lining throughout the tunnel. Install remedial strengthening measures as appropriate.
11	Change in scope of repairs after site investigation, analysis and detailed design.	No site investigation, analysis or detailed design has been undertaken as part of this study.	It is considered likely that the requisite site investigation data and subsequent analysis and detailed design will lead to some rescoping of the proposed remedial works.	Investigative works required, including but not limited to: - Condition survey of all parts of the tunnel. - Investigative cores through lining for full length of the tunnel. - Point cloud survey of the full length of the tunnel to inform structural assessment of the lining and cross-reference against the Aecom point cloud survey to check for recent movements in lining. Structural assessment of the lining throughout the tunnel.