Queensbury Tunnel

Technical Oversight
Phase 1 - Literature Review - Summary Technical Note Review

City of Bradford Metropolitan District Council

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1. Introduction & Background

Queensbury Tunnel, structure HQU 3D, is a disused railway tunnel situated between Bradford and Halifax in West Yorkshire. The tunnel passes directly beneath the town of Queensbury.

The tunnel is approximately 2300m in length, formed from masonry and brick arch with a span of some 8 metres and is situated up to 115m below the surface.

The tunnel was constructed in the 1870s but closed in the 1950s.

Highways England (HE), through the Historic Railway Estate (HRE), currently has responsibility for the maintenance of the tunnel and the long-term management of the asset.

Jacobs Engineering (JE), on behalf of HE, has prepared a number of high-level engineering proposals for the abandonment or refurbishment of Queensbury Tunnel. Depending on the chosen solution, costs presented range in value from £3 million for abandonment to £36 million for refurbishment and reconstruction.

Queensbury Tunnel Society (QTS) has been formed with a view to maintaining the tunnel as an asset with the ultimate goal of reopening the tunnel as a multi-user trail. QTS has reviewed and critiqued the JE reports. QTS has prepared an independent estimate for the refurbishment of the tunnel at approximately £3 million.

2. Scope

AECOM has been commissioned by the City of Bradford Metropolitan District Council (CBMDC) to provide an unbiased review of options proposed by JE and QTS.

This unbiased review has been deemed necessary because of the wide variation in costs for tunnel refurbishment produced by JE and QTS.

The following key documents have been provided for review;

- Queensbury tunnel feasibility report Oct 2009;
  - prepared by JE for BRB (Residuary) Ltd;
- 20160215_HQU_3D Abandonment Options Feb 2016_R1 (draftv1);
  - prepared by JE for HE HRE;
- 3682_hqu_3d_20170619_01_combined ground investigation report June 2017;
  - prepared by JE for HE HRE;
- Queensbury Tunnel Report (October2016) (Private & Confidential) (LR), Asset or Liability?;
  - prepared by QTS;
- QT- Cost Comparisons (Jan2017) (Draftv2) (Private & Confidential);
  - prepared by QTS;
- Queensbury Tunnel Condition (December 2017);
  - prepared by QTS (received 05.01.2018).

Supporting documents were also made available by CBMDC. These documents have been provided for 'information only' and are listed in Appendix A.

As part of the review, AECOM has prepared an independent high level cost estimate based on data contained within the six key documents cited above. Due to the expediency and time constraints of this review, due cognisance of the accuracy of this estimate must be taken into account Potential errors in through cross referencing and corroboration of basis costs may exist, but must be considered as within normal and reasonable bounds. It is also important to note that cost estimate build-ups were not provided within any of the key documents reviewed.

The documents listed in Appendix A have not been examined in detail due to the time restrictions.

This report provides a brief introduction to the tunnel in Section 3, a detailed review of the JE and QTS reports provided by CBMDC in Section 4 and AECOM's commentary in Section 5.

3. The Queensbury Tunnel

3.1 Tunnel form and structure

Queensbury Tunnel passes directly beneath the town of Queensbury from the southern portal at Strines cutting to the northern portal close to the site of Queensbury Station. The tunnel alignment runs in a south westerly to north easterly direction and the tunnel is approximately 2300m in length. The tunnel rises from the southern portal at a gradient of 1:100.

The tunnel is generally horseshoe in profile and is formed from masonry and stone block, with a span of some eight metres. The tunnel was sufficiently large so as to allow twin parallel rail tracks to be installed.

A total of eight intermediate shafts were planned. Each shaft would have been used to afford access to the tunnel, whereupon excavation would have proceeded in opposing directions.

Two of the shafts were not constructed to the full depth of the tunnel due to difficult ground and groundwater conditions, while one shaft was not constructed at all.

It is important to note that the Strines cutting, which was some 59 feet (17.7m) deep when constructed, has since been infilled close to the southern portal.

3.2 Geological setting

The tunnel was constructed through Coal Measures.

Mining for building stone, coal, and fire clay has occurred within the immediate vicinity of the tunnel structures and portals.

3.3 Construction method

Queensbury Tunnel would have been constructed using drill and blast methods throughout.

4. Commentary

The primary focus of the review is based on the most recent abandonment and remediation proposals, and their associated costs.

4.1 Feasibility Study of Future Asset Management (JE, October 2009)

The Queensbury Tunnel Feasibility Report (QTFR) was produced by Jacobs for British Railway Board (BRB) (Residuary) Ltd in 2009. The report was prepared to assess the future asset management of the tunnel and associated structures. As part of the feasibility study, works covered; identification of landowners; access requirements; structural survey; historic records; estimates; requirements for future surveys; and review of BRB data.

AECOM's review has focused on the presented feasibility options.

Three options were proposed: (i) Abandonment by sealing the tunnel portals; (ii) Repair and maintenance; (iii) Abandonment by infilling safety critical areas.

The feasibility study concluded that abandonment of the tunnel by sealing the tunnel portals was not recommended due to the remaining high residual risks. These residual risks are related to shaft and tunnel stability outside of the portal areas. Certainly, AECOM agrees with the statement that the *"potential risk of a shaft lining failure within close proximity to residential properties and developed areas"* is a key concern. It would therefore be expected that any future proposals to revisit the option of sealing the tunnel would also adequately address this residual risk. It is important to note that this has a bearing on the abandonment costs proposed.

The second option presented in the QTFR was to undertake significant repair works such that a continual maintenance regime could be adopted. The proposed repairs are not applicable as the tunnel has deteriorated since 2009, including two partial collapses. The costs associated with this option presented in the feasibility report should therefore not be used as a direct comparison with costs presented in subsequent reports for rehabilitation of the structure.

The QTFR recommends a third option involving partial infilling to safeguard the "critical elements" and remove future liabilities. The critical elements are the shafts and the lengths of tunnel with the lowest cover. AECOM is in agreement with this proposal as it reduces risk and liabilities associated with collapse of the tunnel and shaft linings.

Some key extracts and AECOM commentary from the QTFR include:

- Section 3.6.1 (and 4.1.1): Tunnel Risks states that the *"…the tunnel's masonry and brickwork lining do not serve to retain the structurally self-supporting stratum"* and "*The long sidewall sections are suspected to act as an aesthetic finish…"*. Also, section 3.6.2 Shaft risks note *"...failure of the supporting (tunnel) sidewalls beneath the shaft eyes has a high potential for a global collapse of a shaft lining"*. This is not readily apparent and not noted in later risk assessments. This also contradicts the section 3.6.1 insofar as the tunnel lining supports the shaft lining above.
- Section 4.1.1: Greatest risk of tunnel collapse noted as: (i) Earthquake and/or collapse of mine workings. (ii) Changes in Ground Water Level (GWL) or water flow (however, flooding at southern portal noted as a risk). NB: Neither failure mode cited in later Risk Assessments
- Section 4.1.1: This 2009 report states that where cover is less than 40m infilling needs to occur to remove the risk of collapse/deformation on the surface. This therefore eliminates Option 1 as previously noted.
- Section 4.1.1: Notes progressive collapse as soon as failure occurs. Agreed this is a likely failure mechanism.
- Section 6.6: Options to *"…abandon/seal the structure in its current condition is not recommended due to the high residual risk…"*. Infilling at the portals only as a method of abandonment was not recommended by JE and why the more robust infilling at safety critical areas was proposed.

4.2 Queensbury Tunnel Options Report (JE, February 2016).

4.2.1 General observations

The Queensbury Tunnel Options Report (QTOR) was prepared by JE for HE in 2016. The QTOR takes due cognisance of the deterioration of the asset with time, including the partial collapses which occurred between February 2013 and June 2014. It provides a high level assessment of the feasibility and cost for the closure or repair of Queensbury Tunnel, based on desk study information only.

A total of four options are presented with sub-options thereof. These are:

- Option 1: Do nothing (infill portal headwalls only);
- Option 2: Abandonment with risk reduction;
  - Option 2a: Infill entire tunnel;
  - Option 2b: Infill critical sections;
  - Option 2c: infill collapsed section of tunnel;
  - Option 2d: Infill collapsed section of tunnel plus 'void';
- Option 3: Shaft abandonment;
- Option 4: Tunnel and shaft restoration and upgrading.

The report does not identify a preferred option for progression, but does detail an initial series of investigations required to inform and progress the works. AECOM agrees that the final solution can only be informed and assessed following a target series of intrusive investigations, non-intrusive investigations, and accompanying desk studies.

The report focuses on likely construction cost estimates for each of the options developed.

The report describes the tunnel condition as *"poor to fair"*. Without having carried out a detailed review of the structural examination reports provided for information, this appears to be in agreement with the most recent tunnel visual examination report dated December 2017 and referenced in Appendix 1.

The executive summary states that *"groundwater flow into and through the tunnel has been a continuing problem"*. This appears to agree with anecdotal evidence that water was an issue during shaft and tunnel construction. However, inflows of groundwater through the shafts have not been recorded and it is difficult to quantify flow rates.

The executive summary states that the rock surrounding the tunnel is competent and would not propagate to ground level. However, given the unknown influence of adjacent mine-workings, coupled with a lack of detailed Geotechnical Investigation (GI) data and 'low' cover above the tunnels, AECOM is in agreement with the earlier QTFR that the collapse of the tunnel is likely to propagate to the surface.

The executive summary states that the tunnel lining is *"unstable"*. This statement will be addressed later in this section. Certainly, without repair and maintenance, AECOM agrees that further collapses of the tunnel are considered likely.

A number of studies and analyses were used to inform the repair options proposed. The key information used in the derivation of options includes:

- The method of construction (excavation);
- A structural assessment of the tunnel lining.

Commentary contained within 'Visual inspections' indicates that the tunnel was constructed using two differing methodologies. Certainly this is not the case and the whole tunnel length would have been advanced using drill and blast (D&B) methods. The 'diamond drilling machine' cited will have been used for mechanically drilling shot holes to speed the excavation advance rate. D&B will have fractured the surrounding rock. It is likely that D&B will result in additional loading on the lining and additional water ingress. Zones of fractured rock will occur throughout the whole length of the drive, including those lengths progressed using the 'diamond drilling machine'.

The tunnel collapses and deterioration of the tunnel appears to have been exacerbated by nearby mining activity. Historic records indicate that deformation due to mining was prevalent at or shortly after construction, with remedial tunnel works taking place. Mining records were not checked by AECOM as part of this review. The condition of the tunnel lining at the collapsed areas was recorded over a period of time. Recorded loss of brickwork would have led to increased stresses in the lining. Probable voids behind the lining and subsequent 'wedge type' eccentric rock loading on the lining, coupled with lack of maintenance and poor ventilation (following infilling of the cutting and standing water) are also contributing factors to the tunnel lining failure. Certainly, the stated failure mechanisms of the tunnel lining at the centre of the tunnel (high in-situ stresses) and at the southern portal (adverse water pressures) are both plausible. A rapid drawdown of the water table does result in increased hydrostatic pressures and an increase in load on structures.

4.2.2 Structural assessment: FLAC

The analytical Fast Lagrangian Analysis of Continua (FLAC) Finite Element (FE) software used by JE to assess the tunnel lining is appropriate to determine stresses and bending moments within a tunnel lining. However, it is important to note that the analyses undertaken and presented in the QTOR were based on a number of assumptions. In particular; (i) the FE model was based on an assessment completed at Consibrough, and (ii) limited factual data was available to enable an accurate assessment to be made.

Key areas that need to be confirmed include:

- Geological conditions (impacts applied loading);
- Hydrogeological conditions (impacts applied loading);
- Structural condition (impacts capacity);
- Material (brick or masonry properties and variation thereof);
- Advance rate and ground relaxation (impacts applied loading);
- Affected D&B ground (impacts applied loading);
- Tunnel profile (two are observed above ballast with one currently assessed);
- Tunnel profile and presence (or otherwise) of a structural invert to the tunnel lining (provides lateral restraint);
- Introduction of ballast within the assessment (provides lateral restraint).

The actual applied loads and the method and sequence of modelling cannot be ascertained.

Of the two analyses undertaken, the second, with the inner leaf of brick removed, does not exist in the field. Whilst this is considered acceptable for a 'worst case' assessment, reducing the lining thickness at the haunches only would be more consistent with recorded observations.

It should be noted that there is some inconsistency between the function of the tunnel lining between the QTFR and QTOR: The function of the lining is described as aesthetic and structural respectively. AECOM believes that, based on the data provided, the lining will have been structural in nature. The function of the lining is to support the surrounding rock mass and shaft linings.

4.2.3 Proposed Options

4.2.3.1 Option 1

Particular comments on Option 1 include:

- Infilling at the portals only leaves a residual and significant risk that the tunnel will collapse and migrate to the surface.
- Infilling of portals with a concrete 'bulkhead' is likely to 'seal' the tunnel beyond. Infiltration of groundwater into the tunnel will occur and, with limited means of escape, will result in groundwater rising locally and impacting on other mine workings. The 300mm pipe will, to some degree, prevent this but 'unless maintained' will become blocked and result in changes to GWLs.
- Competency of the rock is noted. Actual conditions can only be ascertained following GI.
- Low risk of void migration to the surface is only applicable to the deeper lengths of tunnel. A moderate but significant long term risk remains where there is reduced over.
- It is assumed that infilling will encompass and stabilise the existing portal structures.

4.2.3.2 Option 2a

Particular comments on Option 2a include:

- The proposed methodology, with some tailoring of infill sequencing and control of groundwater, is acceptable. Without grouting, a void is likely in the soffit in the southern length due to the gradient.
- Certainly it is likely that there would be changes in GWL with other unforeseen impacts at this stage, without further investigation. This was noted in the QTFR.

4.2.3.3 Option 2b

Particular comments on Option 2b include:

- Fracturing of the rock mass from D&B is likely, but no intrusive tests have been undertaken to confirm whether this can be classed as "significant fracturing" and indeed, the extent of any fracturing is unknown.
- There is a misconception that some lengths of tunnel were not constructed using D&B methods. As such, any proposal to infill D&B sections only will be as Option 2a. However, the proposed infilling within the tunnel at both portals (low cover) is considered practical.
- If selected infilling of the tunnel was progressed at the portals, access for future maintenance work within the tunnel would be significantly more hazardous. This is due to; (i) lack of air movement and (ii) water infiltration. Water ingress will undoubtedly lead to flooding of the tunnel and a change in long term GWLs.
- Access for plant and materials through existing (unrepaired shafts) would be considered high risk. This is particularly relevant where there tunnel lining failure occurs beneath a shaft.

4.2.3.4 Option 2c

Particular comments on Option 2c include:

- The principle of this option is considered to be ok, albeit the length of the infill section is undefined. Remaining open tunnel lengths would become increasingly hazardous for access as there is no route through the tunnel from either portal. Further deterioration of the lining will occur due to standing water and lack of air movement.

4.2.3.5 Option 2d

Particular comments on Option 2d include:

- As noted for Option 2c.
- Pumped placement of foamed concrete/grout likely to be required.

4.2.3.6 Option 3

Particular comments on Option 3 include:

- The referenced report, 'HQU/3D Feasibility Study of Future Asset Management (October 2009)' is not available.
- The possible sink-hole scenario remains as there is no physical data available on competency of ground or condition of shaft linings. The most probable failure mechanism is failure of the tunnel followed by shafts.
- Water ingress is correctly anticipated to be high due to passage through all strata to tunnel level. Weathered material (strata) may also exist at lower depths due to folding or faulting. Other collapse mechanisms are possible.
- Shafts 3, 4, 5, and 6 are all in built-up areas. Records for the capping of Shafts 5 and 6 are 'unknown' and therefore it is agreed that these present the highest risk.
- Formation of depressions laterally is a likely failure mechanism. Cover collapsing in on itself leading to a major void remains as a high risk, as stated, with a potential loss of life.
- It is agreed that, without investigation, the shaft linings are most likely predominantly self-supporting (in that they are supported by the tunnel lining and are not reliant on the surrounding ground). The probability could be considered to be lower but the risk still remains high.
- It is agreed that there will be ongoing deterioration without maintenance leading, eventually, to collapse.
- Considering the 'do nothing' option, failure of the shaft lining (or tunnel lining beneath) could lead to progressive collapse and undermine the foundations to the shaft capping. 'Do nothing' will eventually result in failure. Inspection will not limit the risk of collapse but could inform when maintenance and remedial measures would be required.
- Considering the 'infilling' option, it is agreed that infilling will be more expensive than 'do nothing'. However, infilling will be more robust than dealing with shaft failure and consequences thereof.

4.2.3.7 Option 4

Particular comments on Option 4 include:

- Mitigation for mine workings is separate from this study. These costs are not included.
- It is agreed that pointing will be required where there is a loss of mortar.
- Tunnel strengthening through the construction of an inner lining is the most likely method of stabilisation.
- The reconstruction (replacement) of the tunnel lining is unlikely due to prohibitive cost. This is an important factor is determining the cost for remediation. Certainly, reconstruction of the collapsed section of the lining in a shield will be both expensive and problematic. With regards to the comparison with Bilsworth Tunnel, it should be noted that this is a working canal tunnel and required online replacement to maintain through traffic. This is not the case for Queensbury Tunnel as access would be limited to pedestrians and cyclists.

- The proposed reopening of shafts to improve ventilation and airflow through the tunnel structure for this option is agreed. The number of shafts to be reopened would need to be assessed as part of a ventilation study.
- Future drainage could be installed in new hardcore/ballast to limit excavation and disposal of contaminated material.
- Water management and sealing (against major water ingress/leaks) would be required.
- It is agreed that improved access to the southern portal will be needed as the existing access is steep and not suitable.
- The proposed installation of a roadway (tarmacadam to centre), lighting and communication systems within the tunnel for this option is agreed.

4.2.4 Desktop Cost Plans

Desktop Cost Plans for each of the proposed options are presented within the 'Abandonment Options Estimates Report' (AOER) dated 16th December 2015 included within Appendix B of the QTOR.

Importantly, the quantum of repairs used to determine values in the AOER is not defined for any of the proposed options.

The following general comments apply to all of the presented estimates:

- An estimate range of -40% to +40% is applicable based on the preliminary data available.
- The contract type will influence the construction cost.
- An allowance or 15% for design fees for all options is unlikely. This is commented on further for selected options below. The design fees are likely to vary between 5% & 15%. 'Simpler' options with smaller construction values are likely to have proportionally higher design costs.
- Although not stated, it is assumed that other development and project costs are related to advance survey works. This cost is applicable to all options.
- An allowance of +40% for risk to Civil Engineering works is agreed.
- Exclusion of tender and construction inflation is agreed.
- Exclusion of VAT is agreed.
- It is noted that the cost estimate has been prepared and based on information contained within the QTFR and QTOR.
- The stated assumptions are agreed.
- The stated exclusions are agreed.

The construction programmes presented for each of the options are:

- Option 1 - 6 weeks;
- Option 2a - 26 weeks;
- Option 2b - 16 weeks;
- Option 2c - 23 weeks;
- Option 3 - 8 weeks;
- Option 4 - 108 weeks.

It is considered unlikely that Options 1 and Option 3 could be constructed within the allotted timescales. A minimum 4-week period in addition to that quoted is considered reasonable.

There is no significant difference between Options 2a, 2c and 2d. While option 2a requires complete infilling of the tunnel, there is no reference to the infill lengths required for Options 2c and 2d, save for they are to be infilled at the collapsed sections. If this is the case, the programme for this form of targeted infilling seems too great.

The proposed 108-week timescale for Option 4, which includes on-line replacement using a tunnelling shield and precast concrete segmental lining, is realistic. However, the proposed solution is very unlikely to be implemented as on-line replacement to maintain the clear internal area is not required. An alternative option with a cast in-situ lining is considered most appropriate. Based on the key data reviewed, a 44-week programme is considered reasonable. [NB: The proposed repair methods for the shafts and shaft heads are not specified by JE. As such, it is assumed that any repairs are related to pointing, sealing of leaks and water management only.]

Comments on headline costs stated in Appendix B are as follows:

- 01 General Items: Roughly correlate to construction duration and are considered within reasonable bounds.
- 02 Construction works: No build-up available. Options 1, 2b, 3 and 4 are discussed in more detail in Section 5 of this report.
- 03 Accommodation: This is a fixed set-up item, not time related and considered to be within reasonable bounds. It is constant for all options. Costs for Option 3 will be higher, as noted, due to several worksites.
- 04 Facilitating: This is assumed to cover formation of access for the tunnel and shafts, together with the works compound and temporary utilities. Facilitation work will be greatest for Option 3 as noted.
- 05 Design Fee: This is based on a blanket 15% of the construction estimate. It is considered that this percentage is applicable to 'simpler' lower value proposals only. It should be noted that the quoted design fee of £3.5 million for Option 4 is equivalent to circa 25 full time engineering staff for 12 months. This is high. Similarly high figures are likely to exist for Option 2 variants.
- 06 Development Costs: It is assumed that this covers the full suite of investigative works including intrusive and non-intrusive tests plus further searches/studies/impact assessments. This is required for all options. The quoted figure is within reasonable bounds.
- 07 Risks: An addition or 40% is acceptable and in line with works at this preliminary stage.
- 08 Optimism, 09 Inflation and 10 VAT: These are all excluded. This is noted and considered acceptable.

4.2.5 Risk Register

A review of the QTOR risks, by Option has been completed. A summary of the findings are included within Appendix B.

4.3 Queensbury Tunnel Ground Investigation Report (JE, June 2017).

The Queensbury Tunnel Ground Investigation Report (QTGIR) report was prepared by JE for HE in 2017. The GI was undertaken for the express purpose of informing the detailed design of shaft capping works and to estimate the extent of infill within the tunnel, as part of the abandonment of Queensbury Tunnel. The report was not focused on the conditions within the immediate environs of the tunnel, portals or shafts at depth.

The GI confirmed the anticipated ground conditions, namely a shallow depth of topsoil and made ground (0.5m to 0.6m) over sandstone (Elland Flags) and Lower Pennine Coal Measures.

AECOM is in agreement that the GI findings correlate to the British Geological Survey (BGS) mapping.

Some key extracts and AECOM commentary from the QTFR include:

- Water inflow into the shafts was not investigated and, as such, any reference to inflow rates cannot be corroborated.

- The project was classed as geotechnical category 2. This needs to be reviewed as category 3 may be more appropriate.
- Ground cover to above the tunnels is estimated to be approximately 30m to 35m at SH1 and SH8 respectively. The maximum cover (at shaft) is approximately 120m at SH5.
- The coal authority report was not available for review. However, faults are indicated on the BGS mapping and are noted and agreed. These faults will pass through the tunnel horizon.
- Trial pits were taken to 1.2m with rotary cores to a maximum of 9.3m below ground level. This is suitable for the design of remediation works at shaft heads and the GI undertaken is consistent with required purpose/scope.
- Shallow groundwater was recorded in boreholes. These water levels are potentially related to perched watertable(s). Certainly, standing water within SH5 and SH6 were recorded at 50m and 90m below surface respectively.

The Preliminary Engineering Discussion based on the shallow GI supposes that voids resulting from a tunnel collapse will not migrate to the surface. AECOM agrees that choking is considered likely. However, with the combination of shallow cover (30m to 40m), coupled with the large tunnel diameter (8m), drill & blast construction methods and the potential for adjacent overhead mine workings, any ravelling following tunnel collapse could migrate to the surface and remains a real risk.

AECOM is in agreement with the proposed recommendations at portal approaches. Namely to infill at the southern portal 270m to between SH1 & SH2, and 360m at the northern portal to near SH6.

The reference to a ‘boring machine’ relates to the process of drilling shot holes to assist D&B excavation. Any references to better-than-anticipated rock as a result of not using D&B methods are therefore not applicable and misleading.

Shaft capping proposals are satisfactory. However, some future access to allow for consolidation of any infill will be needed.

Although high groundwater inflows are noted, no flow tests were undertaken.

Infilling beneath shaft eyes within the tunnel as a means of stabilization is agreed.

AECOM is in general agreement with identified risks. However, only one risk has been identified for the tunnel. Certainly groundwater will fill the tunnel if the portals are blocked. There is a potential for inundation if bulkheads are not designed and completed correctly.

4.4 Queensbury Tunnel Asset or Liability (QTS, Oct 2016)

The purpose of the Queensbury Tunnel Asset or Liability Report (QTALR) was to propose an alternative remediation method to that presented by JE in the QTOR; more specifically, the proposed Option 4. The QTALR informs the reader of the tunnel construction in context with the geological settings, the challenges that arose and subsequent history form conception, through closure to the current day. This is further supplemented by a summary of the existing condition, including a review of reports prepared by JE on behalf of HE.

4.4.1 General observations

The following comments relate to elements of the QTALR:

- Abandonment of shafts does require additional assessment. However, this is the case for the tunnel, shafts and portals as no detailed information on the structure and geological setting is available.
- A study into impacts of altered hydrogeological conditions and associated impacts was raised by JE.
- It is agreed that the construction of Queensbury Tunnel would have been wholly by D&B.

- It is agreed that the long-term liabilities posed by the minimalistic Option 1 solution presented in JE's QTOR needs to be investigated. This is discussed further in Section 5 of this report.
- An investigation, design and construction estimate of £2.81 million, to be completed in 44 weeks, is not practical or possible. It is anticipated that construction work only, for the alternative remediation method, would take 44 weeks.
- It is noted that ancillaries are excluded from the estimate.
- It is noted that maintenance, lighting, pumping, tarmacadam, ballast, drainage etc. are excluded from the estimate.

A review of the costs has been undertaken as part of the Queensbury Tunnel Cost Comparison Report (QTCCR) published in February 2017. This is presented in more detail in Section 4.5 of this report.

A high level review of costs and a preliminary Desktop Cost Plan for the works have been undertaken by AECOM without prejudice. This includes an independent assessment of construction costs as presented in Section 5.

4.4.2 Current condition

It is important to note that the FE modelling undertaken by JE was based on limited data. Modelling is only as good as the data that is entered and, for accurate results, requires factual data on the lining properties, geotechnical properties and the original construction methods. Comments on the FE model have been made specifically elsewhere.

Without a comprehensive GI, the FE ground model will be unable to predict local 'subtleties' such as wedge block failures and corresponding asymmetric loading. The FE model was undertaken to get a basic understanding of how the lining behaved.

There is no structural analysis of the shafts, their interfaces with the tunnel, or due cognisance of historic (and potentially ongoing) movement as a result of old mine workings. Depending on the options chosen for the future of QT, these assessments will be required.

4.4.3 Abandonment or remediation

For full and safe abandonment, it is recommended that the shafts and tunnels directly beneath shafts are backfilled. Comments on shafts are addressed elsewhere in this report.

Once the portals are sealed and shafts are left 'capped only', it will be an extremely challenging and dangerous operation to inspect the asset or undertake any required remedial/repair works. These risks need to be designed out.

4.4.4 Shafts abandonment

Failure of the tunnel lining or local failure of a shaft is likely to lead to catastrophic failure of the shaft lining and ground immediately above and surrounding the shaft.

For long term stabilisation and risk mitigation (third-party claims or loss of life), infilling with clean stone would be recommended. A concrete cap is not considered a long term maintenance-free solution.

4.4.5 Water management

In the long term, sealing portals will lead to a change in the ground water regime. The impacts on sealing the tunnel are noted and it is agreed that a study into the impacts of altered hydrogeological conditions will be required.

4.4.6 Conclusion

With regards to the remediation alternative, it is agreed that the tunnel does not have to be made perfect, but it must be made safe structurally and be safe to use by the general public, third parties and workers required to maintain the asset. Importantly, not all defects are 'visible' and remedial works required can only be determined following a round of intrusive and non-intrusive investigations.

A similar method of repair to that at Dingle Tunnel, Liverpool, is likely to be suitable within the partially collapsed lengths of tunnel. It is important that the form of the tunnel invert is fully understood before any design solution is developed.

It is likely that a 300mm Steel Fibre Reinforced Concrete (SFRC) Sprayed Concrete Lining (SCL) lining will be satisfactory, but can only be ascertained following full investigation and analysis of true tunnel profiles. A full SCL (closed ring) may be required, possibly together with rock bolts. The new internal structure would need to be drained.

The failure mechanism of the lining needs further investigation. Certainly, a SFRC SCL is ductile. The SCL would carry all applicable loading. Careful consideration of the requirement for footings, full profile linings, and anchors would be needed.

A full list of surveys required to understand how the structure behaves will be developed in any future phases of work.

4.5 Queensbury Tunnel Society Cost Comparisons Report (QTS, Feb 2017)

The Queensbury Tunnel Society Cost Comparisons Report (QTSCCR) critiques cost estimates prepared by JE on behalf of HE. In addition, QTS have prepared a construction cost estimate based on available data and consultations with specialists. The purpose of the report was to examine various costings and 'contextualise' them with other tunnelling projects.

The QTS estimate for repair is £2.81 million. It is noted that there are several items that are excluded. A detailed breakdown of how the figure was derived was not available for AECOM to review. The QTS estimate is discussed later in this report.

AECOM agrees that shafts are, in general, not 'connected' to the surrounding strata. However, some skin friction may be present between the extrados of the shaft lining & surrounding ground. This skin friction is not normally taken into account during structural and stability assessments. It is the tunnel beneath that will carry dead loads of the shaft lining.

With regards to the discussion of JE's use of the term Tunnelling Boring Machine (TBM), it is indeed the case that the whole tunnel would have been mined using D&B methods. The 'TBM' in this instance would in fact have been a diamond percussion drill for installation of explosives. Mechanical means of drilling would have given greater production rates than if shot holes were undertaken by hand.

JE's original cost for repairs at £1.2 million was based on a 2009 'pre-collapse estimate' and is therefore unreasonable to use as a baseline in this case. However, JE's £35 million estimate is based on on-line replacement and, as such, is high. Although the estimate is considered accurate, there are alternative and simpler remediation methods available. These alternative methods will substantially reduce the anticipated construction cost. AECOM has prepared an estimate of the likely construction costs as a Desktop Cost Plan using alternative methods and these are referenced in Section 5 of this report.

This review has been unable to undertake percentile comparisons of various options by JE and QTS due to time limitations. However, an independent assessment of what is considered to be the safest solution to abandonment and a reasonable assessment of repair has been completed. This is discussed in Section 5 of this report.

The repair costs for Dingle Tunnel in Liverpool are not available to the reader. Costs associated with the reinstatement of the tunnel through the partially collapsed lengths are discussed in Section 5. It must be noted that, at 1km into Queensbury Tunnel, works will be more challenging than at the Dingle Station Tunnel.

AECOM agrees that a budget estimate for placing a steel fibre reinforced SFRC SCL within the tunnel would equate to £8 million. However, this figure does not take into account site setup costs, any advance works needed to ensure safe access, or ancillaries for safe operation and maintenance.

Although interesting, a comparison between the respective tunnelling costs of the new High Speed Two (HS2) tunnels and rehabilitated Queensbury Tunnel cannot be made. In particular, there are two differing methods of construction: HS2 costs presented are based on bespoke Pre-cast Concrete (PCC) units installed behind the TBM in 'factory' conditions, whilst Queensbury Tunnel uses bespoke methods with in-situ concrete tailored to individual locations. Importantly, the cost of procuring a specialist 'hard ground' TBM would incur a one-off cost of up to £45 million and take a minimum of one year lead-in time to procure.

AECOM has not made further comparisons between Queensbury Tunnel and the Bressay-Lerwick or Stromeferry tunnels as the latter are 'new' structures, rather than directly comparable refurbishment costs.

It important to note that all repair estimates for Queensbury Tunnel are currently based on visual inspection data only. A detailed examination involving further non-intrusive and intrusive tests will be required to understand the true structural condition of the tunnel lining, shafts and portals. Only then can the remedial works be designed and quantified.

Certainly, the QTFR report prepared by JE in 2009 and referenced in Section 3.1 does not reflect the current tunnel lining condition. As such cost comparisons, by QTS, for the current likely remediation costs prepared by JE, are not directly comparable.

A summary of QTS's costs and programme for design and construction of the remediation works are outlined in section 3.2. The following comments apply:

- The stated investigation, design and construction programme is optimistic. The proposed works will not be able to be completed in the 44-week timescale proposed.
- There is no allowance for advance and planning works.
- Investigations will take a minimum of 4 weeks with specialist teams working concurrently. Reporting and interpretation will follow.
- Structural assessment and the design of remediation measures will take a minimum of 10 weeks. This will likely cover various tunnel sections, shafts, shaft-tunnel junctions and portals. Additional time will be required for reporting, detailed drawing, and approvals.
- The construction programme is anticipated to take 44 weeks. This assumes a solution of; mortar pointing, brick patch repair, SCL patch repair, SCL arch with anchors, and strengthening through placement of a mass concrete arch.
- A project contingency of 20% is insufficient. A value of about 40% needs to be used where no physical data is known for the tunnel and shaft linings and geological conditions.

The QTS review of JE options as proposed in the QTOR is given in section 3.3 of the QTSCCR AECOM's comments are as follows:

- Repointing will be required.
- The proposed method of strengthening with SFRC SCL is suitable. However, this assumes an 'arch' only and further assessment on any requirement for a fully closed ring will be required.
- The on-line reconstruction within a shield is considered both prohibitively expensive and challenging. AECOM's recommendation would be to install a new cast lining using a steel former. The exact arrangement can only be determined following receipt and interpretation of factual data followed by structural assessments and design.
- Reopening of two shafts is recommended as proposed. [NB: An atmospheric and ventilation assessment must be undertaken as part of future investigations and studies. This is particularly important where the 20m deep cutting has been infilled close to the southern portal, forming a 'low point' on the alignment, irrespective of changes in atmospheric conditions at either portal.]
- It is agreed that a new drainage system will be required.
- It is agreed that water management will be required. However, a fully 'sealed' tunnel (and shaft) lining is not considered necessary. The focus should be on the investigation of water paths and

most probably local grouting of the rock mass and voids behind the lining, and subsequent water management.

Bressay-Lerwick and Stromeferry tunnels referenced in sections 3.4 and 3.5 of the QTSCCR are both new tunnels to be built by D&B methods supported by a combination of rock bolts and sprayed concrete in granite. The tunnel structures would be constructed sequentially in a safe and robust manner. They will not face the technical challenges associated with refurbishment of historic masonry/brick-lined tunnels and shafts through bedded and faulted sedimentary rocks. Although useful as a comparison, the geological and hydrogeological conditions beneath Queensbury are considered to be markedly different from both Scottish Tunnels. A full structural (secondary) lining would be recommended at Queensbury. These costs are not included in the cited estimates. Similarly, there are no costs associated with shafts on either of the Scottish tunnels.

The reference to HS2 in section 3.6 of the QTSCCR relates to new tunnels constructed by state-of-the-art TBMs. Depending on location, the TBMs will pass through clays or mudstones. As a comparison, the overall cost is misrepresentative as a number of key items such as spoil disposal and TBM supply and set-up are excluded. For example, an 8m internal diameter TBM costing £45 million would, using QTS figures, likely add £20,000 to each metre constructed.

With limited GI data in all cases, it is difficult to ascertain whether ground conditions at Queensbury are better or worse than those tunnels used in the comparisons. However, engineering judgement would indicate that tunnelling through previously mined coal measures would be more challenging. The quoted figure of £25.6 million may therefore not be the upper bound figure. The estimate does not include costs for on-line shafts. However, it is agreed that a smaller tunnel would reduce costs: A tunnel internal diameter of 5m may be acceptable, depending on plant and ventilation requirements.

A cost comparison between Coombe Down Rail Tunnel and Queensbury Tunnel is mentioned in the closing remarks. No historic data is available on Coombe Down Rail Tunnel for AECOM to assess. However, it can be gleaned that the original condition of the Coombe Down Rail Tunnel, before remedial works took place, was sufficiently safe as to let the general public through with minimal PPE. This would certainly not be the case for Queensbury Tunnel.

5. Discussions

5.1 The Options

Four key options and variations thereof have been identified within the QTOR prepared by JE in 2016.

These options are;

- Option 1: Do nothing (infill portal headwalls only);
- Option 2: Abandonment with risk reduction;
  - Option 2a: Infill entire tunnel;
  - Option 2b: Infill critical sections;
  - Option 2c: infill collapsed section of tunnel;
  - Option 2d: Infill collapsed section of tunnel plus 'void';
- Option 3: Shaft abandonment;
- Option 4: Tunnel and shaft restoration and upgrading.

It is considered that Option 1 and all Option 2 abandonment proposals must be considered alongside and accompanied by Option 3.

It is considered that the proposed Option 1 may be unsuitable due to residual risks as a result of the likelihood of the potential for sinkholes at the ground surface.

The Option 2 proposals are considered suitable.

Option 2a will reduce risks associated with tunnel collapse to as low as reasonably practicable (ALARP) levels.

Option 2b will likely reduce risks where there is low cover over the tunnel lining. However, residual risk will remain and any subsequent repairs to the tunnel (as a result of a tunnel and/or shaft collapse) would likely prove extremely challenging. It for this reason that infilling of the shafts would be recommended.

Option 2c partially infills the tunnel at the collapsed sections approximately midway within the tunnel. However, infilling the centre of the tunnel will likely lead to difficult access conditions from either portal, should further inspection or maintenance be required. 'Dead End' tunnels will be created which carry inherent safety risks as there may be no viable alternative means of escape (excluding shafts).

Option 3 does not propose any remediation measures to the shaft linings or capping structures, should they be 'left in place'. However, the alternative proposal of infilling is more robust and would reduce risks to ALARP.

Option 4 proposes remediation through pointing, strengthening using SFRC SCL methods where the existing lining is showing signs of duress, and on-line replacement of the tunnel lining using a tunnel shield and precast concrete segments through the partially collapsed lengths.

In particular, QTS have questioned the remediation method as proposed by JE for Option 4. An alternative proposal consisting of remediation through pointing, strengthening using SFRC SCL where the lining is showing signs of duress and a cast concrete lining with a reduced cross-sectional area through the partially collapsed lengths.

The option presented by the QTS is considered to be the preferred solution as on-line enlargement to maintain the clear cross sectional area is not required. This will be referenced as Option 4a.

5.2 The Costs

A high level review of the costs presented within the QTOR has been undertaken by AECOM.

It is imperative that the reader recognises that this is a high level desk top estimate based on data within the key reports only. The desk top estimate has been supported through AECOM's own knowledge, the ongoing HS2 and Hinkley Point C projects, together with the additional helpful support of the following Civil Engineering and Tunnelling Contractors: Dyer & Butler Ltd; Shotcrete Ltd and Murphy Ltd. The costs presented are not whole-life costs and do not take into account ancillaries for safe operation and maintenance.

Costs for general items are considered to be within reasonable bounds and are largely time dependent, ranging from £30 thousand to £40 thousand per week.

However, general costs for Options 1 & 3 are anticipated to increase, in-line with the predicted 4-week increase in programme; circa over £120 thousand per option.

The construction cost of infilling for Option 1 has been assessed, by AECOM, at a high level. Assuming that a 20m length of tunnel is infilled at each portal, the total volume of concrete anticipated to be placed is 1800m^3. At a cost of £120 per m^3 for basic supply and placement, without remedial works at portals, this equates to some £216 thousand against £117K in the JE estimate. Overall, using the formula as presented by JE, the AECOM desktop cost limit is for Option 1 is circa £1.34 million (Table C1 Appendix C). This is greater than the £0.99 million estimated by JE.

However and as noted previously, Option 1 leaves residual risks that will need to be addressed in the long-term. Both JE, in the QTFR, and AECOM believe that, given the currently available data, this Option 1 would not be suitable. A more robust option should be chosen in order to reduce risk to ALARP levels.

The construction cost of infilling shafts for Option 3 has been assessed, by AECOM, at a high level. Assuming that 7290m^3 of material has to be placed at a cost of £80 per m^3 for basic supply and placement, and without remedial works at shaft heads, the cost for infilling would be estimated at approximately £583 thousand vs £434 thousand by JE. Overall, using the formulation, as presented by JE, the estimated AECOM desktop cost limit for Option 3 may be circa £2.26 million (Table C2 in Appendix C). This is above the £1.2 million JE cost limit.

Option 2b targets the critical length of tunnel for infilling, namely those lengths with low cover at each portal. The JE cost limit for Option 2b is circa £13.5 million. In order to reduce risks to ALARP, Option 3 (shaft infilling) should also be incorporated. As a minimum, using the Option 3 JE price as presented, the overall cost limit could be anticipated to be £15.2 million. This varies from the AECOM high level desktop cost limit of £8.5 million (Table C3 in Appendix C).

A secondary exercise was undertaken to cross reference desktop costs for Option 2a & 3: full infilling of the tunnel and shafts. The JE cost limit for these works is £22.8 million. The AECOM desktop cost limit (Table C4 in Appendix C) for the work is £22.9 million. This gives a certain degree of confidence in the AECOM desktop cost limit for Option 2b above.

The JE construction cost for Option 4, at £35.3 million (civil engineering cost (£16.75 million), has not been reviewed in detail as it is considered that the proposed remediation measures could be revised to give a more cost-effective solution. This alternative solution will have a reduced construction duration and, correspondingly, reduced design and associated desktop cost limit.

The basis for the revised solution, to this alternative Option 4a, has been developed from the summary inspection records contained within key documentation and supplemented by visual inspections noted in Appendix A.

The anticipated desktop cost for the 'construction works' for Option 4a (including shaft repairs), and as presented in Appendix C Table C5, is £3.495 million. Using a similar formulation for the identified 'General Items', 'Accommodation Works', 'Facilitating Works', 'Design Team Costs', 'Development Costs' and 'Risk' as outlined within JE's QTOR, the overall desktop cost limit for this option is predicted to be £6.01 million.

The QTS proposal, now identified as Option 4a, likely underestimates the time required for investigations, assessments, design, approvals, construction and on costs for risk. Consequently the cost estimate of £2.81 million is considered to be low.

The cost limits for the key options are summarised in Table 1.

Table 1. Summary of Cost Limits

Item	AECOM Cost Limit (2018)	JACOBS Cost Limit (2016)	QTS Estimate (2017)	Comment
Option 1: Portal Headwalls	£1,339,730	£995,855	-	Residual safety risk remains. Progressive collapse at reduced cover. Costs similar.
Option 3: Shaft Infill	£2,264,997	£1,731,519	-	Full shaft infilling. Costs similar.
Option 2a plus Option 3: Infill whole tunnel length and shafts	£22,861,083	£22,884,842	-	Full infilling of tunnel & shaft. Cost cross checks comparable
Option 2b plus Option 3: Infill critical tunnel lengths and shafts	**£8,494,892**	£15,091,216	-	Targeted tunnel and full shaft infilling. Costs vary.
Option 4a: Remediation	**£6,012,419**	£35,381,398	£2,810,000	Differing repair methodologies for AECOM (QTS) / JE. Costs vary.

Appendix A Reference Documents

The following supporting documents were made available by CBMDC for reference;

- Inspection Reports;
  - CARILLION TRANSPORT. (2012).3d – Queensbury Tunnel. Detailed Report;
  - CARILLION Structures Asset Management. (2016). Queensbury Tunnel. Detailed Examination Report;
  - CARILLION. (2010). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION. (2011). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION. (2012). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION. (2013). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION. (2015). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION. (2017). Queensbury Tunnel. Tunnel Visual Examination Report;
  - CARILLION Structures Asset Management. (2017). Queensbury Tunnel. Detailed Examination Report;
  - CARILLION. (2012). Queensbury Tunnel 1. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2010). Queensbury Tunnel. Visual Shaft Examination Report;
  - CARILLION. (2013). Queensbury Tunnel Shaft No.1. Visual Shaft Examination Report;
  - CARILLION. (2014). Queensbury Tunnel. Shaft No.1 Visual Shaft Examination Report;
  - CARILLION. (2014). Queensbury Tunnel. Shaft No.1 Visual Shaft Examination Report;
  - CARILLION. (2015). Queensbury Tunnel. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2016). Queensbury Tunnel. Shaft No.1 Visual Shaft Examination Report;
  - CARILLION. (2017). Queensbury Tunnel. Shaft No.1 Visual Shaft Examination Report;
  - CARILLION. (2011). Queensbury Tunnel. Visual Shaft Examination Report;
  - CARILLION. (2016). Queensbury Tunnel. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2012). Queensbury Tunnel. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2012). Queensbury Tunnel. Visual Tunnel Shaft Examination Report;
  - CARILLION. (2013). Queensbury Tunnel. Shaft No.2 Visual Shaft Examination Report;
  - CARILLION. (2015). Queensbury Tunnel. Shaft No.2 Visual Shaft Examination Report;
  - CARILLION. (2016). Queensbury Tunnel. Shaft No.2 Visual Shaft Examination Report;
  - CARILLION. (2017). Queensbury Tunnel. Shaft No.2 Visual Shaft Examination Report;
  - CARILLION. (2016). Queensbury Tunnel. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2012). Queensbury Tunnel. Tunnel Air Shaft Detailed Examination Report;
  - CARILLION. (2013). Queensbury Tunnel. Shaft No.3 Visual Shaft Examination Report;
  - CARILLION. (2015). Queensbury Tunnel. Shaft No.3 Visual Shaft Examination Report;
  - CARILLION. (2016). Queensbury Tunnel. Shaft No.3 Visual Shaft Examination Report;
  - CARILLION. (2017). Queensbury Tunnel. Shaft No.3 Visual Shaft Examination Report;
  - NOSLEN ACCESS CO (1986). Queensbury Tunnel. Shaft No.4 Inspection Report;
  - CARILLION. (2006). Queensbury Tunnel. Shaft No.4 Visual Detailed Report;
  - CARILLION. (2009). Queensbury Tunnel. Shaft No.4 Visual Detailed Report;
  - CARILLION. (2012). Queensbury Tunnel. Shaft No.4 Detailed Examination Report;

- CARILLION. (2005). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2008). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2009). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2010). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2013). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2014). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2015). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2016). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2017). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2011). Queensbury Tunnel. Shaft No.4 Visual Examination Report;
- CARILLION. (2010). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2013). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2014). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2015). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2016). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2017). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2011). Queensbury Tunnel. Shaft No.5 Visual Examination Report;
- CARILLION. (2012). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2013). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2014). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2015). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2016). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2017). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2011). Queensbury Tunnel. Shaft No.6 Visual Examination Report;
- CARILLION. (2012). Queensbury Tunnel. Tunnel 7 Air Shaft Detailed Examination Report;
- CARILLION. (2010). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2011). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2013). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2014). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2015). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2016). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2017). Queensbury Tunnel. Shaft No.7 Visual Examination Report;
- CARILLION. (2015). Queensbury Tunnel. Tunnel 7 Air Shaft Detailed Examination Report;
- CARILLION. (2008). Queensbury Tunnel. Visual Tunnel Examination Report;

Appendix B Risk Assessment Review for QTOR

Generic Hazards

Item 1: Lack of systematic maintenance is also an issue.

Item 2: Note. High in-situ lining stresses determined from FE model based on several assumptions. Use of sfrc for strengthening is a tried and tested repair method.

Item 3: Infilling of the Strines cutting has exacerbated the deterioration of the tunnel. Agreed that a method of water management is needed, either through a PS of gravity sewer.

Item 4: Agreed. Rapid drawdown of water will lead to unstabilizing hydrostatic forces on the lining.

Item 5: The extent of fractured rock is unknown. It is also not known whether this has been addressed in the FE analysis.

Item 6: Pressure relief systems (holes) are an alternative method of relieving hydrostatic pressures on the tunnel (and shaft) linings rather than grouting of the rock mass. Fully sealing/grouting the rock mass around the tunnel (& shafts) will lead to a recharge of the water table and potential impacts on other third parties. Similarly to 5 above, it is not known whether hydrostatic loading has been applied to the tunnel lining analysed.

Item 7: Capping of shafts and infilling of the cutting has restricted airflows and will result in a more rapid deterioration than could otherwise have been anticipated. GI for the full overburden depth, at shaft locations, will be expensive. Monitoring strategy = agreed.

Item 8: SH 5 & 6. Agreed.

Item 9: Probability of ‘death’ needs to carry a high risk rating. Shaft failures will likely be rapid, catastrophic and difficult to predict.

Item 10: ‘Tunnel lining collapse’ should carry a higher risk rating, similar to ‘item 1’. Agreed GPR, cores and endoscopic cctv to be undertaken to determine extent of any voids/delamination of the brick/masonry lining.

Option 1

Item 1.1: Carries max risk ranking and would not be recommended.

Item 1.2: Carries the risk that uncontrolled collapses will occur. Risk ranking 25 as item 1 (not 12).

Item 1.3: Agreed. Pipe blockage will affect the surrounding hydrogeology. An assessment needs to be made of likely impacts.

Item 1.4: Infill <40m cover OK. Risk still remains at shafts. Higher risk ranking in these localised zones.

Option 2a

Item 2a.1: Likelihood of ‘death’ should carry the highest ranking. Approach OK.

Item 2a.2: Access = OK

Item 2a.3: Noted. As 1.3 above.

Item 2a.4: Infilling from the northern portal would be possible, though logistically more difficult.

Option 2b

Item 2b.1: As 2a.1

Item 2b.2: As 2a.2

Item 2b.3: Impacts on shafts remain. Tunnel and subsequent shaft collapse carries a higher risk ranking – possibility of death.

Item 2b.4: Comment as 2b.3

Options 2c & 2d

Item 2c.1: As 2a.1

Item 2c.2: As 2b.2

Item 2c.'5': As 2a.4

Option 3.1

Comments as in generic risks.

Option 3.2

Item 3.2.1 to 3.2.5 – danger of death carries the highest risk ranking. Comments as above

Option 4

Item 4.1: Agreed

Item 4.2: Inundation has not been mentioned in the infilling options. This will be more critical when infilling as access/egress will only be available from one portal. Death = higher ranking

Item 4.3: Death = higher risk. Comment agreed.

Item 4.4: This is a project risk, not H&S.

Item 4.5: Accident. Not noted for other options. Needs to be added. Death = higher ranking. Risk managed through safe systems of work.

Item 4.6: Noted. Project risk.

Appendix C AECOM High Level Desktop Cost Plan

The high level desktop cost plan for **Option 1** with is given in Table C1.

Table C1. Option 1 High Level Desktop Cost Plan

Item	High Level Cost
Civil Engineering Works	
Tunnel Works	
Infilling	£216,000
Sub-Total	**£216,000**
General Items	
General Items Allowance	£300,000
Facilitating works	£44,000
Accommodation works	£33,000
Sub-Total	**£377,000**
Total (Civil Engineering Works)	**£593,000**
Project / Design Team Fees	
Detailed Design Allowance	£88,950
Total (Project / Design Team Fees)	**£88,950**
Development / Project Costs	
Development / Project Costs Allowance	£275,000
Total (Development / Project Costs)	**£275,000**
Risk / Optimism Bias	
Risk Allowance	£382,780
Optimism Bias Allowance	Excluded
Total (Risk / Optimism Bias)	**£383,780**
Inflation	
Inflation Allowance	Excluded
Total (Inflation)	**Excluded**
VAT	
VAT Allowance	Excluded
Total (VAT)	**Excluded**
COST LIMIT (OPTION 1)	**£1,339,730**

The high level desktop cost plan for **Option 3 shaft infilling only** is given in Table C2.

Table C2. Option 3 (shaft infilling) High Level Desktop Cost Plan

Item	High Level Cost
Civil Engineering Works	
Shaft Works	
Infilling	£583,200
Sub-Total	**£583,200**
General Items	
General Items Allowance	£175,155
Facilitating works	£55,000
Accommodation works	£49,500
Sub-Total	**£584,500**
Total (Civil Engineering Works)	**£1,167,700**
Project / Design Team Fees	
Detailed Design Allowance	£175,155
Total (Project / Design Team Fees)	**£175,155**
Development / Project Costs	
Development / Project Costs Allowance	£275,000
Total (Development / Project Costs)	**£275,000**
Risk / Optimism Bias	
Risk Allowance	£647,142
Optimism Bias Allowance	Excluded
Total (Risk / Optimism Bias)	**£647,142**
Inflation	
Inflation Allowance	Excluded
Total (Inflation)	**Excluded**
VAT	
VAT Allowance	Excluded
Total (VAT)	**Excluded**
COST LIMIT (OPTION 3)	**£2,264,997**

The high level desktop cost plan for **Option 2b** with **shaft infilling** is given in Table C3.

Table C3. Option 2b & shaft infilling (Option 3) High Level Desktop Cost Plan

Item	High Level Cost
Civil Engineering Works	
Tunnel Works	
Infilling	£3,402,000
Sub-Total	**£3,402,400**
Shaft Works	
Infilling	£583,200
Sub-Total	**£583,200**
General Items	
General Items Allowance	£920,000
Facilitating works	£82,500
Accommodation works	£49,500
Sub-Total	**£1,052,000**
Total (Civil Engineering Works)	**£5,037,200**
Project / Design Team Fees	
Detailed Design Allowance	£755,580
Total (Project / Design Team Fees)	**£755,580**
Development / Project Costs	
Development / Project Costs Allowance	£275,000
Total (Development / Project Costs)	**£275,000**
Risk / Optimism Bias	
Risk Allowance	£2,427,112
Optimism Bias Allowance	Excluded
Total (Risk / Optimism Bias)	**£2,427,112**
Inflation	
Inflation Allowance	Excluded
Total (Inflation)	**Excluded**
VAT	
VAT Allowance	Excluded
Total (VAT)	**Excluded**
COST LIMIT (OPTION 2b +3)	**£8,494,892**

The high level desktop cost plan for **Option 2a** with **shaft infilling** is given in Table C4.

Table C4. Option 2a & shaft infilling (Option 3) High Level Desktop Cost Plan

Item	High Level Cost
Civil Engineering Works	
Tunnel Works	
Infilling	£12,452,400
Sub-Total	**£12,452,400**
Shaft Works	
Infilling	£330,400
Sub-Total	**£330,400**
General Items	
General Items Allowance	£1,040,000
Facilitating works	£82,500
Accommodation works	£49,500
Sub-Total	**£1,177,500**
Total (Civil Engineering Works)	**£13,960,300**
Project / Design Team Fees	
Detailed Design Allowance	£2,094,045
Total (Project / Design Team Fees)	**£2,094,045**
Development / Project Costs	
Development / Project Costs Allowance	£275,000
Total (Development / Project Costs)	**£275,000**
Risk / Optimism Bias	
Risk Allowance	£6,531,738
Optimism Bias Allowance	Excluded
Total (Risk / Optimism Bias)	**£6,531,738**
Inflation	
Inflation Allowance	Excluded
Total (Inflation)	**Excluded**
VAT	
VAT Allowance	Excluded
Total (VAT)	**Excluded**
COST LIMIT (OPTION 2a +3)	**£22,861,083**

The high level desktop cost plan for **Option 4a** is given in Table C5.

Table C5. Option 4a High Level Desktop Cost Plan

Item	High Level Cost
Civil Engineering Works	
Tunnel Repair Works	
Repointing	£78,000
Brickwork & Stonework Repair and Replacement	£47,450
SCL Patching and Dowels	£104,550
SCL Full Arch Repair and Rock Bolts	£817,950
Repair of Collapsed Sections	£343,380
Grouting Voids Behind the Lining	£119,340
Sub-Total	**£1,510,670**
Shaft Repair Works	
Repointing	£92,630
Sub-Total	**£92,630**
General Items	
General Items Allowance	£1,760,000
Facilitating works	£82,500
Accommodation works	£49,500
Sub-Total	**£1,892,000**
Total (Civil Engineering Works)	**£3,495,291**
Project / Design Team Fees	
Detailed Design Allowance	£524,293
Total (Project / Design Team Fees)	**£524,293**
Development / Project Costs	
Development / Project Costs Allowance	£275,000
Total (Development / Project Costs)	**£275,000**
Risk / Optimism Bias	
Risk Allowance	£1,717,834
Optimism Bias Allowance	Excluded
Total (Risk / Optimism Bias)	**£1,717,834**
Inflation	
Inflation Allowance	Excluded
Total (Inflation)	**Excluded**
VAT	
VAT Allowance	Excluded
Total (VAT)	**Excluded**
COST LIMIT (OPTION 4a)	**£6,012,420**