Queensbury Tunnel

Asset or Liability?

PHOTO © DAVID ENYORI

OCTOBER 2016

Queensbury
TUNNEL SOCIETY

Contents

Acknowledgements

Sources

Feasibility Study of Future Asset Management
(Jacobs/British Railways Board (Residuary))(October 2009)

Queensbury Tunnel Options Report
(Jacobs/Highways England Historical Railways Estate)(Draft)(February 2016)

Institution of Civil Engineers virtual archive

National Archives

West Yorkshire Archives

Network Rail

British Newspaper Archive

Halifax Central Library (Halifax Courier/Halifax Guardian)

Forgotten Relics

Jan Rapacz

(Contains public sector information licensed under the Open Government Licence v3.0)

Photographs

Cover photo © David Enyori

Other colour photos © Four by Three/Graeme Bickerdike
(unless otherwise stated)

Black and white photos courtesy of Forgotten Relics collection
(unless otherwise stated)

Queensbury TUNNEL SOCIETY

Executive summary

The Historical Railways Estate (HRE), part of Highways England, examines and maintains around 3,200 disused railway structures. Of that number, the 2,501-yard (2,287 metres) long Queensbury Tunnel - between Bradford and Halifax in West Yorkshire - has the highest risk profile. This is due to its deteriorating condition, difficulties with access and the close proximity of dwellings to four of its construction shafts.


Local platelayers gang

In 2024, HRE's ten-year lease expires on a short section of approach cutting immediately outside the tunnel's south portal. Thereafter, control of this land will revert to its owner who has the right - and intention - to fill it for industrial development purposes. Having done so, much of the tunnel will flood (due to its 1:100 falling gradient to the south and high levels of penetrating groundwater) and it will not be possible to reach the bottom of at least three - possibly four - of the shafts. Furthermore, with only one access point and reduced ventilation, significant health and safety risks will arise.

In order to manage its liabilities long term, HRE has been developing plans to abandon Queensbury Tunnel. Early indications suggest the cost of the associated work will be in the region of £3 million. The Queensbury Tunnel Society, supported by the Queensbury Community Heritage & Action Partnership (QCHAP) and Cycle Queensbury, believe that if a large amount of public money is going to be spent, it would be preferable to engineer a solution that would allow the structure to be brought back into use as part of a cycle path. The landowner at the south end has expressed a willingness - in principle - to maintain an access route into the tunnel for such a purpose.

In 2015, HRE commissioned Jacobs, its consulting engineers, to produce an Options Report for abandonment or repair of the tunnel. A draft of this report was provided to stakeholders following a meeting on 31st March 2016.[1]

The options put forward by Jacobs range from a 'minimalist' form of abandonment (concrete plugs at the portals), through various levels of infilling to full repair. Costings for each option were developed by quantity surveying exercises/desk studies.

HRE presented these costings to the Minister of State at the Department for Transport: around £3 million for abandonment (sealing both ends of the tunnel with concrete plugs and backfilling the shafts) against £35 million to

1 It should be recognised that any comment herein on the draft Options Report may be invalidated by changes in the final version.

repair the tunnel for cycle path use. It is clear that, in the context of current pressures on public spending, the latter figure was unsustainable. HRE has therefore continued with its preparations for the tunnel's abandonment.

However, a review of the draft Options Report - involving discussions with mining, tunnelling and geotechnical specialists[2] - raises questions about several assertions made by Jacobs (see Parts 3.1 & 5). Given that HRE states that it takes a "risk averse" approach to asset management and, by definition, abandonment of the tunnel has to *permanently* address all the liabilities associated with it, these specialists raise issues regarding:

- the abandonment methodology for the shafts, about which little substantive detail is offered
- the potential impact of unmanaged groundwater which will flood the tunnel if/when the current pumping regime is withdrawn
- a misunderstanding about the methods of construction used in Queensbury Tunnel and conclusions based upon it.

The significance of these issues need to be considered in the context of future access. Once the entrances and shafts have been sealed/filled, it will be impractical to gain entry into the tunnel. In other words, the abandonment works must be 'right first time'; there will be no realistic opportunity to undertake further works if needs arise at some future time.

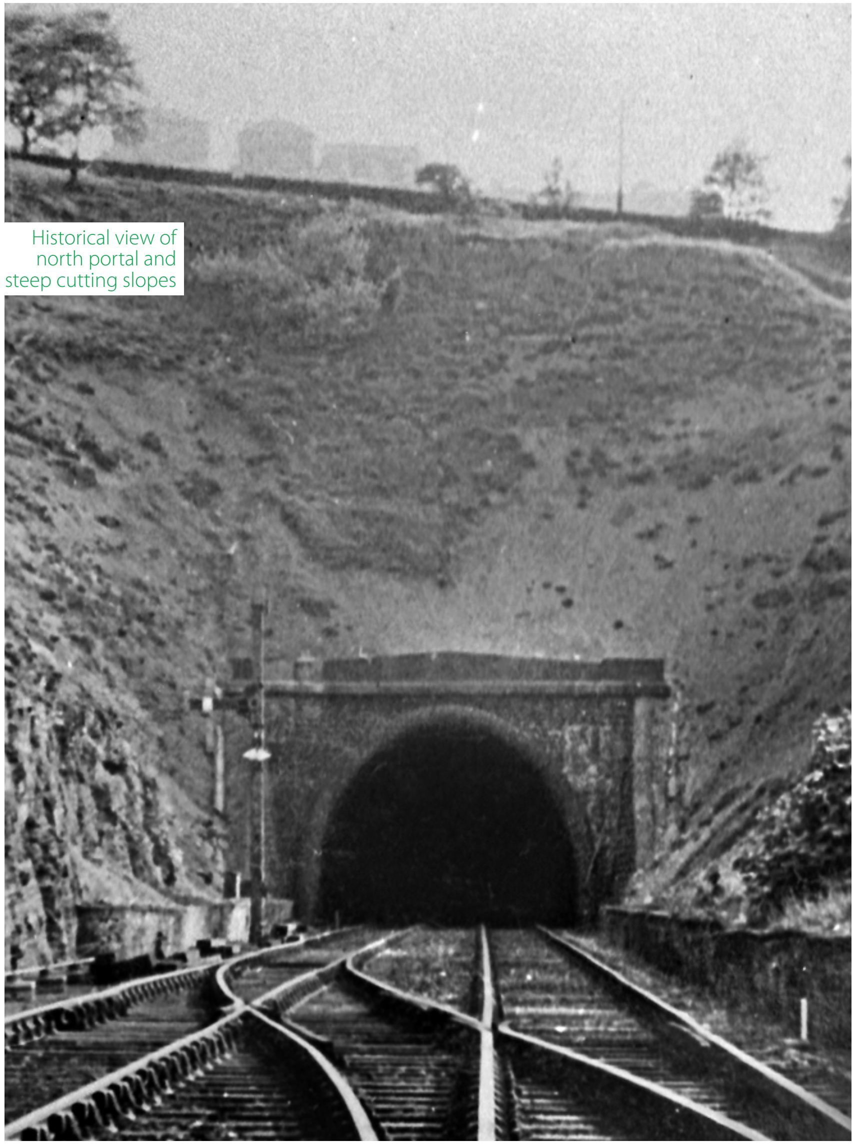
2 In this context, "specialist" means independent engineers and contractors with longstanding experience of designing and delivering tunnel/shaft remediation projects for the operational railway and/or mining/utility companies.

On this basis, it is legitimate to consider whether the nature/extent of the works outlined in the draft report are sufficient to address the long-term liabilities associated with the tunnel and, therefore, whether the £3 million abandonment costing put forward by Jacobs can be regarded as robust.

Early in 2016, HRE agreed to the Queensbury Tunnel Society arranging an independent assessment of the tunnel with a view to better understanding its condition, the repair works needed prior to any public reuse and the associated costs. This resulted in a site visit on 22nd June 2016, under the supervision of Hammonds ECS, HRE's contractor, and the Mines Rescue Service. Taking part on behalf of the Queensbury Tunnel Society were an experienced civil engineer specialising in tunnel remediation and two representatives from SES Group, the contractor responsible for successfully repairing a collapsed disused railway tunnel under a suburb of Liverpool in 2012.

Following the visit, a remediation plan was developed and a specification of works drawn up (see Part 3.2). Based on this, a budget cost of £2.81 million has been established for repairing the tunnel, including a 20% contingency. The programme of works would last 44 weeks.

It must be emphasised that this plan only addresses the structural defects, making the tunnel safe to walk through; it does not cover works relating to a cycle path (drainage, lighting, rebuilding the north portal, tarmac surface etc). The shafts could not be assessed during the site visit; however an estimated figure for repair works is included within the budget cost based on the defects/comments recorded in HRE's visual examination reports from 2015/16.



Historical view of north portal and steep cutting slopes

There is clearly a very significant disparity between the £35 million costing provided by Jacobs - based on a high-level desk study - and that established following the site visit and development of the remediation plan. It should be noted that, from the outset, the mining, tunnelling and contracting specialists consulted by the Queensbury Tunnel Society could not understand how Jacobs had arrived at their costing[3]. One engineer commented - perhaps somewhat flippantly - that "we could rebore the tunnel and drive another one alongside it for £35 million."

The Queensbury Tunnel Society's costing of £2.81 million aligns with the consensus view that remediation could be achieved for a similar sum to that allocated for abandonment, rather than 12 times as much.

It is reasonable to conclude that the draft Options Report was an inadequate basis for Ministerial decision-making about the affordability of repairing Queensbury Tunnel. The Society's position is that the abandonment process should therefore be halted pending a review of the most appropriate and cost effective way forward for the tunnel, one which would bring the broadest possible benefits for the public's considerable investment.

To better inform such a review, Sustrans has been asked to undertake a study with the intention of quantifying the economic impact a reopened Queensbury Tunnel would have both locally and regionally. They expect to report in spring 2017. ■

---

3 It should be noted that the draft Options Report does not specify quantities, rates or methodologies.

Part 1

An overview of the tunnel

Queensbury Tunnel Society

1.1 Construction

Queensbury Tunnel was driven by the Great Northern Railway between May 1874 and July 1878. It formed part of the company's Halifax, Thornton & Keighley Railway scheme, engineered by John Fowler. Located between Holmfield and Queensbury stations, the tunnel extends for 2,501 yards (2,287 metres) and was built to accommodate two tracks by contractor Benton & Woodiwiss. At least eight men lost their lives during the works.

To expedite progress, the intention was to sink eight construction shafts, but these were respaced shortly before work started, resulting in No.7 shaft being eliminated. However the northernmost shaft - which was the only one to retain its originally planned position - was referred to as No.8 shaft throughout the tunnel's operational life.

Due to overwhelming water ingress, Nos. 5 & 6 shafts were abandoned in 1875. This created a 1,200-yard section into which there was no intermediate access. It was partly as a consequence of this that the contractual construction programme of two years was significantly exceeded.

For a short time, progress with the heading (pilot tunnel) was assisted by use of a rock drilling machine supplied by Major Beaumont of the Royal Engineers which increased the miners' rate of progress by 3-5 times.

The tunnel opened to goods traffic on 14th October 1878. ■

1.2 Repairs during operational period

The tunnel's lining was generally built in lengths of approximately 15 feet. Its arch consists mostly of five locally-fired brick rings to an ovoid profile (see historical cross section on page 8), supported on stone sidewalls about 8 feet in height.

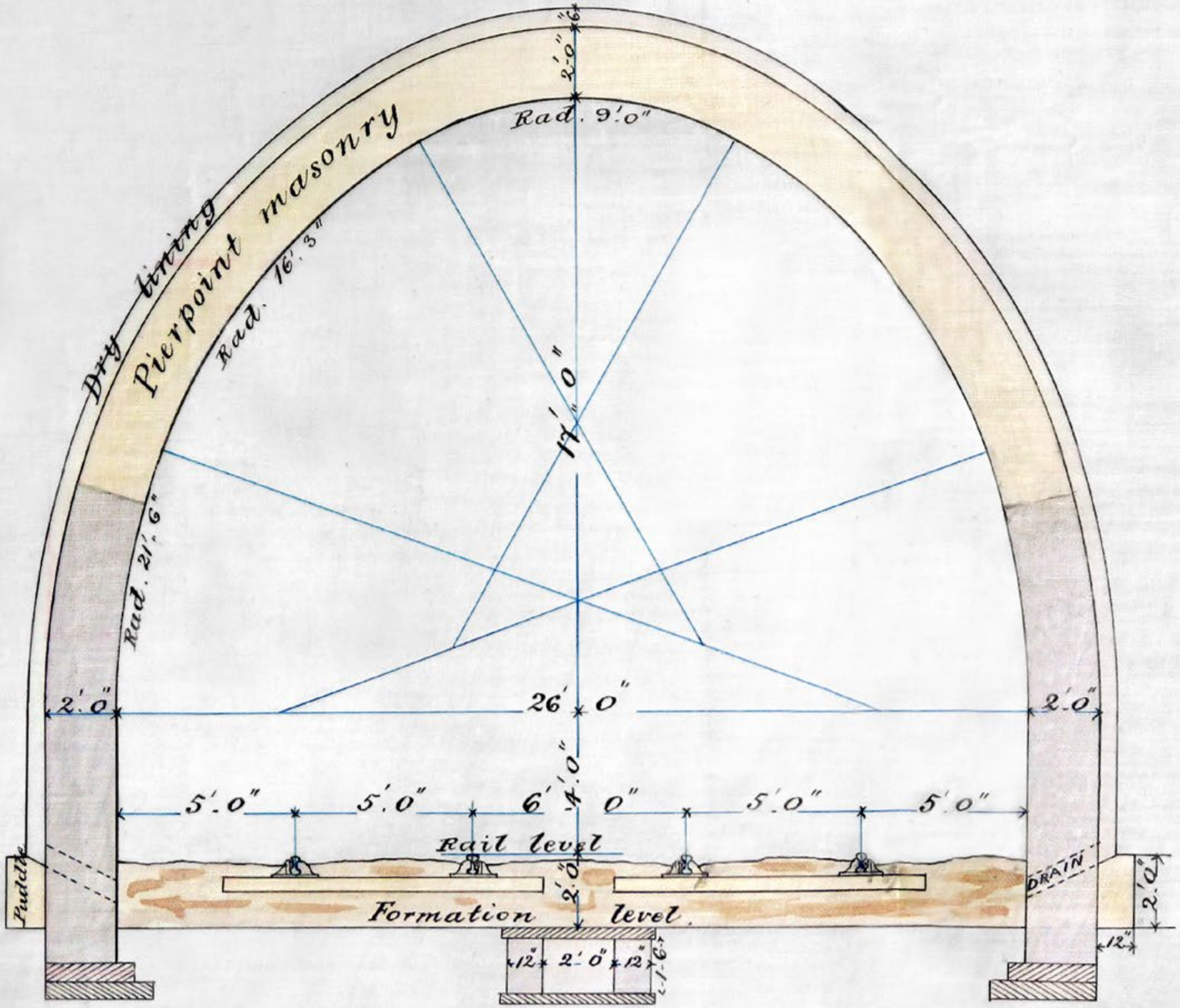
Subsequently, engineering brick was used for numerous patch repairs and the construction of half-a-dozen refuges towards the south end of the tunnel. These were probably inserted around the turn of the 20th century. The arch is stone at both ends, at four of the five shafts and at the location of a geological fault.

In 1882, four years after opening, significant defects were identified which required sections of sidewall and some lengths of arch to be rebuilt. This work took several months to complete and was mostly concentrated at a location in the northern half of the tunnel where it intersected with mine workings. The opportunity was taken to provide refuges as part of these works; previously, there was none.

Between 1924 and 1927, a programme of arch and sidewall repairs was undertaken, particularly between Nos. 1-2 shafts and south of No.4 shaft. No.3 shaft was relined and strengthened in 1934/5. No.8 shaft was partly recased and repointed in 1950.

The line through the tunnel closed in May 1956 and track lifting took place in 1963. ■

1.3 Historical cross section

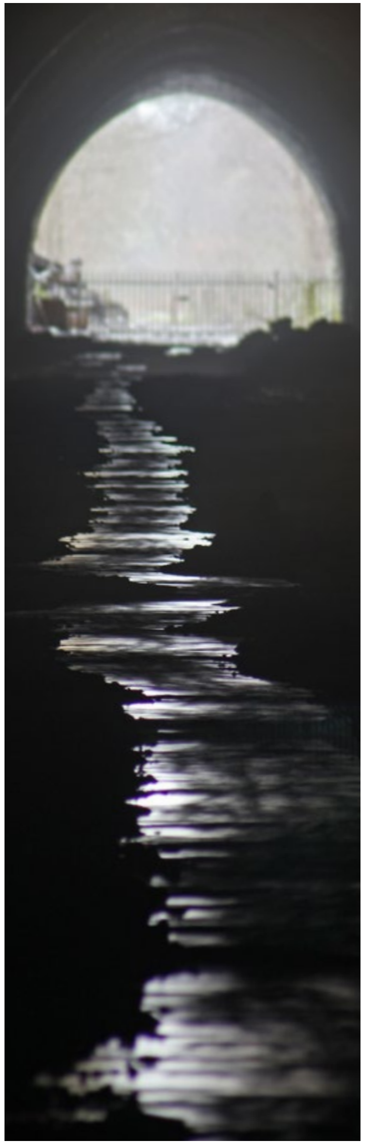


1.4 Geology and ground cover

According to the British Geological Survey 1:50,000 scale Solid and Drift Sheet 77 (Huddersfield), Queensbury Tunnel passes through the Lower Coal Measures (Westphalian A Group). This formation comprises a sequence of interbedded strata of the Elland Flags (Millstone Grit) and coal measures[4].

The tunnel is around 130 metres below ground level at its deepest point. The cover is less than 40 metres for the first 135 metres beyond the portals, above which is grassland. Nos. 1 & 8 shafts are located within these sections. ■

4 Source: *Feasibility Study of Future Asset Management* (October 2009) (Jacobs/British Railways Board (Residuary)).



1.5 Local mining activity

Historically, the area around Queensbury has seen extensive near-surface and deep mining. Consequently, the Great Northern Railway deemed it prudent to acquire a pillar of coal to support part of the tunnel around where No.6 shaft was sunk. However, in 1877, this coal was errantly mined, resulting in a need for the seam to be hand-packed with stone.

The tunnel's northern section is within the zone of influence from two worked seams at a depth of 40-100 metres. These were last worked in 1903. There are several mine shafts and adits around this part of the tunnel, including a number of passageways driven across its line either side of No.8 shaft in 1899.

Last worked in 1931, there are two seams at a depth of 100-150m through the central section of the tunnel. Compression of one of these seams is thought to be a contributory factor in the development of severe defects to the brick lining, notably two partial collapses and extensive spalling.

At its southern end, the tunnel is in the likely zone of influence of a coal seam within 50m of the surface, last worked in 1941. There are a number of shafts and adits close to the portal.

In 1882, a mining engineer's report for the Great Northern Railway recorded that the Halifax Soft seam lies at a depth only 20 yards from rail level, whilst the Halifax Hard seam is worked adjacent to the tunnel. ■

Queensbury TUNNEL SOCIETY

1.6 History since closure

Queensbury Tunnel was notoriously wet. This was a factor in the line's closure and has subsequently contributed to a general deterioration in the tunnel's condition. Although visual examinations have been carried out by HRE and its predecessor, British Railways Board (Residuary)(BRB(R)), the structure has not benefited from any substantive maintenance over the intervening period.

In 1967, the southern approach cutting (except the 50 feet closest to the tunnel portal) was sold to Halifax Corporation for waste tipping purposes. The Chief Civil Engineer of British Rail's North Eastern Region stipulated that a ramp must be provided for vehicular access into the tunnel but did not insist on any drainage provision through the cutting.

The tunnel falls to the south on a gradient of 1:100. Considerable quantities of water enter via the shafts, through the lining and, currently, from a stream which discharges into the northern approach cutting. Consequently, as the infilling work progressed and the track drainage failed, floodwater backed-up into the tunnel. For much of the past decade, the furthest extent of the water was around 1,000 yards from the south portal, with the southernmost 300 yards of tunnel being completely submerged. At Christmas 2015, there was 35 feet of water at the portal.

In 2012 and 2015, temporary pumps were used to dewater the tunnel for inspection purposes. However the rapid drawdown of water led to mortar loss and a loosening of masonry in the lining. During the spring/summer of 2016, HRE installed electric pumping equipment which now prevents the tunnel from flooding.

Southern approach cutting during dewatering

In January 1990, an inspection identified 1,335m^2 of loose/hanging brickwork in need of attention throughout the tunnel. Some of this was removed to provide safe access for research staff carrying out grouting/waterproofing experiments.

As part of its ongoing major tunnels programme, HRE is progressing plans for significant works with a view to abandoning the tunnel and its shafts. The nature of these plans - as currently understood - is discussed in Part 3.1. ■

Queensbury TUNNEL SOCIETY

1.7 Reopening campaign

The village of Queensbury developed around a huge mill which is still a considerable local landmark.

Sitting on high ground to the west of Bradford, Queensbury can feel rather disconnected as a result of agencies focussing their attention on urban areas closer to the city centre where considerable social challenges are found.

To redress this imbalance, a local campaign was launched to renew community engagement with Queensbury's history. A heritage venue has already been established in the mill; now the focus is on restoring the tunnel for use as a cycle path and linking it to the village by upgrading the former railway station access road, now privately-owned. If successful, it is hoped the scheme would bring economic and social benefits both to the local area and wider Yorkshire region, as well as helping the village to feel better about itself. Sustrans has been asked to undertake a study with a view to quantifying those benefits.

In order to abandon the tunnel, it is likely HRE will have to invest around £3 million to effectively and permanently address the associated liabilities. The view of the campaign group is that such levels of public money would be better spent on repairing the tunnel to enable its reuse, converting it from a liability into an asset. There are several obstacles to achieving this goal, not least whether the necessary repairs can be carried out for an affordable cost. ■

Robert Goodwill, then Parliamentary Under Secretary of State for Transport (in dark suit), discusses the tunnel's potential with campaign group leader Norah McWilliam (furthest left) during a stakeholders' visit on 23rd June 2014.

Queensbury TUNNEL SOCIETY

Part 2

Current condition

Queensbury TUNNEL SOCIETY

2.1 The tunnel

Despite being driven through the hard strata of millstone grit and coal measures, a 60-year absence of substantive maintenance has resulted in a deterioration in the condition of Queensbury Tunnel. However, whilst some parts can only be categorised as poor - specifically where partial collapses and other major defects have developed - it should be recognised that large sections remain in fair condition.

A section of the tunnel with few defects

Amongst the general, expected defects are panels of missing brickwork (some of them deliberately removed to facilitate safe access, having become loose), open joints, spalling to the brick faces and a softening/loss of mortar due to the flooding and water ingress.

There does appear to be a close corrolation between the presence of coal seams adjacent to the tunnel and concentrations of defects. This is likely due to the loading on the lining increasing over time - exceeding its intended capacity - as the superincumbent material slowly compresses the coal.

Missing brickwork close to No.8 shaft

The working of a 'Hard Bed' seam immediately adjacent to the tunnel between tabs[5] 27-35 - together with poor workmanship during construction - was responsible for defects being recorded in both the sidewalls and arch just four years after the tunnel opened. Remedial works took several months. Today, defects are again emerging in this part of the tunnel, with a longitudinal crack at the D/S[6] haunch, together with spalling at the crown and U/S[7] haunch. There is also a significant bulge/deformation in the U/S sidewall.

---

5 The tunnel is 2,501 yards (2,287 metres) long and, for record purposes, is divided into 150 sections each 50 feet (15.24 metres) long. The start and end of each section are known as "tablets" (or "tabs") from the markers used historically. Tab 0 is at the north portal; tab 150 is 1 yard (1 metre) from the south portal.

6 D/S: the Down (south-east) side of the tunnel on which trains ran towards Halifax.

7 U/S: the Up (north-west) side of the tunnel on which trains ran towards Bradford.

Queensbury TUNNEL SOCIETY

Within a 200-yard section either side of No.4 shaft are three severe bulges in the haunches, as well as a large bulge in the U/S sidewall and smaller bulges opposite on the D/S. These defects are caused by severe, localised overstressing of the lining. It should be noted that voids above the arch - up to 7 feet high - are described in the mining engineer's report from 1882. Good practice was to fill such voids to prevent loose material falling onto the extrados and overloading the arch, however some contractors had an 'out of sight, out of mind' culture. Checks were often cursory or non-existent.

Between tabs 82-102, the arch is extensively affected by deep brickwork spalling. The tunnel intersects with a coal seam between tabs 82-97. Moreover, panels of missing brickwork - one or two bricks deep - have been recorded on examination reports dating back at least 20 years. Between February 2013 and June 2014, partial collapses occurred at the location of two such missing panels.

In 2014, HRE asked Jacobs to carry out numerical stress analysis[8] of the lining around tab 90 where the first collapse occurred. However, a ratio of horizontal-to-vertical stress of 0.5 was applied - more typical of soft-ground tunnelling in sands or clays; use was also made of an unrepresentative loading model incorporating a built invert. Queensbury Tunnel was driven through rock and has no built invert. The model should also have taken into consideration the geology across the line of the tunnel - notably, thin interbedded layers of variable soft material with competent rock above.

The results of the analysis showed symmetrical stress concentrations in the haunches, a failure mode not seen at either of the two collapses. Generally, the failure modes through the tunnel are:

- asymmetrical collapses, with failure in one haunch
- symmetrical, with the crown rising, the haunches flattening and stress concentrations in the haunches and crown
- asymmetrical, with severe bulging in the sidewall
- asymmetrical, with severe bulging in the haunch.

It was concluded by Jacobs that, from the outset, the lining only just had sufficient strength to withstand the load of the superincumbent material, and that the spalling and subsequent collapses resulted from high compressive stresses in the lining exceeding the compressive strength of the brickwork once the inner ring(s) of brickwork had been lost. However the veracity of this conclusion is open to question due to the modelling deficiencies.

Numerous patch brickwork repairs were carried out between tabs 82-90 during the tunnel's operational period, notably in the 1920s. Some of the spalling occurs at the longitudinal edges of these repairs, probably due to the material generally used (engineering brick) being considerably harder than the original bricks and therefore placing adjoining areas under

8 This work was carried out using FLAC (Fast Lagrangian Analysis of Continua), two-dimensional explicit finite difference software for geotechnical analysis of soil, rock, groundwater and ground support.

greater strain. One consequence of this is that a number of repair panels are separating from the rest of the arch and lipping over the adjacent brickwork, partly as a function of poor bonding.

Progressive lining collapse in a disused North Yorkshire tunnel.

It is likely that the 170-yard section of tunnel between tabs 81-91 will suffer further collapses and, in the long-term, these will join together. A similar unravelling is occurring in a disused tunnel in North Yorkshire (pictured above), however the underlying drivers are different to those at Queensbury.

At tabs 93-94, a longitudinal fracture developed in the U/S high haunch which was stabilised using wedges. Between 2010-2013, the lining sheared at the southern end of this fracture, causing another to form parallel with it and pushing the higher part of the arch upwards by ~200mm, over the adjacent brickwork.

Next to No.2 shaft on the U/S is a refuge constructed around the turn of the 20th century in engineering brick. A 10mm wide crack has developed in its arch, widening to 50mm at floor level. The back of the refuge is separating, as is the outer face of adjoining tunnel sidewall. Immediately to the south, a ~1m^2 section has broken away; to the north is a bulge which extends diagonally upwards into the length of arch supporting the shaft.

Flooding followed by rapid dewatering has contributed to the loss or loosening of several stone blocks in the arch close to the south portal. The outer face of stonework is missing in two places, each being ~1m^2 in size. At the U/S haunch, a section of stonework around one of these areas is peeling away, the void behind being clearly visible.

Much of the track drainage is still functional, although blockages result in water running along the solum in places. There is localised water ingress through the lining, particularly at two locations between Nos. 1-2 shafts where it enters under pressure.

Whilst the condition of the tunnel at some locations presents very considerable challenges, there are comparatively few defects between tabs 35-70 (583 yards) and tabs 102-124 (367 yards), representing about 38% of the tunnel's length. A further 51% is affected by relatively minor defects which are routinely found, managed and remediated in operational railway tunnels. ■

2.2 The shafts

All five of the completed construction shafts are now capped at the top with concrete beams, their protection walls having been dismantled to a height of 2-3 feet (except No.3 shaft which is capped at ground level). Although the shafts represent a significant liability to HRE, their current condition is not a cause for particular concern.

No.1 shaft

(112 feet deep, 9 feet diameter)
The condition of this shaft is unknown due to low oxygen levels making it unsafe for examiners to enter. That part which can be seen from ground level looks to be fair. The shaft, which is flooded, is capped at its base by a concrete dome.

No.2 shaft

(324 feet deep, 9 feet diameter, cap located next to a farm access lane)
The condition of this shaft is generally fair, but locally poor. The lining is mostly brick, but with one masonry section. There is exposed rock for 11 feet at a depth of ~130 feet. The shaft suffers from considerable water ingress, notably from an adit which enters at a depth of 258 feet. A rotten wooden ring beam is thought to be the cause of horizontal fractures, open joints, bulging and a section of sagging brickwork 100-110 feet from the surface. There is an average mortar loss of 10-20mm and areas of spalling up to 40mm deep.

No.3 shaft

(379 feet deep, 12 feet diameter, cap located between two bungalows)
The protection wall has been completely removed; access for ropes is via a manhole in a chicken coop. The condition of the shaft is fair. It was relined in engineering brick in 1934/5 and includes a series of seven reinforced concrete frames, keyed through the original brickwork into the surrounding rock. All of these are now degraded with 15-90% of the concrete missing; the exposed rebar is corroded and exhibiting impact damage, probably resulting from protection wall debris being tipped down the shaft during demolition. Large lumps of concrete are wedged around some of the frames. There is an average mortar loss of 3mm.

No.4 shaft

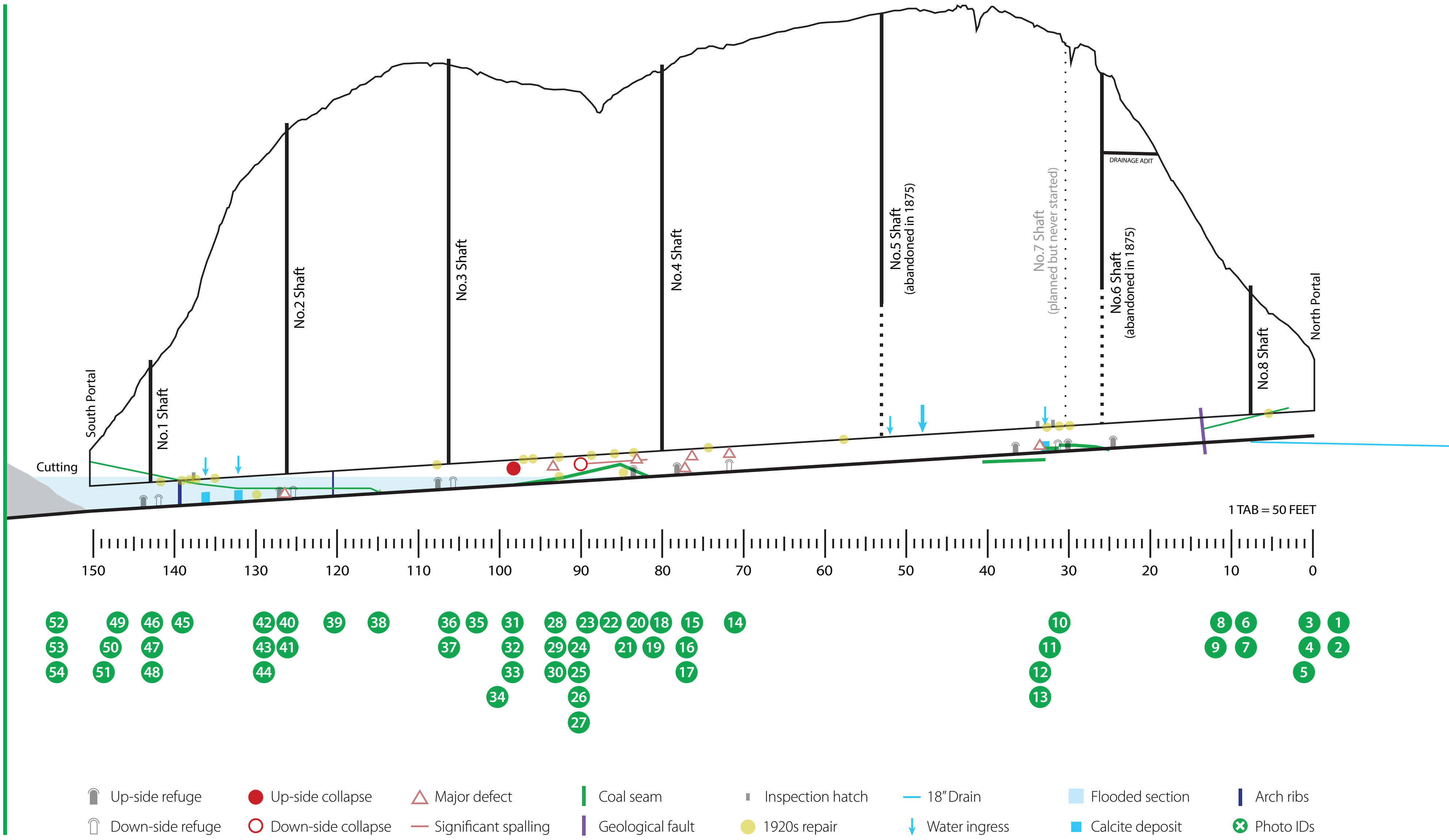
(361 feet deep, 12 feet diameter, cap located between two bungalows)
The condition of this shaft is fair. Six feet of lining immediately above the kerb was rebuilt in 1952. There are extensive deposits of calcite and ochre, small areas of missing brickwork and isolated spalling. There is very little mortar loss.

No.8 shaft

(125 feet deep, 9 feet diameter)
The condition of this shaft is fair. It was partly relined and repointed in 1950. The remaining protection wall has open mortar joints, loose stone blockwork and cracking. There is considerable water ingress from a broken drainage pipe at a depth of 56 feet. Below this, the brickwork has suffered some spalling and mortar loss. ■

Queensbury TUNNEL SOCIETY

2.3 Longitudinal section

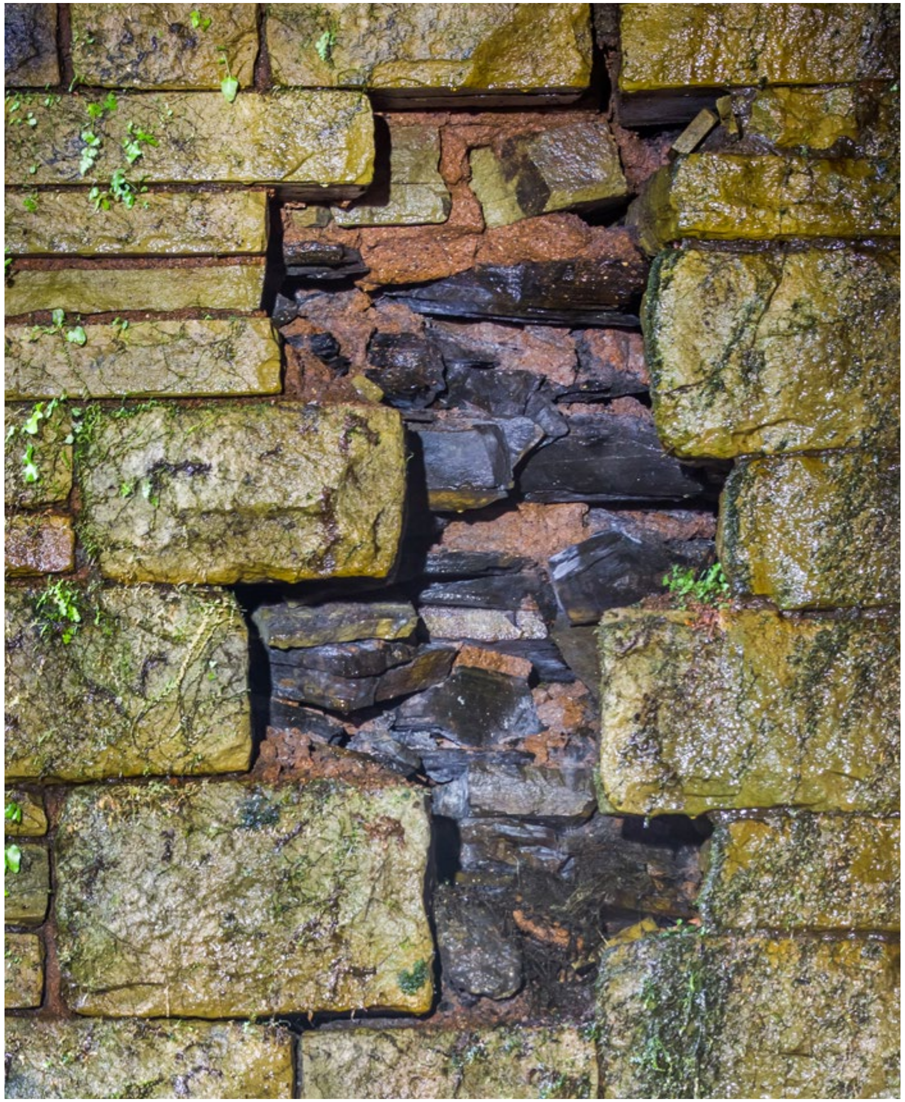


Queensbury TUNNEL SOCIETY

1 Historical photo of the north portal.
© D Ibbotson/Jan Rapacz collection

2 Contemporary photo of the north portal. Most of the parapet/copings are missing, as are the wing walls on both sides.

3 0 +15ft General view showing the form of construction between the north portal and No.8 shaft.



4 0 +15ft Missing stonework in D/S sidewall adjacent to the north portal.

5 1 +0ft Spalled stonework and bulge at U/S haunch.

Queensbury TUNNEL SOCIETY

Typical area of missing outer brick ring at the north end of the tunnel. In many cases, these areas were removed (the brickwork having become loose) to provide safe access for staff carrying out grouting/waterproofing experiments in the 1990s.

8
+15ft

General view of No.8 shaft showing areas of missing brickwork. The arch at the other shafts is built in stone.

8 11 +10ft A slot cut in the arch as part of grouting/waterproofing experiments in the 1990s.

9 12 +10ft Holes cored through the arch for grout injection purposes.

10 | 31 +20ft

Wide view through the area of 1883 sidewall and arch repairs, showing some crushing of brickwork at the crown and spalling at U/S low/mid haunch alongside the inspection hatch.

32
+15ft

Calcite formation on U/S sidewall with severe bulge or deformation adjacent to the taped-off catchpit.

12 33 +21ft One of three inspection hatches inserted to allow monitoring of debris falling onto the extrados. A mining engineer's report from 1882 described the void above the arch as being 7 feet high in places.

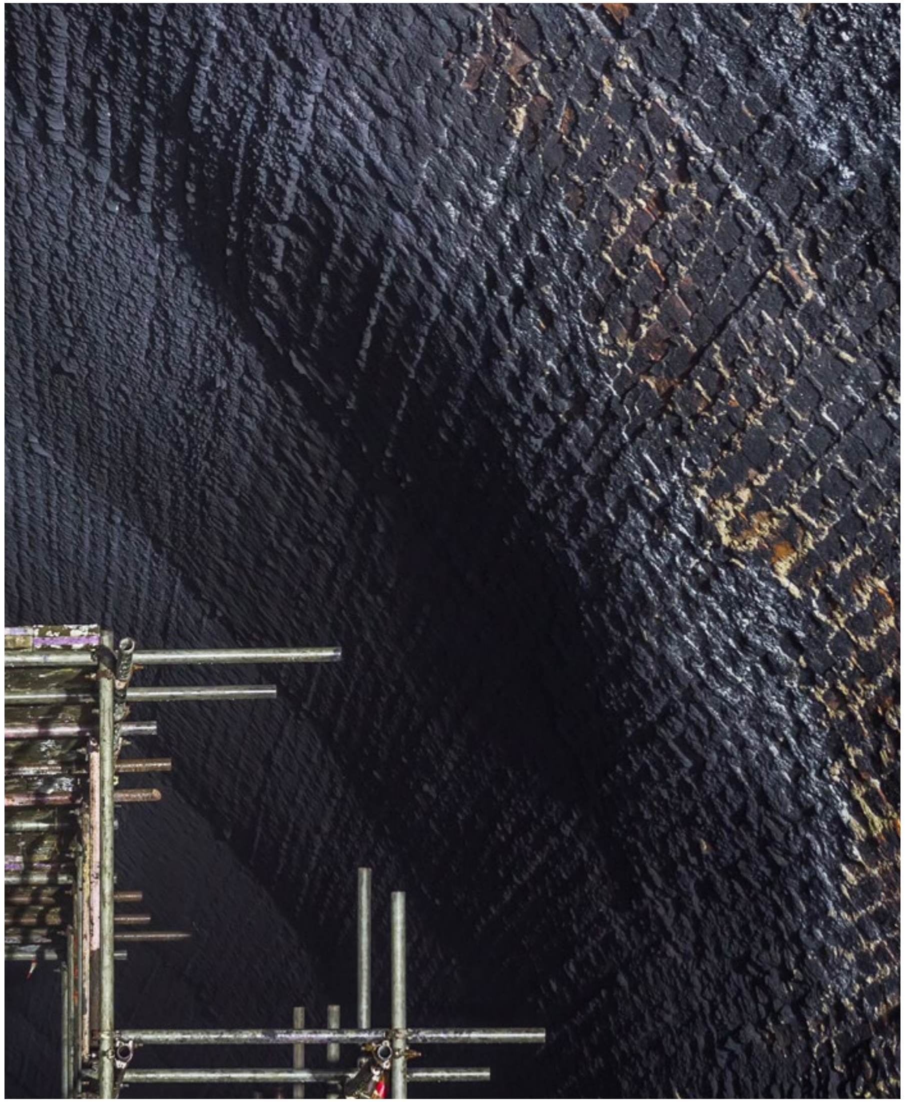
13 33 +25ft Longitudinal crack developing at D/S haunch where the arch was replaced in 1883 in 5-foot lengths. Some spalling apparent at the crown.

Queensbury TUNNEL SOCIETY

14 71 +10ft

Severe bulge at D/S haunch, with loose/hanging/spalled bricks and open joints.

Queensbury TUNNEL SOCIETY



15 | 76 +35ft | Severe bulge at U/S haunch.

16 | 77 +5ft | Three bulges in D/S sidewall.

Queensbury TUNNEL SOCIETY

17

77
+5ft

Severe bulge in U/S sidewall.

Queensbury TUNNEL SOCIETY

18

80
+15ft

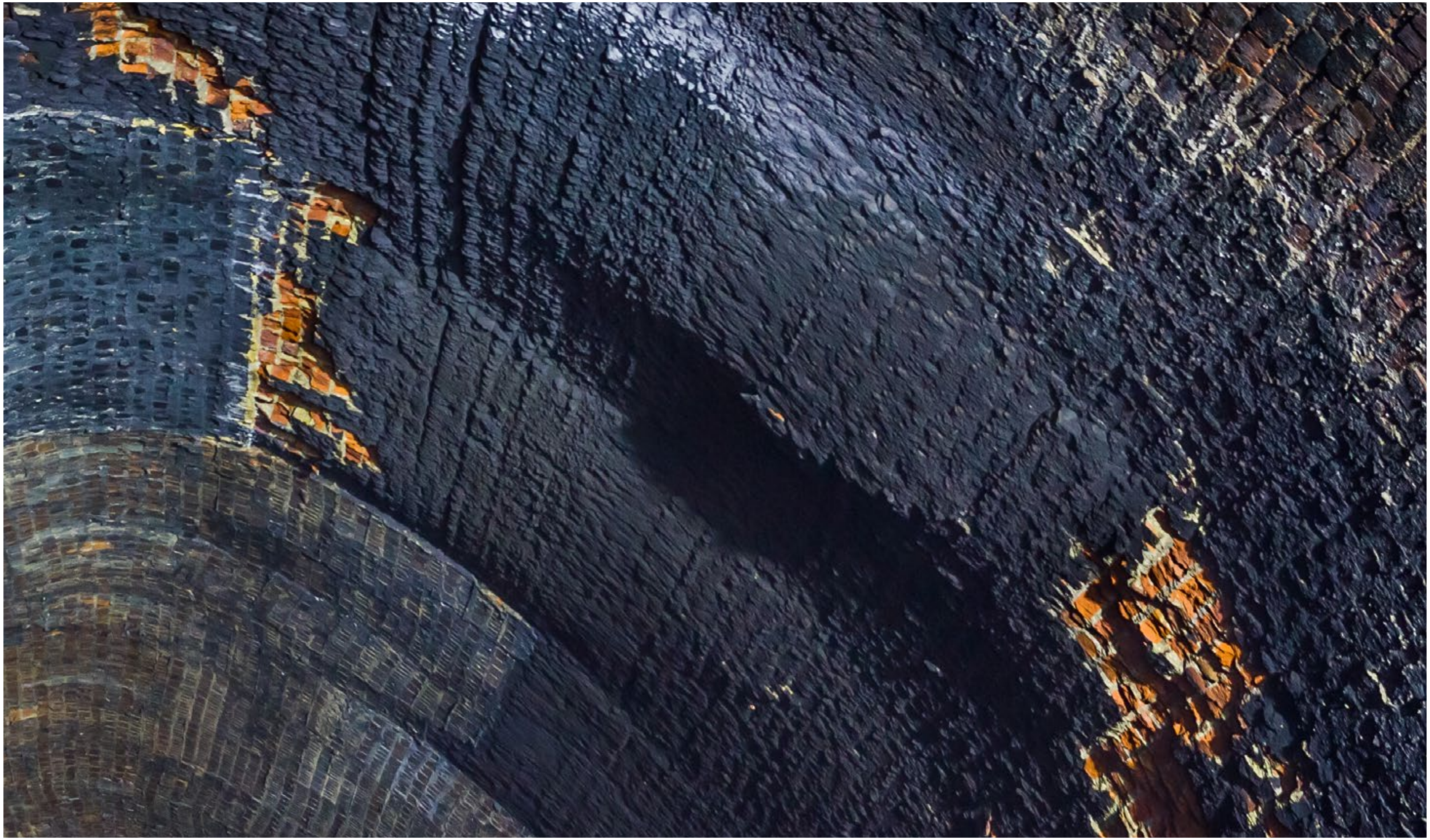
General view of No.4 shaft.

Queensbury
TUNNEL SOCIETY

19 | 81 +15ft

Spalling at crown and low haunches (1 brick deep) on both U/S and D/S. Severe bulge at U/S haunch. D/S haunch heavily repointed close to camera. Note 1920s arch repairs.

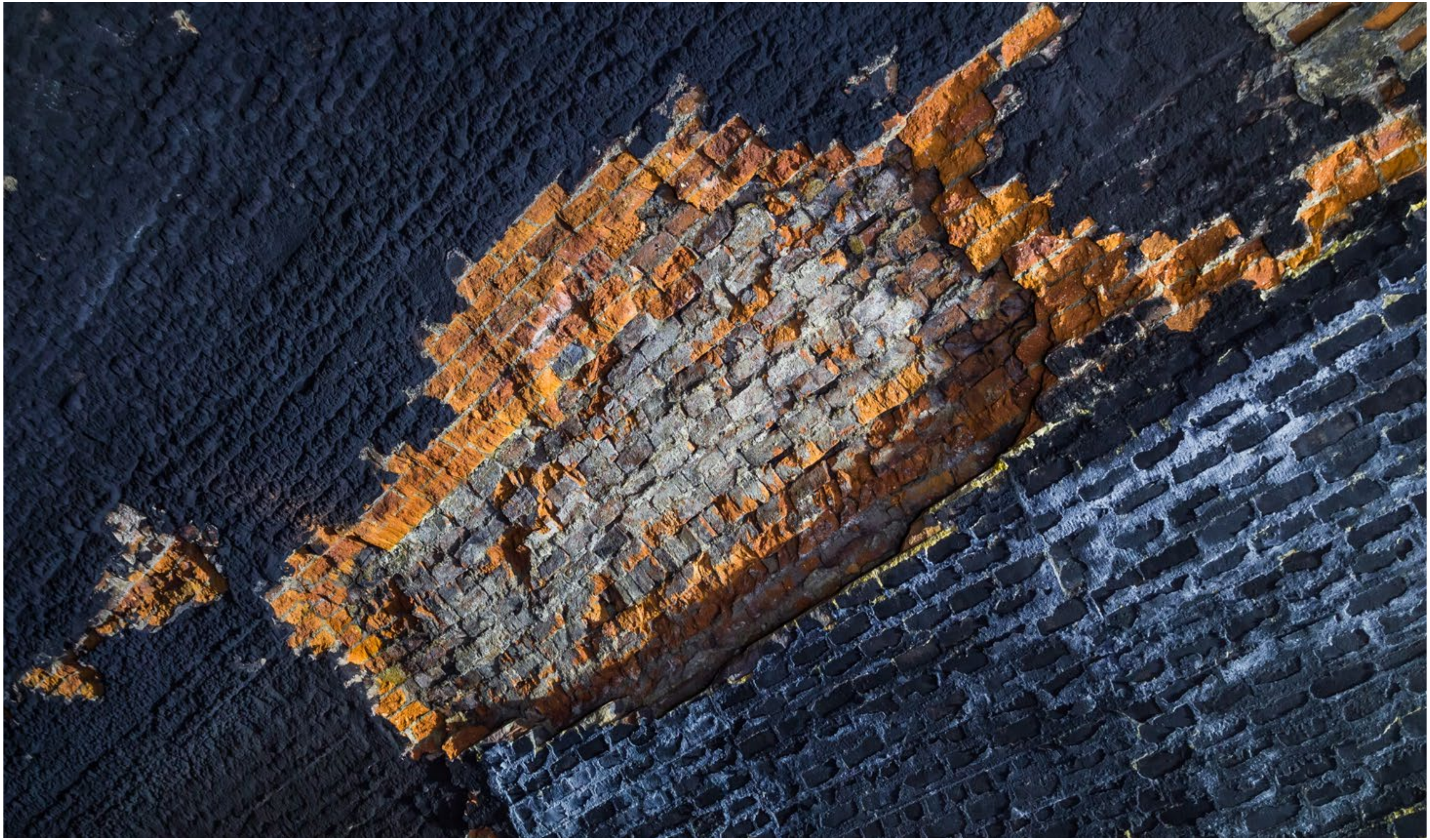
Queensbury TUNNEL SOCIETY



20 | 82 +30ft

Closer view of severe bulge at U/S haunch.

Queensbury TUNNEL SOCIETY



21 | 84 +15ft

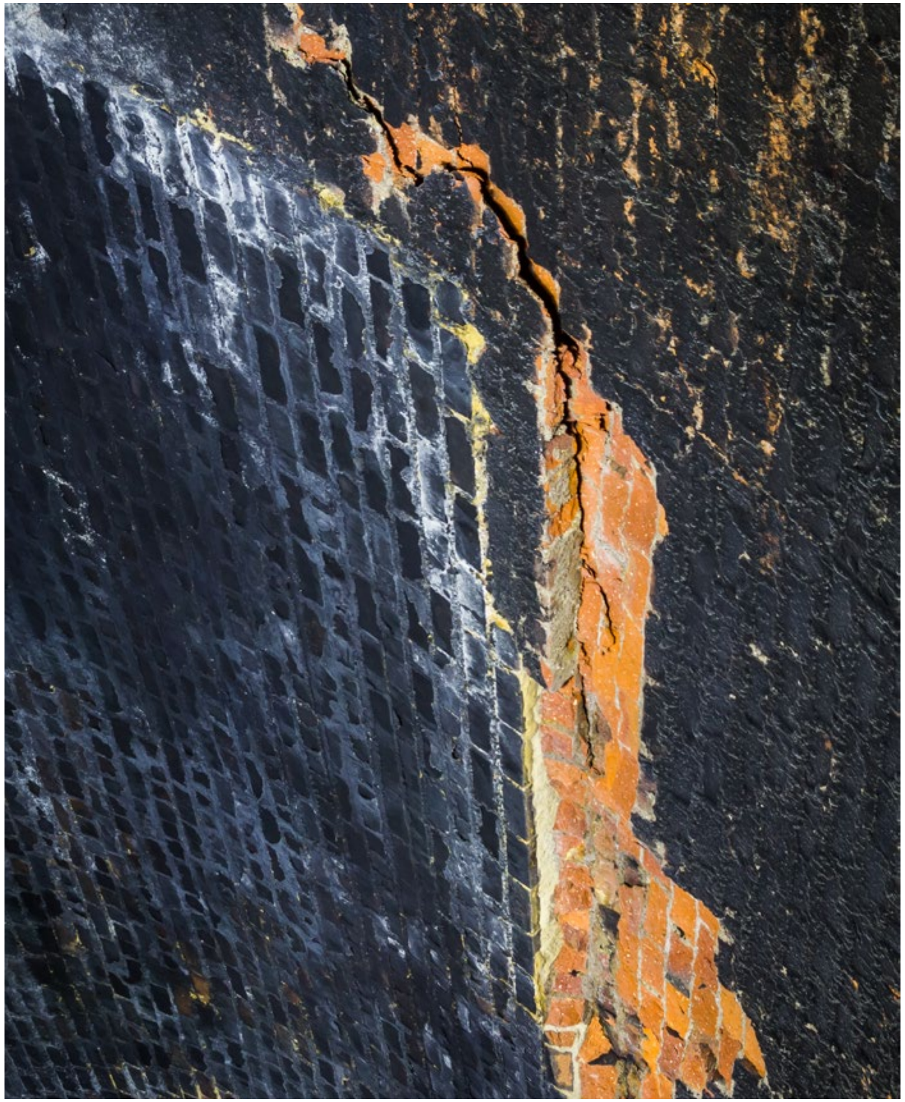
Missing brickwork at U/S haunch (1-2 bricks deep) above patch repair.

Queensbury TUNNEL SOCIETY

22 86 +30ft

Spalling at crown and low/mid haunches (1-2 bricks deep) on both U/S and D/S. Significant flattening of arch at U/S high haunch. Note 1920s arch repairs towards collapse.

Queensbury TUNNEL SOCIETY



23 89 +15ft Outer brickwork ring separating from arch below patch repair and lipping adjacent brickwork.

24 90 +30ft Spalling and separation of outer brickwork ring at U/S low haunch opposite collapse.

25 | 90 +30ft

Collapse of one length, D/S haunch and crown. Void extending upwards 3-4m. Adjacent lengths strengthened with spray concrete.

Queensbury TUNNEL SOCIETY

26 | 90 +30ft

View up into void at collapse.

27 90 +30ft 2007 view of missing brickwork at D/S haunch where collapse occurred in February 2013.

28 93 +5ft Longitudinal fracture at U/S high haunch. Evidence of flash coat of spray concrete (post March 2010).

29 | 93 +5ft

Longitudinal fracture at U/S high haunch, packed with wedges. At the south end, lining has displaced upwards by ~200mm.

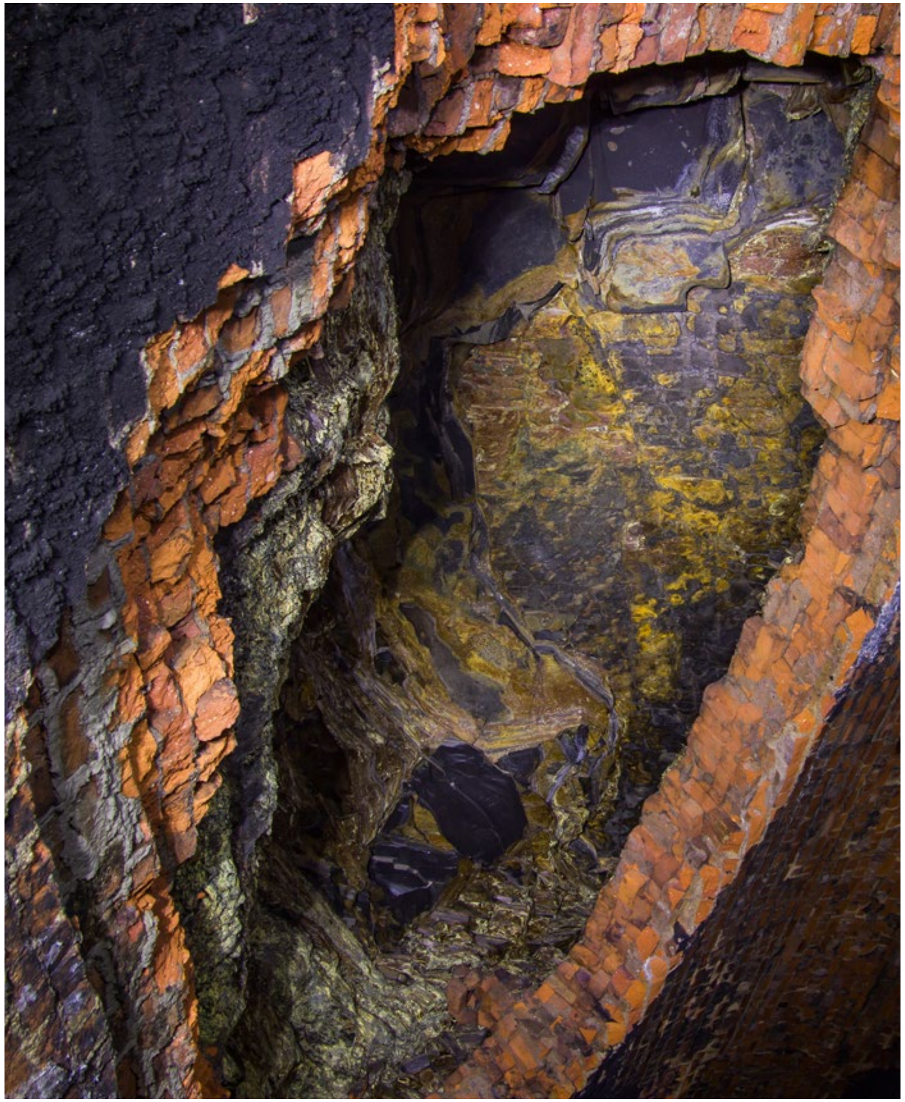
30 | 93 +15ft

Displaced lining at south end of fracture.

31 98 +25ft

Collapse of one length, U/S haunch only. Void extending outwards ~2m and upwards behind remaining brickwork to crown.

Queensbury TUNNEL SOCIETY



32 98 +25ft View up into void at collapse.

33 98 +25ft Arch ring face and friable material behind lining.

34 100 +30ft Typical brickwork defect at crown between tabs 99-104.

35 103 +0ft 2007 view looking north. Missing brickwork at U/S (left) haunch - above pile of bricks on solum - is location of collapse at tab 98+25 feet.

36 105 +35ft

General view of No.3 shaft.

37 105 +35ft View up No.3 shaft showing brick relining and reinforced concrete frames, added for strengthening in 1934/5.

Queensbury TUNNEL SOCIETY

38

115
+5ft

Typical area of missing outer brick ring. Note, very little mortar and two courses of brick on edge.

39

120
+30ft

Structural section of arch ribbing. Note packing behind second rib. Open joints and crack at D/S high haunch.

40 126 +35ft General view of No.2 shaft showing volume of water.

41 127 +15ft Cracked/deformed refuge, with partial collapse of U/S sidewall on south side and diagonal bulge/open joints into shaft length on north side.

42 128 +15ft Spalled and missing brickwork at U/S haunch, together with vegetation growth.

Queensbury TUNNEL SOCIETY

43 129 +25ft Water penetrating the lining under pressure at crown and D/S haunch.

Queensbury TUNNEL SOCIETY

44 | 129 +25ft

Calcite formation on D/S with stalactites and running water.

45 | 139 +10ft

Section of arch ribbing with some laggings in situ. Spalled/wet/missing brickwork at crown.

46 143 +5ft Refuge with exposed rock to rear.

47 143 +15ft Concrete dome cap at base of No.1 shaft.

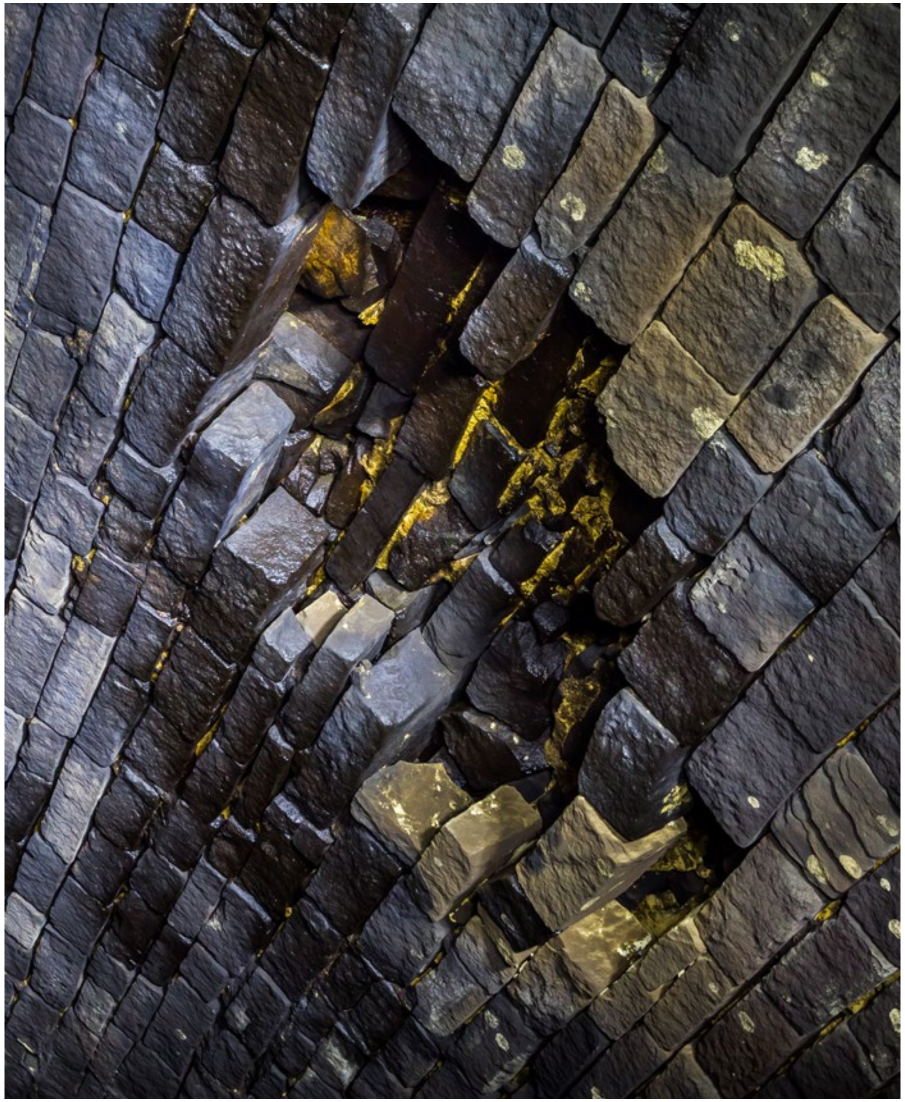
48

143
+15ft

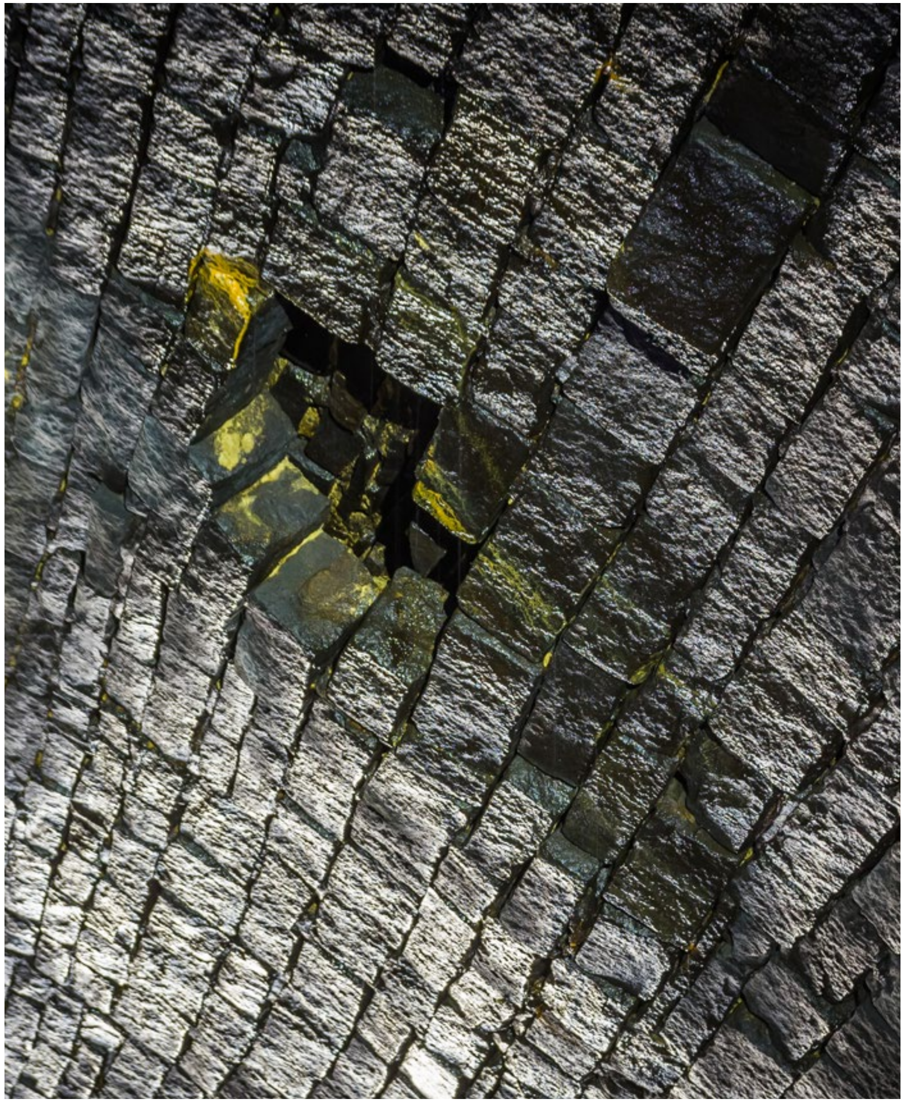
General view of No.1 shaft. The tunnel at this location was completely submerged until January 2016.

Queensbury TUNNEL SOCIETY

49 147 +0ft General view showing the form of construction between the south portal and No.1 shaft. Note loose/hanging stones at U/S haunch.



50 147 +40ft Missing stonework at D/S haunch.



51 148 +35ft Missing/loose stonework at U/S haunch, peeling away to create void behind.

Queensbury TUNNEL SOCIETY

(52) View of remaining southern approach cutting when flooded.

(53) View of south portal after dewatering. Note pipework (left) for long-term pumping arrangements. Pumps are located in a sump in the tunnel entrance.

54

Historical photo of the south portal
© H C Casserley/Jan Rapacz collection

Queensbury TUNNEL SOCIETY

Part 3

Abandonment or remediation?

Queensbury
TUNNEL SOCIETY

3.1 HRE's abandonment strategy

Cap of No.4 shaft between two bungalows

In 2009, Jacobs' *Feasibility Study of Future Asset Management*, commissioned by British Railways Board (Residuary), recommended that, as part of an abandonment process, critical parts of Queensbury Tunnel should be infilled in order to mitigate identified risks. This work, including the provision of structural plugs at the portals and below the shafts, was costed at £5.125 million.

Justifying the need for structural plugs below the shafts, the study stated that "Failure of the supporting sidewall structures beneath the shaft eyes has a high potential for a global collapse of a shaft lining. However, localised failures of the lining at any point along the height of the shaft as a result of deterioration from ground water ingress could also result in a sectional failure within the shaft lining, leading to a total collapse. The shaft sections subjected to the highest level of moisture ingress, lack of firm supporting strata, and the highest risk of becoming a failure mechanism for localised collapse are the upper regions of lining within close proximity to surface level."

It should be noted that the presence of dwellings next to the two deepest completed shafts (Nos. 3 & 4) - and the associated liabilities - has been one of the drivers in BRB(R)/HRE pursuing the option of abandonment.

In 2016, Jacobs' draft[9] *Queensbury Tunnel Options Report* outlined three options for closure:

1 secure the portals with 20 metres of foam concrete, then allow the tunnel "to progressively collapse on its own accord"
2 further reduce the residual risk by either partial or complete infilling
3 backfilling the shafts.

Subject to the outcome of investigation work, the decision has been provisionally taken to implement options 1 and 3, at a cost of around £3 million. This is a more 'minimalist' approach - and hence is less expensive - than the one proposed previously by Jacobs, partly due the absence of structural plugs below the shafts.

Allowing the tunnel "to progressively collapse on its own accord" is predicated on the conclusion that, due to the strength of the surrounding rock, "there is low risk of a collapse of the tunnel resulting in void migration to (or near to) the ground surface, except in the short lengths where the depth of cover is less than 40m". The draft Options Report makes no comment on the implications of an arch/sidewall collapse below one of the shafts.

The significance of these issues needs to be considered in the context of future access. Once the entrances and shafts have been sealed/filled, it will be impractical to gain entry into the tunnel. In other words, the abandonment works must be 'right first time'; there will be no realistic opportunity to undertake further remediation if needs arise at some future time.

The stone kerb at the base of No.4 shaft.

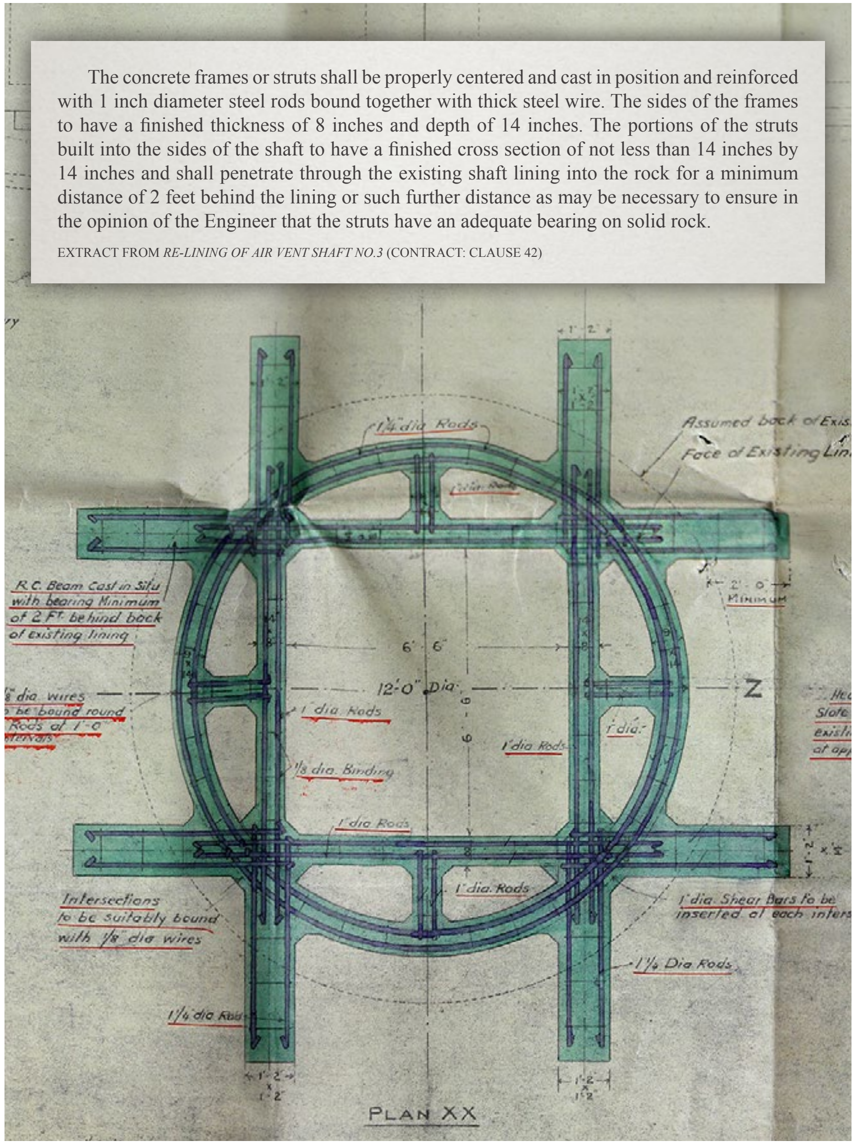
Shaft abandonment

It is possible that any failure of a shaft lining would lead to ground settlement and migration of material into the shaft. At Nos. 3 & 4 shafts, this would have the potential to destabilise the foundations of the dwellings at either side.

9 It should be recognised that any comment herein on the draft Options Report may be invalidated by changes in the final version.

The concrete frames or struts shall be properly centered and cast in position and reinforced with 1 inch diameter steel rods bound together with thick steel wire. The sides of the frames to have a finished thickness of 8 inches and depth of 14 inches. The portions of the struts built into the sides of the shaft to have a finished cross section of not less than 14 inches by 14 inches and shall penetrate through the existing shaft lining into the rock for a minimum distance of 2 feet behind the lining or such further distance as may be necessary to ensure in the opinion of the Engineer that the struts have an adequate bearing on solid rock.

EXTRACT FROM *RE-LINING OF AIR VENT SHAFT NO.3* (CONTRACT: CLAUSE 42)



DOCUMENTS: NATIONAL ARCHIVES

Jacobs' draft Options Report states that "Ongoing deterioration of the shaft linings will inevitably lead to localised failure of some sections. However, the shaft linings **are connected into the surrounding strata** and this should limit the extent of any failures."

Whilst Queensbury Tunnel's shafts might be exceptional, it is generally the case that no *structural* connections are established between a shaft lining and the ground it is sunk through[10]. Fundamentally, its load is carried by the kerb of stone/brick/cast iron forming the shaft eye and transferred into the arch of the tunnel lining.

On the basis of evidence from historical records (see left), it can be assumed that the lining of No.3 shaft **is connected** into the surrounding rock by seven reinforced concrete frames inserted in 1934/5. However it must be recognised that:

- the typical strength of concrete used in the 1930s was around half that of modern concrete
- the concrete is significantly degraded, with 15-90% missing
- the reinforcement has suffered corrosion and impact damage
- the combined weight of the original lining plus 1930s concrete/brickwork is more than double that of the linings in the other two 'deep' shafts (Nos. 2 & 4).

10 Occasionally, support footings (known as 'elephants' feet') are provided but often only where another structure - such as an adit - intersects with the shaft.

In practice, a significant proportion of the load (estimated at between 40-60%, depending on the strata, quality of packing etc) *is* transferred into the surrounding ground through friction, but it would not be reasonable to rely upon this in developing an abandonment scheme[11].

In principle, the risk of a collapse is considerably mitigated by HRE's intention to backfill the shafts, however the design, material(s) and associated methodology has to be appropriate. The draft Options Report includes no specifications, stating only "foam concrete/rock debris or similar".

With wet shafts, as those at Queensbury Tunnel are, abandonment would typically involve backfilling with a granular material (e.g. 50mm clean stone), dropped from the surface. As this material is unconsolidated, it contains voids filled with air or water. These are displaced over time due to internal stresses, resulting in settlement both during and shortly after the filling operation. If the material is not of sufficient quality, further settlement can occur for up to two years. The extent of settlement can be estimated at 5-7% of the shaft depth, or more if material is lost from the base of the shaft into the tunnel.

If voids exist behind a shaft lining - as is often the case - it should also be recognised that horizontal loading from the fill material can result in lining failure and migration of fill into the void.

11 In abandoning/backfilling its shafts, Network Rail stipulates the installation of a support structure designed to carry 100% of the shaft load.

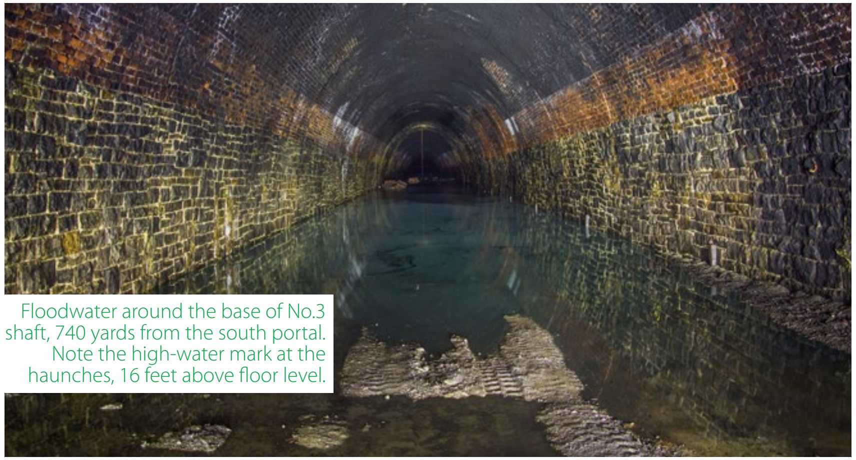
Given the nature of the liabilities associated with the lane passing No.2 shaft and dwellings adjacent to Nos. 3 & 4 shafts, the risk averse approach - to ensure no possibility of surface subsidence - would be to also install a shallow-surface cap founded on solid rock (or, if not practical, in the superficial deposits on a competent strata accessible from the surface). This cap would be constructed from reinforced concrete, have a thickness of no less than 450mm and a diameter at least twice that of the relevant shaft. However, the draft Options Report makes no reference to any such cap provision.

Water management

The south-falling 1:100 gradient of the tunnel, the volume of water ingress and the partial backfilling of the approach cutting resulted in 35 feet of floodwater accumulating at the south portal in December 2015.

HRE's intention is to install 20-metre long concrete plugs at both ends of the tunnel. These plugs would include a 300mm diameter pipe to allow equalisation of water pressures on each side and "prevent the plugs acting as dams."

In the short-term, this would result in the remaining section of southern approach cutting continuing to flood with water discharging from the tunnel. However it is the landowner's eventual intention - on expiration of HRE's current ten-year lease - to backfill the cutting for industrial development purposes. At this point, the plug at the south end would indeed act as a dam.



Floodwater around the base of No.3 shaft, 740 yards from the south portal. Note the high-water mark at the haunches, 16 feet above floor level.

The consequences of this need to be understood. It is likely that the tunnel would flood to a greater extent than it ever has before, possibly prompting some deterioration in sidewall condition through the section around No.4 shaft which has not previously been affected.

If water accumulated to an effective depth of 57 feet at the south portal, four shaft kerbs (including those at the three deeper shafts) would be sitting in water, with the potential to accelerate the deterioration of the shafts' support mechanisms. The water could also encourage further settlement of the shaft infill material into the tunnel, depending on the type of material used and the rate/extent of water level changes.

Bulging and fractures have developed around a refuge in the U/S sidewall beneath No.2 shaft where the lining is carrying a greater load and the depth of floodwater has been 15-20 feet (almost up to the kerb) for several years.

The draft Options Report does recognise the need for a flood risk assessment to be undertaken prior to any works starting. If the water is unable to escape in the way it has historically, it will be diverted elsewhere and this could have an impact beyond the tunnel. But if so, what is the contingency plan and what are the cost implications? This represents an uncertainty that needs to be managed out.

Conclusion

The draft Options Report provides little substantive detail on the proposed abandonment works - particularly in relation to the shafts - giving the impression that key aspects such as materials and methodologies have not yet been fully examined. Some assertions made in the report are questionable but have, nevertheless, been used to inform decision-making.

On this basis, it is legitimate to consider:

- whether the nature/extent of the works as outlined in the draft report are sufficient to address the long-term liabilities associated with the tunnel
- whether the £3 million abandonment costing put forward by Jacobs can be regarded as robust.

It should however be noted that this costing, together with a repair figure of £35 million, was presented to the Minister of State at the Department for Transport and must have significantly influenced his conclusion that repair was not an affordable option for Queensbury Tunnel. ■

Queensbury TUNNEL SOCIETY

To accommodate a foot/cycle path, Queensbury Tunnel has to be made safe; it does not have to be made perfect. Although the level of work required must not be underestimated given the structure's numerous severe defects, particularly through its central section, this does underline the need for a pragmatic and proportionate approach, developed by engineers with specialist understanding of the challenges involved.

There is little benefit in remediating a defect that currently has no structural impact, other than making it look more aesthetically pleasing. It is certainly not desirable from a cost perspective. Any future deterioration can be addressed through the maintenance regime which would have to be established if Queensbury Tunnel was to reopen.

Four tunnels on Derbyshire's Monsal Trail were pragmatically repaired before reopening.

It is of course understood that members of the public must feel confident that the structure does not present a threat to their safety. However we can also reasonably presume that riding a bike through a concrete tube would have limited appeal; the railway heritage nature of the asset is a key part of the attraction. This is demonstrated by the Monsal Trail (Peak District) and Two Tunnels Greenway (Bath), both of which incorporate more than 2,000 yards of disused railway tunnel. In developing a remediation scheme, the mindset must therefore be focussed on retaining as much of the existing structure as engineering requirements allow. This demands a fine balance being struck.

To inform development of the accompanying remediation plan, a visit to Queensbury Tunnel took place on 22nd June 2016, under the supervision of Hammonds ECS, HRE's contractor, and the Mines Rescue Service.

Taking part on behalf of the Queensbury Tunnel Society were:

- an experienced civil engineer specialising in tunnel remediation and tunnel maintenance strategy, both for railway and utility companies
- two representatives from SES Group, a civil engineering and railway contractor with a background in mining. The company was responsible for successfully remediating collapses in both a disused railway tunnel under Liverpool[12] in 2012 and the Grinkle Beck culvert[13] in North Yorkshire. It also carries out shaft decommissioning projects.

---

12 More information: www.ses-group.co.uk/Dingle-Station.aspx (external link)

13 More information: www.ses-group.co.uk/Grinkle-Beck-Culvert-Repairs.aspx (external link)

In terms of routine defects, the specification for remediation is mostly built around standard repair methodologies, devised by Network Rail and based on best practice. These are summarised as follows:

- recasing small areas (up to 1m^2) of missing brickwork
- sprayed concrete patch repairs at larger areas (over 1m^2) of missing brickwork
- breaking out and replacing defective brickwork where isolated spalling has occurred
- repointing open joints with a fast-setting waterproof mortar, such as NATCEM 35.

In addition, ring dams would be installed at Nos. 2, 3, 4 & 8 shafts and pans/downpipes where running water is penetrating the lining.

At the two partial collapses, an approach would be taken similar in principle to that developed by SES Group and Donaldson Associates in Dingle Tunnel, Liverpool.

Here, a section of lining comprising nine brick rings collapsed without warning, leaving a hole in the arch measuring 9.7 x 6 metres[14]. A conical void extended 6 metres upwards into the sandstone, revealing the foundation slab of a house.

14 It should be noted that the collapses in Queensbury Tunnel are much smaller, the largest measuring approximately 5 x 4 x 3 metres.


Collapse void in Dingle Tunnel

PHOTO © SES GROUP


Steel arches and support system

PHOTO © SES GROUP


Concrete infilling

PHOTO © SES GROUP

Completed remediation in Dingle Tunnel

PHOTO © SES GROUP

Queensbury TUNNEL SOCIETY

SES Group used a propping system to support the area around the void and then deployed two galvanised steel arches to provide safe access beneath. With shuttering installed at both ends, these arches served as formwork for the pouring of foam concrete to crown level. The void above was then filled with cement grout by means of injection and breather pipes.

In Queensbury Tunnel, fibre-reinforced spray concrete would be used to create a 300mm secondary lining through the badly-spalled section (tabs 81-90) and at four other locations where severe bulges have developed.

Aesthetically, there is an understandable aversion to concrete, particularly in relation to heritage structures. However, the cost of fully repairing the tunnel in brick - even if this was possible from a technical and health & safety perspective - would be unsustainably high. The concrete would represent another chapter in the tunnel's evolutionary story, accounting for a little over 10% of its length, plus a collection of patch repairs. These could perhaps be used as canvases for artwork or railway history interpretations.

In terms of strength, the comparison between a sprayed concrete lining and one constructed in brick is not straightforward. 19th century brickwork was extremely variable but did generally improve over time.

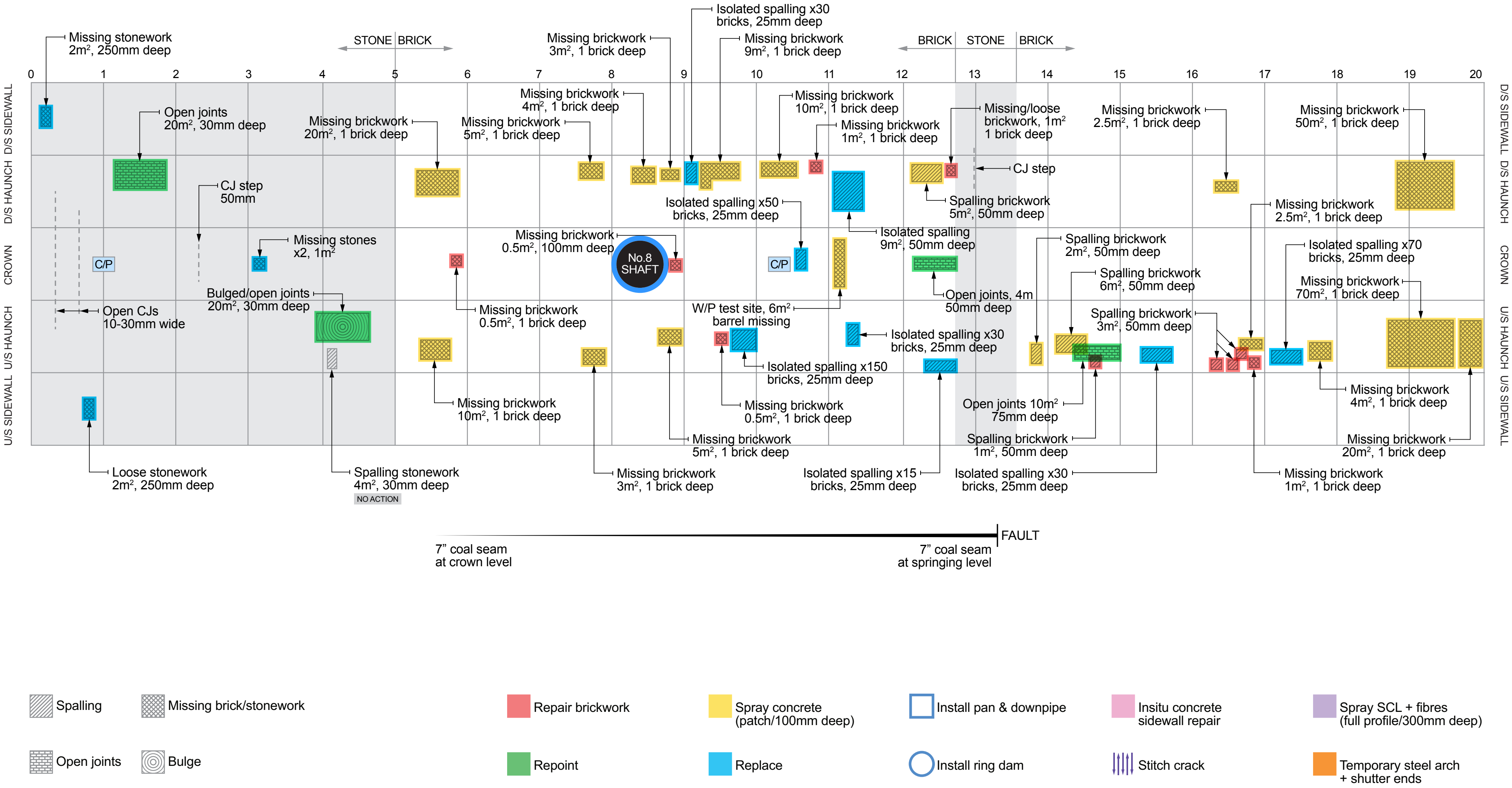
In simplistic terms, taking an average strength of 5N/mm^2 (i.e. 25N/mm^2 bricks in lime mortar), a 550mm-thick brickwork lining would have an axial load capacity of 900kN, with a materials partial safety factor of 3. A 300mm-thick sprayed concrete lining - with a strength of 45N/mm^2 and a materials partial safety factor of 1.5 - would have an axial load capacity of 9,000kN.

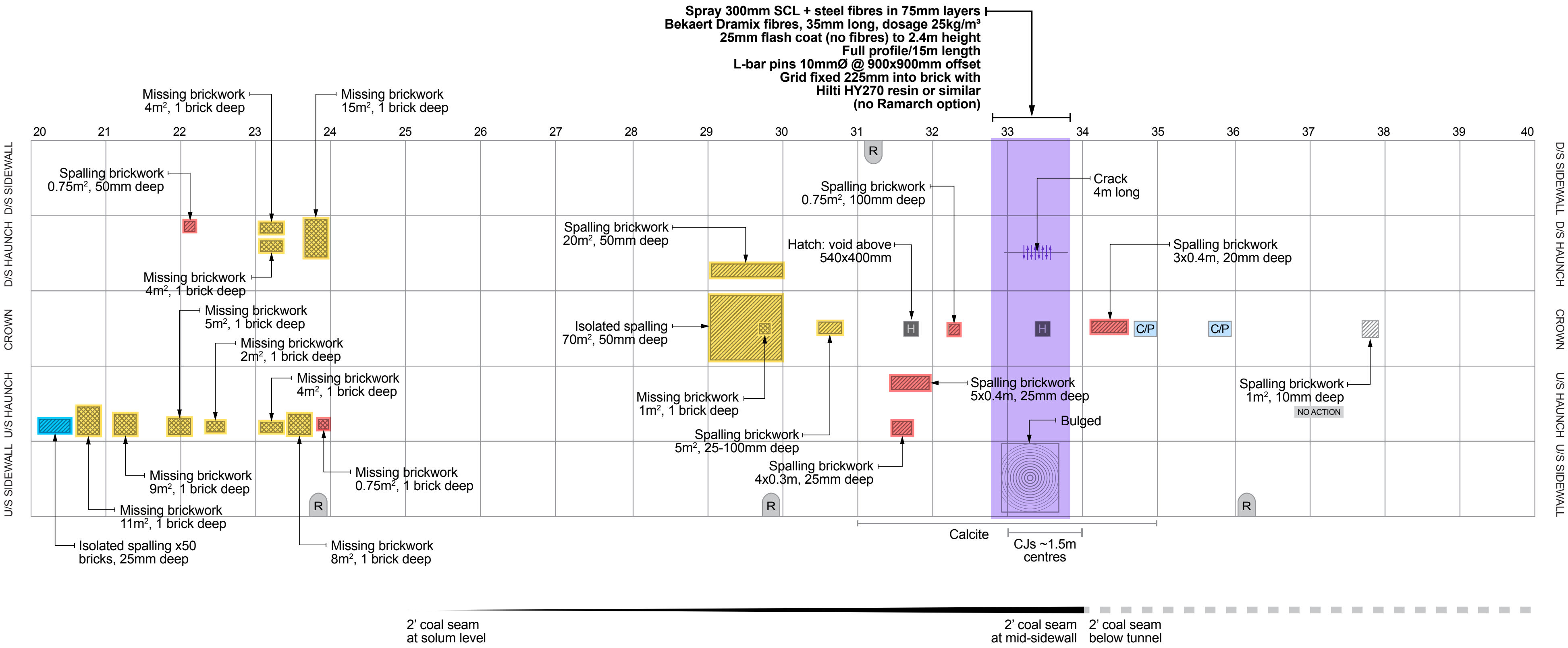
However, Queensbury Tunnel's existing lining is failing in bending due to eccentric loading, causing crushing, cracking and deflection. The tensile capacity of brickwork is virtually nil; unreinforced concrete is not much better. Fibre-reinforced concrete offers marginal improvements in bending but its big advantage is that it is ductile and does not fail so rapidly.

In summary, the intention of the sprayed concrete lining would be to make the existing brickwork redundant.

Next to No.2 shaft, at the bulge and distorted refuge, a reinforced concrete slab would be cast across the full width of the tunnel, incorporating a minimum 300mm-thick upstand wall on the U/S to resist movement of the sidewall. This structure would be independent of the existing lining.

The application of these methodologies is set out on the following remediation plans. In moving forward to the design stage, a tactile survey, investigations and analysis would be carried out to validate any assumptions made in developing them. ■

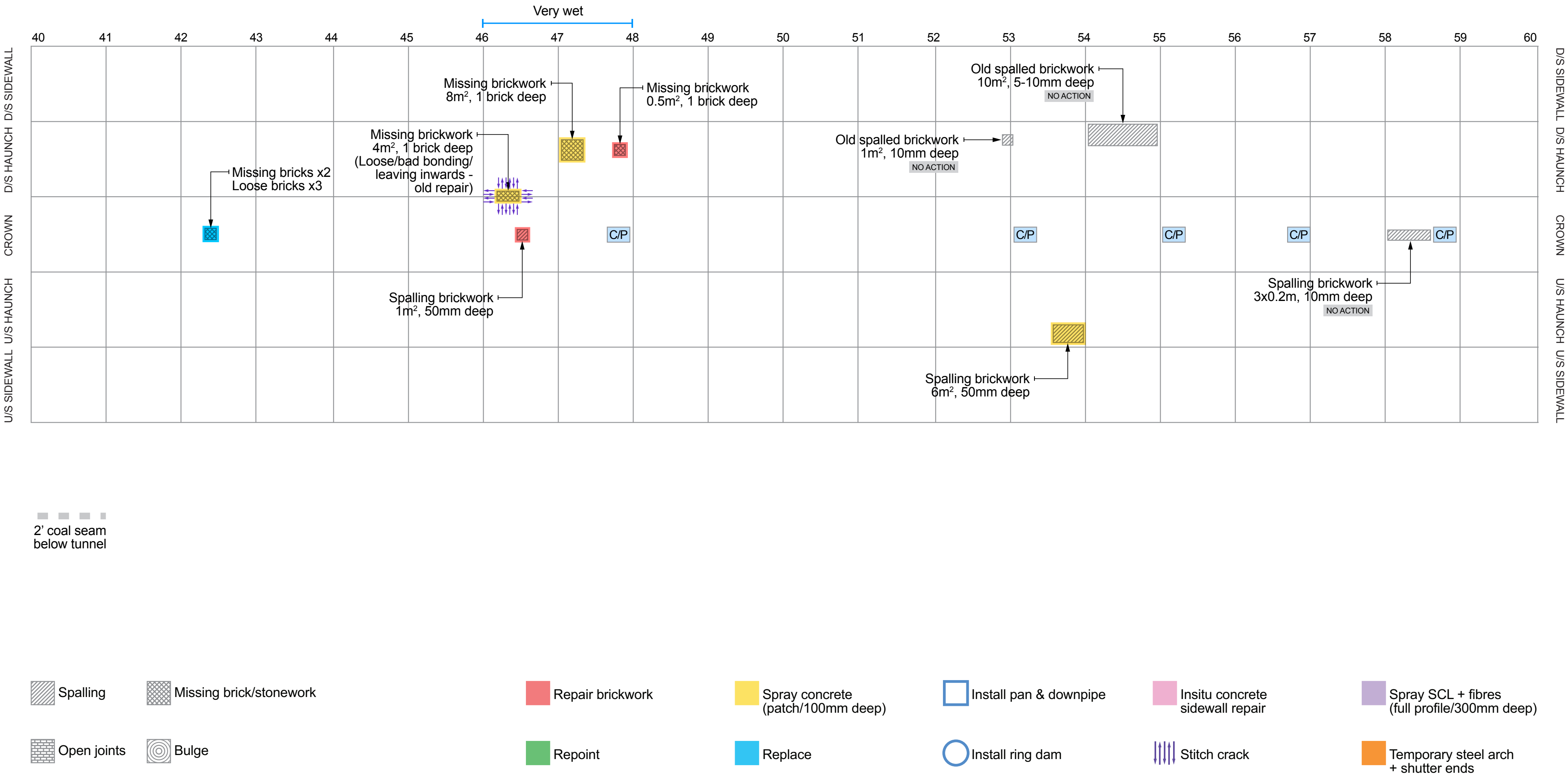

Missing stonework
2m², 250mm deep
STONE BRICK
Missing brickwork
3m², 1 brick deep
Isolated spalling x30
bricks, 25mm deep
Missing brickwork
9m², 1 brick deep
BRICK STONE BRICK
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
Open joints
20m², 30mm deep
Missing brickwork
20m², 1 brick deep
Missing brickwork
4m², 1 brick deep
Missing brickwork
5m², 1 brick deep
Missing brickwork
10m², 1 brick deep
Missing brickwork
1m², 1 brick deep
Missing/loose
brickwork, 1m²
1 brick deep
Missing brickwork
2.5m², 1 brick deep
Missing brickwork
50m², 1 brick deep
CJ step
50mm
CJ step
Isolated spalling x50
bricks, 25mm deep
Spalling brickwork
5m², 50mm deep
Missing brickwork
2.5m², 1 brick deep
Missing stones
x2, 1m²
Missing brickwork
0.5m², 100mm deep
No.8
SHAFT
Isolated spalling
9m², 50mm deep
Spalling brickwork
2m², 50mm deep
Isolated spalling x70
bricks, 25mm deep
C/P
C/P
Spalling brickwork
6m², 50mm deep
Missing brickwork
70m², 1 brick deep
Open CJs
10-30mm wide
Bulged/open joints
20m², 30mm deep
Missing brickwork
0.5m², 1 brick deep
W/P test site, 6m²
barrel missing
Open joints, 4m
50mm deep
Spalling brickwork
3m², 50mm deep
Isolated spalling x30
bricks, 25mm deep
Isolated spalling x150
bricks, 25mm deep
Missing brickwork
10m², 1 brick deep
Missing brickwork
0.5m², 1 brick deep
Open joints 10m²
75mm deep
Missing brickwork
4m², 1 brick deep
Missing brickwork
5m², 1 brick deep
Spalling brickwork
1m², 50mm deep
Missing brickwork
20m², 1 brick deep
Loose stonework
2m², 250mm deep
Spalling stonework
4m², 30mm deep
NO ACTION
Missing brickwork
3m², 1 brick deep
Isolated spalling x15
bricks, 25mm deep
Isolated spalling x30
bricks, 25mm deep
Missing brickwork
1m², 1 brick deep
7" coal seam
at crown level
7" coal seam
at springing level
FAULT
Spalling
Missing brick/stonework
Open joints
Bulge
Repair brickwork
Repoint
Spray concrete
(patch/100mm deep)
Replace
Install pan & downpipe
Install ring dam
Insitu concrete
sidewall repair
Stitch crack
Spray SCL + fibres
(full profile/300mm deep)
Temporary steel arch
+ shutter ends



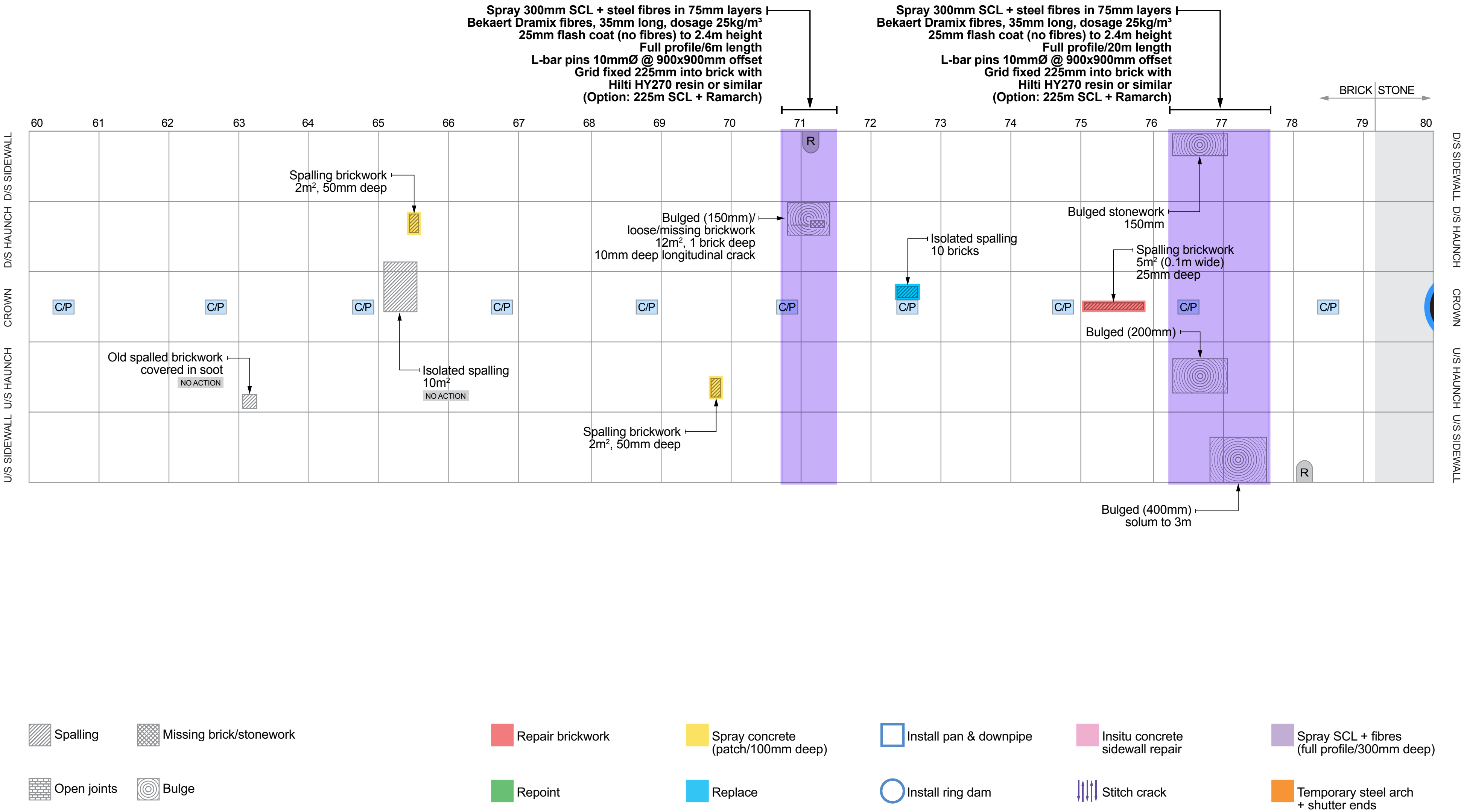
Spalling | Missing brick/stonework | Repair brickwork | Spray concrete (patch/100mm deep) | Install pan & downpipe | Insitu concrete sidewall repair | Spray SCL + fibres (full profile/300mm deep)

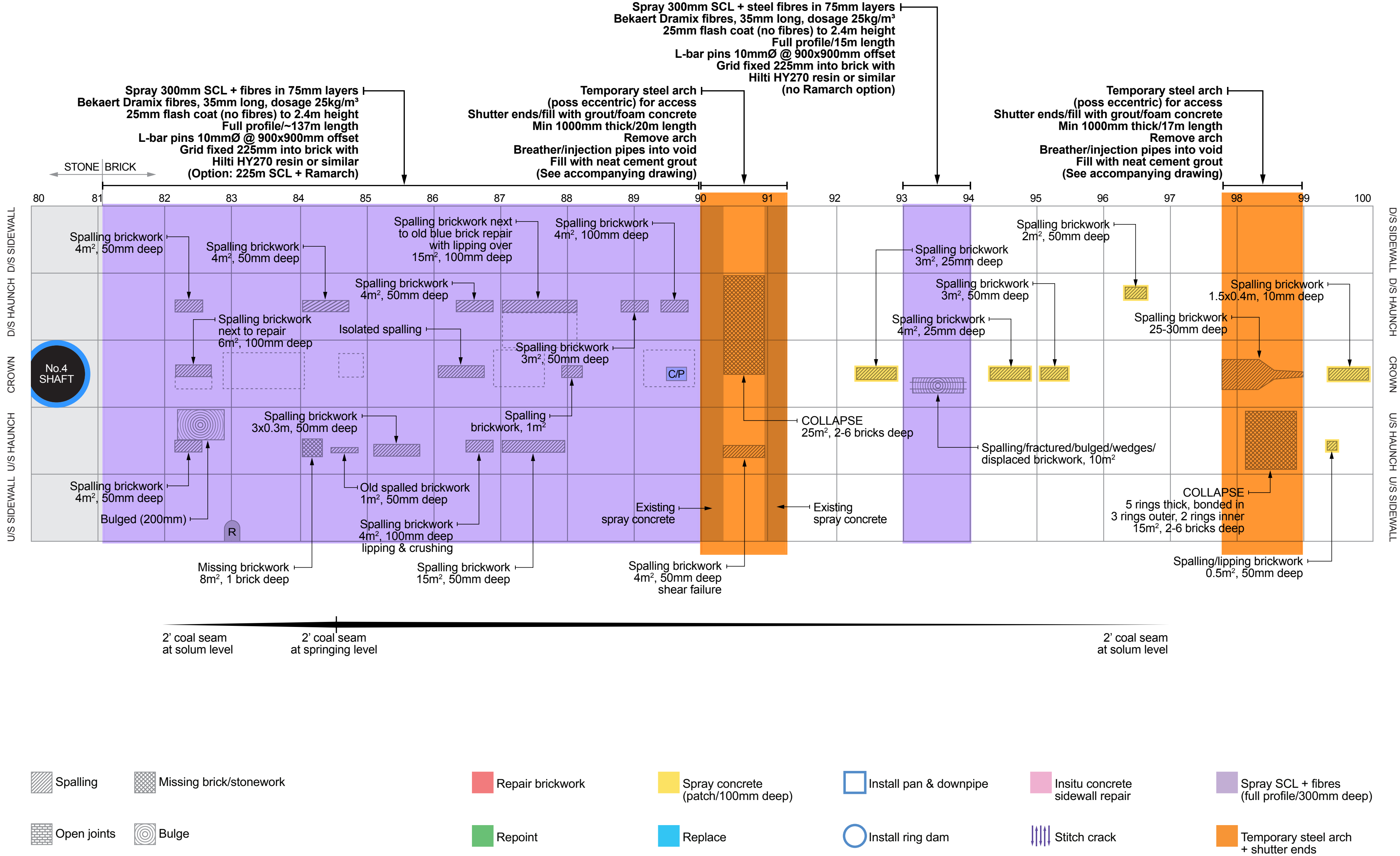
Open joints | Bulge | Repoint | Replace | Install ring dam | Stitch crack | Temporary steel arch + shutter ends

Queensbury TUNNEL SOCIETY

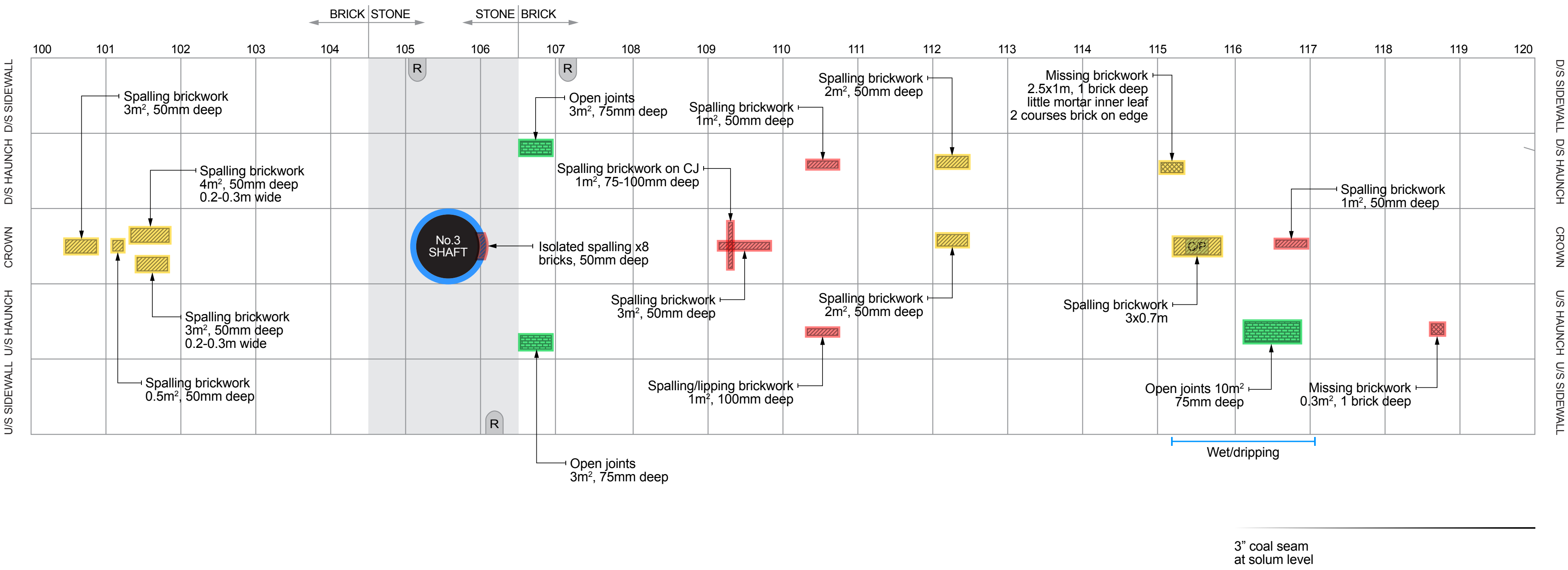


Very wet
40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
Missing brickwork
8m², 1 brick deep
Missing brickwork
0.5m², 1 brick deep
Old spalled brickwork
10m², 5-10mm deep
NO ACTION
Old spalled brickwork
1m², 10mm deep
NO ACTION
Missing brickwork
4m², 1 brick deep
(Loose/bad bonding/
leaving inwards -
old repair)
Missing bricks x2
Loose bricks x3
C/P
C/P
C/P
C/P
C/P
Spalling brickwork
1m², 50mm deep
Spalling brickwork
3x0.2m, 10mm deep
NO ACTION
Spalling brickwork
6m², 50mm deep
2' coal seam
below tunnel
Spalling
Missing brick/stonework
Open joints
Bulge
Repair brickwork
Repoint
Spray concrete
(patch/100mm deep)
Replace
Install pan & downpipe
Install ring dam
Insitu concrete
sidewall repair
Stitch crack
Spray SCL + fibres
(full profile/300mm deep)
Temporary steel arch
+ shutter ends


Spray 300mm SCL + steel fibres in 75mm layers
Bekaert Dramix fibres, 35mm long, dosage 25kg/m³
25mm flash coat (no fibres) to 2.4m height
Full profile/6m length
L-bar pins 10mmØ @ 900x900mm offset
Grid fixed 225mm into brick with
Hilti HY270 resin or similar
(Option: 225m SCL + Ramarch)
Spray 300mm SCL + steel fibres in 75mm layers
Bekaert Dramix fibres, 35mm long, dosage 25kg/m³
25mm flash coat (no fibres) to 2.4m height
Full profile/20m length
L-bar pins 10mmØ @ 900x900mm offset
Grid fixed 225mm into brick with
Hilti HY270 resin or similar
(Option: 225m SCL + Ramarch)
BRICK
STONE
60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
R
Spalling brickwork
2m², 50mm deep
Bulged (150mm)/
loose/missing brickwork
12m², 1 brick deep
10mm deep longitudinal crack
Bulged stonework
150mm
Isolated spalling
10 bricks
Spalling brickwork
5m² (0.1m wide)
25mm deep
C/P
Bulged (200mm)
Old spalled brickwork
covered in soot
NO ACTION
Isolated spalling
10m²
NO ACTION
Spalling brickwork
2m², 50mm deep
Bulged (400mm)
solum to 3m
Spalling
Missing brick/stonework
Open joints
Bulge
Repair brickwork
Repoint
Spray concrete
(patch/100mm deep)
Replace
Install pan & downpipe
Install ring dam
Insitu concrete
sidewall repair
Stitch crack
Spray SCL + fibres
(full profile/300mm deep)
Temporary steel arch
+ shutter ends

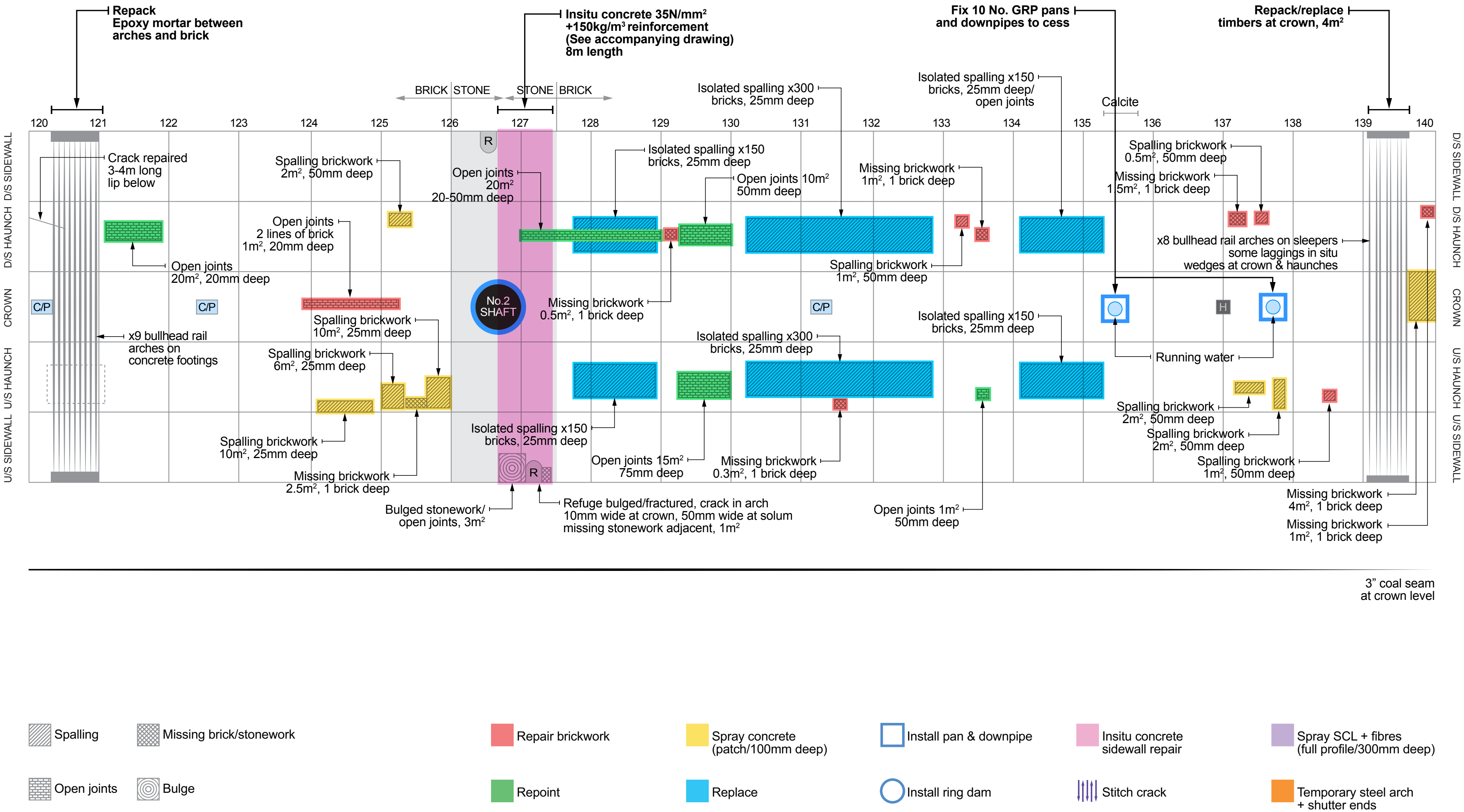


Spray 300mm SCL + fibres in 75mm layers
Bekaert Dramix fibres, 35mm long, dosage 25kg/m³
25mm flash coat (no fibres) to 2.4m height
Full profile/~137m length
L-bar pins 10mmØ @ 900x900mm offset
Grid fixed 225mm into brick with
Hilti HY270 resin or similar
(Option: 225m SCL + Ramarch)
Temporary steel arch
(poss eccentric) for access
Shutter ends/fill with grout/foam concrete
Min 1000mm thick/20m length
Remove arch
Breather/injection pipes into void
Fill with neat cement grout
(See accompanying drawing)
Spray 300mm SCL + steel fibres in 75mm layers
Bekaert Dramix fibres, 35mm long, dosage 25kg/m³
25mm flash coat (no fibres) to 2.4m height
Full profile/15m length
L-bar pins 10mmØ @ 900x900mm offset
Grid fixed 225mm into brick with
Hilti HY270 resin or similar
(no Ramarch option)
Temporary steel arch
(poss eccentric) for access
Shutter ends/fill with grout/foam concrete
Min 1000mm thick/17m length
Remove arch
Breather/injection pipes into void
Fill with neat cement grout
(See accompanying drawing)
STONE BRICK
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
No.4 SHAFT
Spalling brickwork 4m², 50mm deep
Spalling brickwork 4m², 50mm deep
Spalling brickwork next to old blue brick repair with lipping over 15m², 100mm deep
Spalling brickwork 4m², 100mm deep
Spalling brickwork 4m², 50mm deep
Spalling brickwork next to repair 6m², 100mm deep
Isolated spalling
Spalling brickwork 3m², 50mm deep
C/P
Spalling brickwork 3x0.3m, 50mm deep
Spalling brickwork, 1m²
Spalling brickwork 4m², 50mm deep
Bulged (200mm)
R
Old spalled brickwork 1m², 50mm deep
Spalling brickwork 4m², 100mm deep lipping & crushing
Existing spray concrete
Missing brickwork 8m², 1 brick deep
Spalling brickwork 15m², 50mm deep
Spalling brickwork 4m², 50mm deep shear failure
COLLAPSE 25m², 2-6 bricks deep
Existing spray concrete
Spalling brickwork 3m², 25mm deep
Spalling brickwork 3m², 50mm deep
Spalling brickwork 4m², 25mm deep
Spalling/fractured/bulged/wedges/ displaced brickwork, 10m²
Spalling brickwork 2m², 50mm deep
Spalling brickwork 1.5x0.4m, 10mm deep
Spalling brickwork 25-30mm deep
COLLAPSE 5 rings thick, bonded in 3 rings outer, 2 rings inner 15m², 2-6 bricks deep
Spalling/lipping brickwork 0.5m², 50mm deep
2' coal seam at solum level
2' coal seam at springing level
2' coal seam at solum level
Spalling
Missing brick/stonework
Open joints
Bulge
Repair brickwork
Repoint
Spray concrete (patch/100mm deep)
Replace
Install pan & downpipe
Install ring dam
Insitu concrete sidewall repair
Stitch crack
Spray SCL + fibres (full profile/300mm deep)
Temporary steel arch + shutter ends



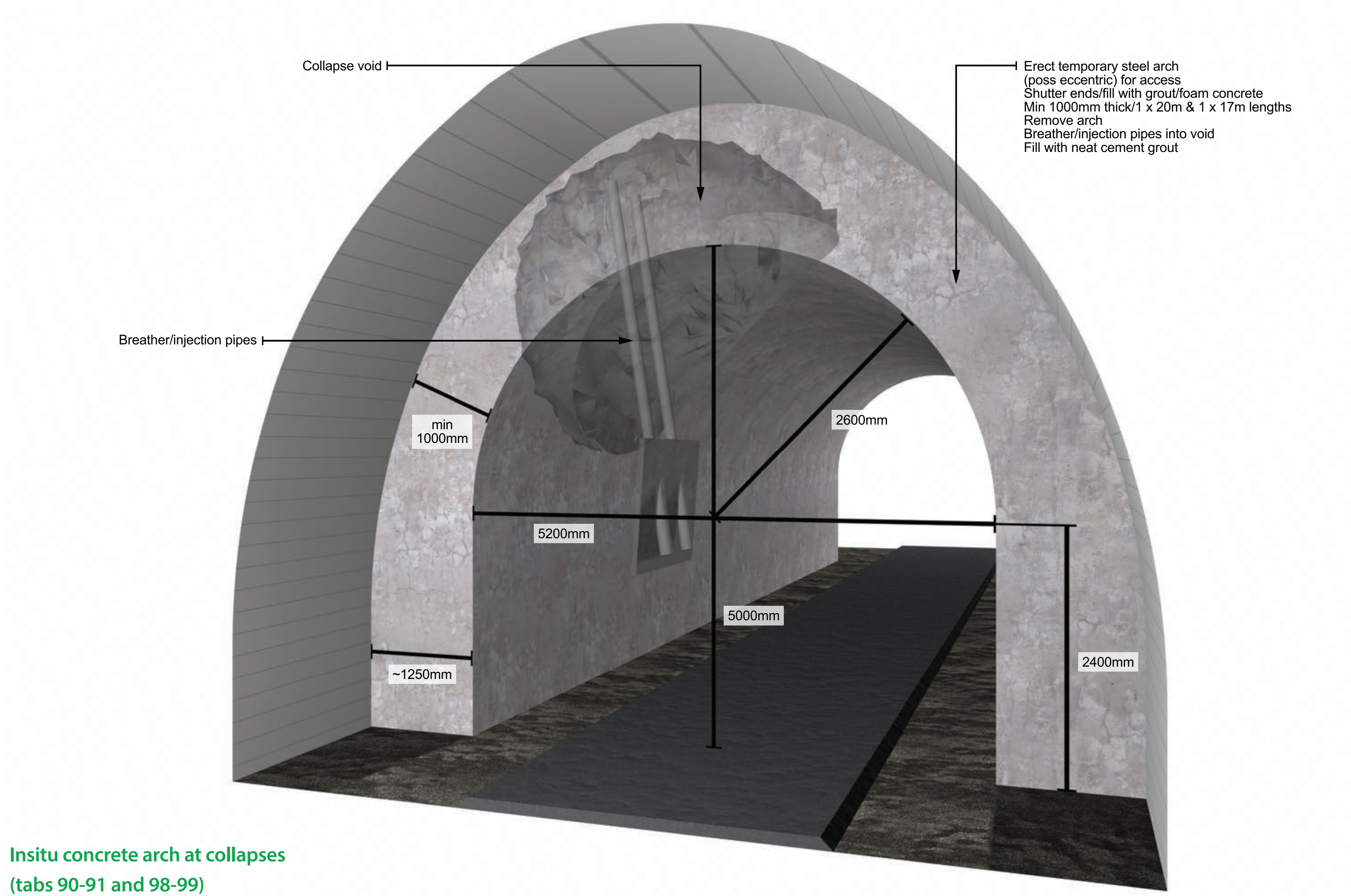
Spalling | Missing brick/stonework | Repair brickwork | Spray concrete (patch/100mm deep) | Install pan & downpipe | Insitu concrete sidewall repair | Spray SCL + fibres (full profile/300mm deep)

Open joints | Bulge | Repoint | Replace | Install ring dam | Stitch crack | Temporary steel arch + shutter ends

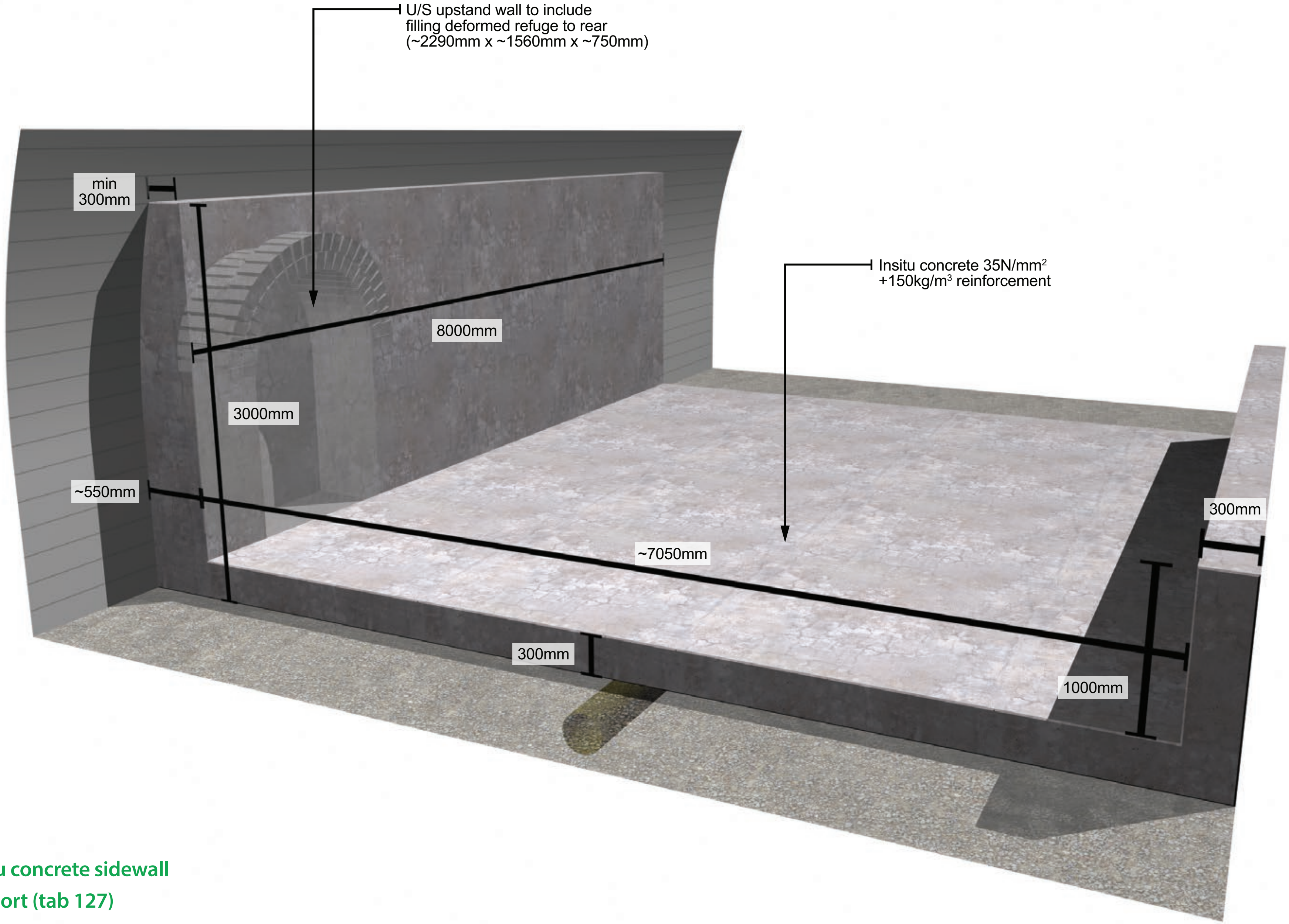


Repack
Epoxy mortar between arches and brick
Insitu concrete 35N/mm²
+150kg/m³ reinforcement
(See accompanying drawing)
8m length
Fix 10 No. GRP pans and downpipes to cess
Repack/replace timbers at crown, 4m²
BRICK STONE
STONE BRICK
Isolated spalling x300 bricks, 25mm deep
Isolated spalling x150 bricks, 25mm deep/ open joints
Calcite
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
R
Crack repaired 3-4m long lip below
Spalling brickwork 2m², 50mm deep
Open joints 20m² 20-50mm deep
Isolated spalling x150 bricks, 25mm deep
Open joints 10m² 50mm deep
Missing brickwork 1m², 1 brick deep
Spalling brickwork 0.5m², 50mm deep
Missing brickwork 1.5m², 1 brick deep
Open joints 2 lines of brick 1m², 20mm deep
Open joints 20m², 20mm deep
x8 bullhead rail arches on sleepers some laggings in situ wedges at crown & haunches
Spalling brickwork 1m², 50mm deep
C/P
No.2 SHAFT
Missing brickwork 0.5m², 1 brick deep
H
Spalling brickwork 10m², 25mm deep
Isolated spalling x150 bricks, 25mm deep
x9 bullhead rail arches on concrete footings
Isolated spalling x300 bricks, 25mm deep
Running water
Spalling brickwork 6m², 25mm deep
Spalling brickwork 2m², 50mm deep
Spalling brickwork 2m², 50mm deep
Isolated spalling x150 bricks, 25mm deep
Spalling brickwork 10m², 25mm deep
Open joints 15m² 75mm deep
Missing brickwork 0.3m², 1 brick deep
Spalling brickwork 1m², 50mm deep
Missing brickwork 2.5m², 1 brick deep
Bulged stonework/ open joints, 3m²
Refuge bulged/fractured, crack in arch 10mm wide at crown, 50mm wide at solum missing stonework adjacent, 1m²
Open joints 1m² 50mm deep
Missing brickwork 4m², 1 brick deep
Missing brickwork 1m², 1 brick deep
3" coal seam at crown level
Spalling
Missing brick/stonework
Repair brickwork
Spray concrete (patch/100mm deep)
Install pan & downpipe
Insitu concrete sidewall repair
Spray SCL + fibres (full profile/300mm deep)
Open joints
Bulge
Repoint
Replace
Install ring dam
Stitch crack
Temporary steel arch + shutter ends

Stitch around areas
prior to replacement
BRICK
STONE
140
141
142
143
144
145
146
147
148
149
150
D/S SIDEWALL
D/S HAUNCH
CROWN
U/S HAUNCH
U/S SIDEWALL
Missing brickwork
22m², 1 brick deep
R
Exposed
rock at rear
Missing/loose stonework
2.25m², 200mm deep
Missing stonework
1m², 200mm deep
Bulged (100mm)
Inner leaf peeling out
Blind
(Concrete dome
above eye)
No.1
SHAFT
C/P
C/P
Missing stones
0.5m² each
Hanging stones
0.5m² each
Spalling stonework
1m², 30mm deep
Exposed
rock at rear
R
Missing stonework
0.5m², 200mm deep
Missing stonework
0.3m², 200mm deep
Missing stonework
1m², 200mm deep
Wet/dripping
Spalling
Missing brick/stonework
Open joints
Bulge
Repair brickwork
Repoint
Spray concrete
(patch/100mm deep)
Replace
Install pan & downpipe
Install ring dam
Insitu concrete
sidewall repair
Stitch crack
Spray SCL + fibres
(full profile/300mm deep)
Temporary steel arch
+ shutter ends



Insitu concrete arch at collapses
(tabs 90-91 and 98-99)



Insitu concrete sidewall support (tab 127)

Queensbury TUNNEL SOCIETY

3.3 Costing

The budget proposal for delivery of the specified remediation works is:

Core civil engineering/workforce costs (This is based on a 44-week programme, with work taking place five days a week during normal office hours. It includes a 20% contingency for the brickwork repair elements to account for observation/estimation errors during the site visit, as well as a 1,000m^2 repointing contingency.)	£1,734,824
Estimate for shaft repairs (This is based on 8 weeks work within the core 44-week programme. It was not possible to assess the shafts during the site visit and there is insufficient detail in HRE's examination reports to gain an accurate understanding of the works required.)	£96,154
Mobilisation/compound/security/demobilisation	£113,449
Tactile condition surveys & drawings/investigations/ FE analysis/mining report (inc. estimate for shaft repairs)	£124,690
Design (inc. estimate for shaft repairs)	£65,696
Project costs	£210,541
Project contingency @ 20%	£469,071
Total cost	**£2,814,425**

This costing:

- represents a snapshot in time and will increase as the condition of the tunnel deteriorates
- takes no account of inflation, e.g. changes in labour/material costs
- only covers structural repairs to the tunnel, not costs relating to the proposed cycle path (surfacing, lighting, rebuilding north portal etc)
- excludes Value Added Tax (VAT).

It has been assumed that:

- the existing pumping arrangements at the south end of the tunnel will remain in situ and operational for the duration of the works and thereafter
- no land acquisition costs will be incurred.

Queensbury TUNNEL SOCIETY

Part 4

Ownership

Queensbury
TUNNEL SOCIETY

4.1 Future ownership options

Author: Ian White, Chairman, Railway Paths Ltd

The future of Queensbury Tunnel is being actively considered at the present time due to the proposed abandonment by the Historical Railways Estates (HRE) on behalf of the Department for Transport and a counter proposal by the Queensbury Tunnel Society, backed by QCHAP and Cycle Queensbury, to see the tunnel repaired and made part of the Great Northern Railway Trail.

Studies have been undertaken to look at the extent and cost of the repair work required. Further studies will be required to determine the economic benefit of the linkage to the Trail and to develop a funding strategy for the works.

On the basis that funding is achieved and the works are successfully completed, the question of the ownership of the refurbished tunnel needs to be considered. This paper identifies and considers the various options that exist.

Background

Ownership and responsibility for the tunnel and its shafts passed to the British Rail Board (Residuary) Ltd in 2001 and, in 2013, on the abolition of the BRB(R), was transferred to the HRE, within the Department for Transport, along with many other redundant railway structures to monitor and maintain.

A long-standing policy has been to see Queensbury Tunnel abandoned, i.e. being permanently sealed, the shafts rendered safe and no future access of any kind being allowed into the tunnel. This would minimise any long-term risk to the Department for Transport and reduce - if not eliminate - any call for future funding on the public purse.

HRE's consulting engineers, Jacobs, were commissioned to prepare a study to determine the cost of implementing this policy along with the options to manage risk and to consider the possible reopening of the tunnel. The draft findings of this report were made available in early 2016.

Proposal

The Queensbury Tunnel Society and its supporters have proposed that the tunnel be repaired to a sufficient standard to allow unrestricted public access into it as part of the Great Northern Railway Trail route. If this is achieved, a number of ownership and management options exist regarding the future use of the tunnel.

In determining the options, the following must be borne in mind. Firstly if, after the tunnel was repaired, a catastrophic collapse should occur then all parties would agree to 'walk away' from the project with the then owner of the tunnel and shafts being responsible for sealing it up and abandoning it at minimum risk to the general public and adjacent landowners. Therefore a residual financial liability would exist to cater for such an eventuality.

Queensbury TUNNEL SOCIETY

Secondly, that if funding for the day-to-day running of the tunnel - once it was reopened to public access - was to be withdrawn, then the then-current owner of the tunnel could seal it off to render it secure, but with possible provisos that if funding was to made available in the future, the tunnel could be reopened or alternatively decide to permanently abandon it.

The options identified so far are as follows:

Option 1

HRE progresses its option to abandon the tunnel by permanently preventing future access and ensuring that any future collapse of the tunnel and/or its associated shafts causes no risk to the general public or adjacent landowners. HRE would however retain permanent liability for the tunnel even though this would be deemed to be minimal or even non-existent.

Option 2

The tunnel is repaired to a condition suitable for public access and forming part of a designated cycle route. HRE retains ownership and is responsible for the day-to-day operation of the tunnel. HRE would be liable for the long-term upkeep, maintenance and management of the tunnel in its proposed use as a cycle route. All long-term costs relating to the stability of the tunnel and shafts would be borne by HRE.

Option 3

As Option 2 with HRE retaining ownership, but funded by means of a contract to operate the tunnel on an annual basis by a third party

organisation i.e. Cycle Queensbury, Bradford City Council or others. HRE would retain responsibility for the long-term stability of the tunnel and its shafts, but operating costs would be borne by others. On withdrawal of funding, HRE could decide to close the tunnel either permanently or to mothball it for future use.

Option 4

HRE retains ownership but leases the day-to-day operation to another organisation such as Sustrans, Bradford City Council, Railway Paths Limited, Cycle Queensbury. HRE would retain responsibility for the long-term stability of the tunnel and its shafts, but operating costs and delivery were borne by others. Annual costs could be drawn down from any initial dowry or funded annually by another organisation. Withdrawal of adequate funds would again lead to HRE closing the tunnel either permanently or to mothball it for future use.

Option 5

HRE would transfer ownership and operation of the tunnel and shafts - with or without an appropriate dowry (based upon a calculation of commuted maintenance sum and Discounted Cash Flow analysis) - to a suitable competent organisation.

To satisfy the requirements of the Secretary of State for Transport, competence would relate to the ability to discharge the relevant statutory and common law duties, having adequate technical knowledge on the maintenance of the tunnel and shafts to manage risk, and sufficient financial stability to maintain the tunnel into the foreseeable future.

The new owner of the tunnel would then be permanently liable for the safe condition of both it and its shafts, as well as the day-to-day operating and maintenance costs associated with running the cycleway.

Some form of Trust could be created to hold ownership on behalf of other organisations provided the above competences could be demonstrated.

Option 6

As Option 5 but the day-to-day operation of the tunnel is contracted to another organisation as in Option 4, with annual payments being made to cover ongoing day-to-day maintenance and running costs. ■

Part 5

The "tunnel boring machine"

Queensbury Tunnel Society

Misunderstood construction method

In a section entitled *Background and History of Queensbury Tunnel*, Jacobs' draft Options Report states:

"It is reported that several types of tunnel boring machine[1] were tried in the heading but whilst a number had proved effective elsewhere, none was successful in the hard strata through which Queensbury Tunnel was driven. However, after about half the Tunnel had been driven, a suitable machine was located. This machine was developed and supplied by the Diamond Rock Boring Company and was powered by compressed air. In July 1877, it was brought to work from the bottom of No.4 shaft. The rate of progress was three to five times that of manual labour, contributing significantly to the heading's completion on 2nd October…"

([1] These machines all assumed the form of a large drill.)

No source is recorded for this information.

Jacobs makes a number of extrapolations from the use of a "tunnel boring machine" (TBM); however these are all erroneous due to a misunderstanding about the type and role of this machine (described on pages 88-89). It should have been identified as a "rock drilling machine"[15], used only to drill holes in the working face for blasting purposes and thus helping the miners to advance the heading more productively. No part of the tunnel was actually 'bored'.

---

15 Sources include Minutes of the Great Northern Railway and Minutes of the Proceedings of the Institution of Civil Engineers.

Extrapolations

Jacobs states that the tunnel boring machine was used to excavate "most of the northern half of the tunnel", bringing with it a number of benefits. Specifically it:

- removed "the requirement for completion of Shafts 5 and 6"
- "did not fracture the surrounding rock as much as blasting"
- "resulted in a significantly "better" tunnel with lower water inflows and lower maintenance requirements"
- resulted in "the relative lack of defects throughout the bored length of the tunnel."

A computer-generated illustration of a heading.

The distinction between bored and conventional "drill and blast" sections of the tunnel is a theme that runs through the draft report. For example:

- (page 1) "Excavation of the Tunnel was carried out using a combination of "drill and blast" techniques and a tunnel boring machine powered by compressed air."
- (page 6) "The drill and blast method of construction will have resulted in a greater amount of fracturing of the surrounding rock mass than in the machine bored northern half of the tunnel."
- (page 7) "Due to…a change in the method of construction of the tunnel, Shafts 5 and 6 were never completed…"
- (page 9) "The method of excavation of the Tunnel changed at Shaft 4 (tablet 80.5), with the length north of this Shaft excavated by mechanical boring and therefore developing fewer defects."
- (Page 14) "Infilling the "drill and blast" sections of the Tunnel with foam concrete or similar would reduce the quantity of fill material required to partially stabilise the Tunnel…"
- (page 14) "The length of bored Tunnel between Shaft 4 and Shaft 8 would be left open as it does not appear to be vulnerable to deterioration or collapse in the short to medium term."
- (Appendix A: Risk Register) "Risk of future tunnel collapse/Cause: Drill & blast construction method in certain sections of the tunnel. "
- (Appendix C: Numerical Stress Analysis) "The collapses are in one of the deepest sections of the tunnel that were constructed using drill and blast excavation (as opposed to mechanical boring)."

Commentary on the extrapolations

Historical drawings indicate that Nos. 5 & 6 shafts had been abandoned around two years before the machine's arrival at Queensbury[16]; in both cases, this was as a result of significant water ingress.

The draft Options Report quantifies the extent of the machine-bored section of tunnel in a table on page 6, indicating that it extends from tabs 24-79, a distance of 917 yards. The machine was operational in Queensbury Tunnel for no more than three months[17], implying a rate of progress - from just one working face - of at least 306 yards per month.

16 One historical drawing states that No.5 shaft was abandoned on 18th December 1875 and No.6 shaft on 15th January 1875, although a different drawing suggests October 1875 and July 1875 respectively.

17 The machine was brought to Queensbury in July 1877. The heading was completed on 2nd October 1877.

For context, in the late 1890s, Catesby Tunnel on the Great Central Railway's London Extension was constructed from 20 working faces at an average rate of 110 yards per month. This was described as "almost a record in rapid tunnel building."[18]

Mining and geotechnical specialists believe that the relative lack of defects through the section of Queensbury Tunnel between tabs 35-70 is most likely due to it being beyond the zone of influence of any coal seams. Defects are re-emerging around tabs 31-34 where lengths of arch and sidewall were replaced in 1883. The Halifax Hard Bed seam is adjacent to the tunnel at this point and was mined despite the Great Northern Railway having acquired the rights to the coal.

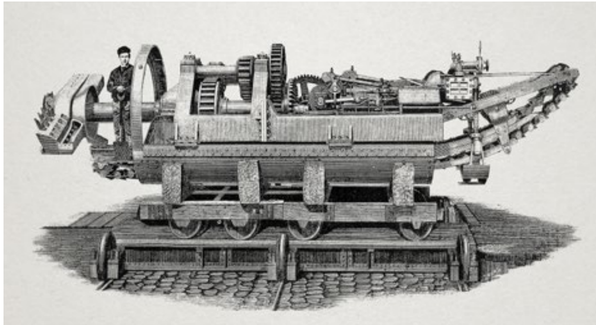
Diamond Rock Boring Company

Tunnel boring machines - as opposed to tunnelling shields - can be traced back to the 1840s, involving either arrays of percussion drills or cutting discs. Their effectiveness and reliability varied considerably.

Lieutenant Frederick Edward Blackett Beaumont of the Royal Engineers developed at least two TBMs. In 1863, he applied for a patent on a machine equipped with chisels and used unsuccessfully during the construction of a water tunnel. He rose to the rank of Captain in 1866 and, nine years later, applied for a patent on a machine with a rotating cutting wheel; this consisted of radial arms fitted with steel bits, mounted on a horizontal shaft.

18 F D Fox, Minutes of the Proceedings of the Institution of Civil Engineers, January 1900

Beaumont built two more TBMs to a patent of Colonel T English for an early attempt at a Channel Tunnel. These were used to drive more than 4,000 yards of headings before the scheme was abandoned.

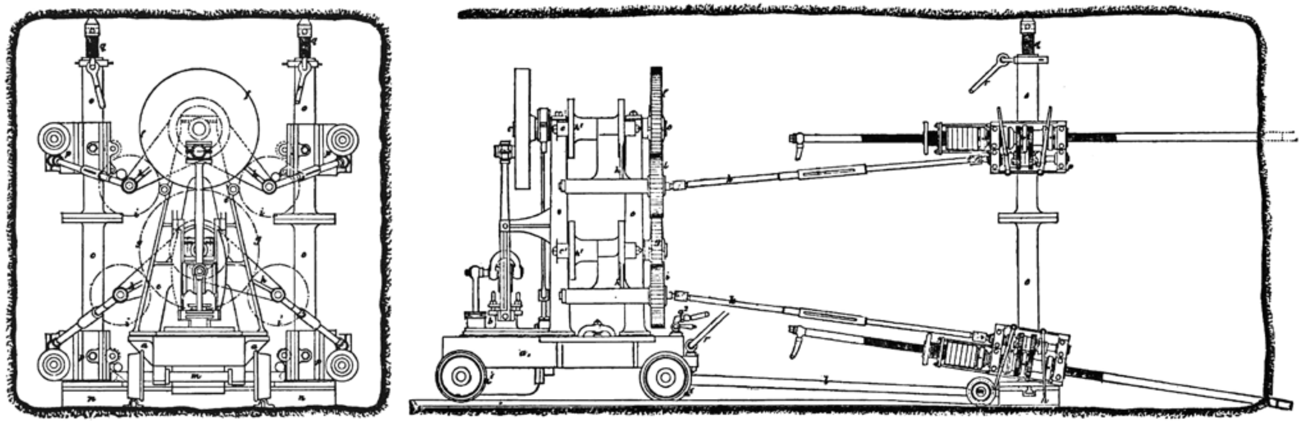


The 1880s Channel Tunnel machine (left) was 33 feet in length and operated by compressed air. It was capable of cutting 5/16" for every rotation of its cutting head, at a rate of two revolutions per minute.

However, it was with a different type of machine that Beaumont enhanced his reputation as a capable inventor and shrewd businessman. At the Paris exhibition of 1867, he saw an American diamond cutter, designed by Rodolphe Leschot and his father George-August. Beaumont patented an improved version the following year, working alongside a railway machinery engineer, C J Appleby. In 1872, the patent rights were passed to the Diamond Rock Boring Company (DRBC), with Beaumont - now a Major - installed as its chairman.

Operated by compressed air, the machine comprised hollow tubes rotating at 250rpm, each tipped with an annular steel ring within which projecting diamonds were set. Depending on the strata type, a forwards force of 400-800lb was applied. Water was pumped down the tubes to flush out debris and cool the diamonds.

Diamond core drilling developed an excellent reputation, with the Beaumont/Appleby machines recognised as industry leaders. Although mostly used for mining applications, the DRBC was contracted to drive the headings for Clifton Down Tunnel near Bristol, Cymmer Tunnel in South Wales, and both Wellhead and Lees Moor tunnels on the Great Northern Railway's extension line from Thornton to Keighley in West Yorkshire.



The front elevation (left) and side elevation (right) of the Beaumont/Appleby diamond drill cutter (UK patent No.1682, 1868), as adapted for tunnelling purposes from Leschot's machine.

The heading at Lees Moor measured 8 feet wide by 7 feet high. Beaumont claimed a rate of progress of 35 yards per week. He described how "holes were bored to a depth of about 6 feet; and with four machines [drills] the rock could be bored to that depth, with sixteen holes, in two hours, including the time necessary to bring the machine forward, from its siding to the face, to complete the work of boring, and to bring the machine back. After the holes were drilled, the centre holes inclining somewhat to the front, heavy charges of dynamite were fired in them, which loosened and shook the rock to the bottom, and the work of demolition was completed by firing the outside charges. The work was done in two hours, and it took four hours to remove the debris, completing the operation of 6 lineal feet of gallery in eight hours, which gave an advance of 18 feet per day."[19]

It was this machine that was brought to Queensbury in July 1877: a rock drilling machine, **not** a "tunnel boring machine". Its use still involved 'drilling and blasting', except the holes were bored mechanically rather than being hand-drilled by miners.

The headings

Due to the abandonment of Nos. 5 & 6 shafts in 1875, the contractor was left with 1,200 yards of Queensbury Tunnel to construct without intermediate access, between Nos. 4 & 8 shafts. It is believed that these shafts were sunk to their required depth by the end of 1875; thereafter, work would have quickly got underway to connect them by driving headings. These were 10 feet square.

---

19 Colonel Beaumont, Minutes of the Proceedings of the Institution of Civil Engineers, 1883

Around 18 months had passed by the time Beaumont's rock drilling machine arrived at Queensbury and it is reasonable to believe that considerable progress would have been made with the headings in that time. Assuming the miners advanced at a consistent rate in both headings and that the machine improved that rate by four times[20], it can be estimated that the machine assisted in driving around 282 yards of heading, with the junction made close to tab 38. This is broadly consistent with the rate of progress claimed by Beaumont in Lees Moor Tunnel.

Beaumont's rock drilling machine in use at the Croesor slate quarries.

20 On 13th October 1877, the Leeds Mercury reported that "The rate of progress attainable [using the machine] is from three to five times that of manual labour."

Following its completion, the heading had to be enlarged from 10 feet square to a size of approximate 31 feet wide by 26 feet high to accommodate a two-track railway, its formation and the tunnel lining. This work was also carried out using 'drill and blast' techniques.

Conclusion

Jacobs' mistaken assertion that 917 yards of Queensbury Tunnel was driven using a tunnel boring machine has questionable relevance in the context of HRE's 'minimalist' approach to abandonment. It would however have been highly significant if HRE had pursued the option of partially infilling the tunnel, potentially influencing the choice of which sections to infill.

Notwithstanding this, the basic nature of the error tends to colour any judgement of the draft report and suggests a misunderstanding of tunnel construction methodology. The error does not just appear once; it is perpetuated throughout the draft report and a number of conclusions are errantly drawn from it, sometimes in the face of contradictory evidence.

HRE should have rejected the draft Options Report and asked Jacobs to rewrite it without reference to a tunnel boring machine and the associated extrapolations. There are several possible explanations as to why it did not do so. Instead the draft report has been used to inform both engineering and Ministerial decision-making about the future management of a structure with the highest risk profile of any on HRE's inventory. ■

More than two dozen disused railway tunnels have been restored to use as hosts to cycle paths. Amongst them are (top, left-to-right) Cwm-y-Glo Tunnel in North Wales, Earlsheaton Tunnel near Dewsbury and Ashbourne Tunnel in Derbyshire; (bottom, left-to-right) the mile-long Combe Down Tunnel in Bath, part of the Two Tunnels Greenway, and Headstone Tunnel on the Monsal Trail in Derbyshire.

Queensbury
TUNNEL SOCIETY