Queensbury Tunnel
Cost Comparisons

FEBRUARY 2017

Queensbury
TUNNEL SOCIETY

Contents & Sources

Sources

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

Queensbury Tunnel: Asset or Liability?
Queensbury Tunnel Society (October2016)

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

Lerwick to Bressay: STAG 2 report - Fixed Tunnel Link
Zettrans/Donaldson Associates (May 2008)

Shetland Inter-Island Transport Study - Fixed Link Working Paper – "Bottom-Up" Cost Estimates
Shetland Island Council/Donaldson Associates (August 2016)

Stromeferry Review of Tunnel Options
Highland Council/URS (February 2014)

High Speed Two: A Guide to Tunnelling Costs
HS2 (2015)

Combe Down Tunnel Inspection Report
Bath & North East Somerset Council/Mott MacDonald (August 2009)

1 Background

The Historical Railways Estate (HRE)(part of Highways England) examines and maintains around 3,200 disused railway structures on behalf of the Department for Transport (DfT). In 2015, HRE commissioned Jacobs, its consulting engineers, to develop a high-level report into abandonment and repair options for Queensbury Tunnel in West Yorkshire which has the highest risk profile of any structure for which it is currently responsible. This status reflects the tunnel's locally-poor condition, access issues and the close proximity of dwellings to four of its construction shafts.

A draft version of the report was submitted to HRE in February 2016. It considered a number of possible approaches to abandonment, with costs ranging from £995,855 to £21.2 million. The cost of repair was stated as £35.38 million.

A campaign group, now operating under the banner of the Queensbury Tunnel Society (QTS), has been making a case for the tunnel to be repaired so that it can be incorporated into a network of local cycle paths when funding allows. However HRE presented the findings of the draft report to Robert Goodwill MP, then Minister of State at the Department for Transport, who decided - on the basis of Jacobs' costing - that repair was not affordable. As a result, HRE is now progressing with its plans for abandonment.

In October 2016, QTS published its own report into the condition of the tunnel and put forward a remediation scheme costed at £2.81 million. Some analysis was also included of Jacobs' draft report, calling into question a number of statements and conclusions for which no supporting evidence was provided, notably that:

- "The shaft linings are connected into the surrounding strata"
  If correct, this would have the effect of reducing the likelihood of a future shaft collapse and, in part, justify the withdrawal of structural concrete plugs beneath the shafts which had been specified in Jacobs' 2009 *Feasibility Study of Future Asset Management*, potentially saving around £750,000 in abandonment costs. However it is clear from studies of Network Rail's permanent shafts (of which it has 811) that *structural* connections are **almost never** provided between a shaft's lining and the ground it is sunk through.

- "Most of the northern half of [Queensbury] tunnel" was driven using a "tunnel boring machine"
  This is entirely incorrect and reflects a misunderstanding on Jacobs' part about the type and role of a machine used to increase the rate of progress at which one of the headings (pilot tunnels) was driven. In the context of a partial infilling option being selected for abandonment, the error had the potential to influence deliberations around which sections to infill. More broadly, the nature of the error is so basic that it tends to colour any judgement of the draft report as a whole.

As a result of these concerns and others, QTS has made clear its view that HRE should have rejected Jacobs' draft report and it has asked the Department for Transport to prevent any further abandonment work being carried out until a full and robust review of all possible future options for the tunnel has been completed. The DfT has not responded to that request.

Despite the doubts over the veracity of Jacobs' report, it is clear that the £35.38 million repair figure remains a significant obstacle in the minds of some stakeholders. HRE insists that any reuse of Queensbury Tunnel for publically-beneficial purposes must involve its transfer to another statutory body. However any such body would be understandably reluctant to take on the structure if the high level of associated liabilities indicated by Jacobs is correct.

The purpose of this report is to examine the various repair costings developed for Queensbury Tunnel and contextualise them using unit prices associated with other tunnelling projects.

Cost comparisons between tunnel projects involving different challenges in different ground conditions using different methodologies can only have limited value. However, when unit prices are examined, they can offer useful insight.

In the past eight years, Jacobs has produced two studies into future asset management options for Queensbury Tunnel. The first, commissioned by British Railways Board (Residuary) in 2009, included a cost for lining repairs of £1.2 million. Its 2016 study for the Historical Railways Estate put forward a repair costing of £35.38 million. This represents an increase of 2,850%.

The 2009 proposal had the intention of effectively 'resetting' the tunnel's condition from an ongoing maintenance perspective and facilitating safe workforce access for annual examinations. The 2016 figure was developed in the context of the tunnel's possible reuse by members of the public. On neither occasion do the respective reports offer any detail as to the extent of the intended lining works and it is possible that the 2009 scheme would have taken a very 'minimalist' approach. However it is also stated that the options and costs set out in 2016 result from a high-level desktop assessment. The £35.38 million figure is described as an "order of magnitude estimate" with an accuracy level of ±40% (£21.23 million to £49.53 million).

It is clear that the condition of Queensbury Tunnel deteriorated in the seven years between Jacobs' two reports. Notably, partial collapses occurred in 2013 and 2014, and severe defects were identified at four other locations. Deep spalling and panels of missing brickwork are indicators that more failures are likely in the future (see photo above).

The report published by the Queensbury Tunnel Society (QTS) in October 2016 identified a method of repair for each recorded defect, although it did not provide a detailed breakdown of costs. The specification was developed by an engineer specialising in tunnel reconstruction whilst SES Group, a contractor holding a civils framework contract with Network Rail, assisted in developing a 44-week programme of works and the associated remediation figure of £2.81 million.

© SES GROUP

Using a design developed during its remediation of a large collapse in Liverpool's Dingle Tunnel (see photo above), SES Group was able to cost repair of the two collapses in Queensbury Tunnel at around £275,000. This figure aligns closely with that of the Dingle project when adjustments are made for the quantities involved. Beyond this, an engineering consultant and two contractors have separately estimated that a secondary spray concrete lining could be installed through the entire length of Queensbury Tunnel (2,287 metres) for £5-10 million, depending on its thickness (150-300mm).

According to the QTS report, around 38% of the tunnel exhibits very few defects and a further 51% has a significant number of defects, but these are minor in nature. 11% is in poor condition, with major defects recorded. QTS' average repair cost per metre is £1,229, compared with Jacobs' 2016 figure of £15,470 per metre, 1,159% higher.

In 2015, High Speed Two published *A Guide to Tunnelling Costs* covering the various elements of bored/mechanised tunnel construction involved in the HS2 project. It reflects baseline estimates from the second quarter of 2011, prepared in support of the 2013 Phase 1 (London-West Midlands) hybrid Bill submission. The Guide provides an indicative cost of £22,000/£25,000[1] per **route** metre (depending on the type of tunnel boring machine (TBM) used) for driving and lining **twin** bores, each 8.8 metres internal diameter. Jacobs' £15,470 per metre cost for repairing Queensbury Tunnel is therefore 29%/24% higher than HS2's figure of £11,000/£12,500 per metre for constructing **one** new bore.

1 This figure excludes design fees, the disposal of arisings, workforce time/management and the purchase of the TBM.

Between 2008-2016, options were examined for several new road tunnels in Scotland, five linking islands in the Shetlands and two for a proposed diversion of the A890 Stromeferry bypass, north-east of the Kyle of Lochlash. Detailed costings were developed for three of the options.

The tunnels involved 'drill and blast' construction techniques but each was different in terms of profile, cross section, lining thickness, provision of a structural invert and accommodation for walkers/cyclists. Despite this, the unit prices for excavation and primary support only differ by 17%, falling within a range of £175-211/m^3 (using a UK contractor working to UK standards).

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One of the many 'drill and blast' road tunnels in Norway where the engineering approach and regulatory culture results in considerably lower construction costs than in the UK (see Section 3.4).

Taking a figure of £200/m^3 (which assumes a 500mm thick lining/no structural invert), it can be estimated that a new Queensbury Tunnel - identical in size to the existing one (2,287m long, 46m^2 cross-sectional area (56m^2 without lining)) - could be excavated and lined for around £25.61 million, 28% less than Jacobs' estimate for repairing the existing tunnel[2].

Tunnel engineering specialists advise that the more favourable ground conditions at Queensbury would likely provide improved excavation rates over those through the hard rock at Stromeferry, resulting in a lower unit cost. Hence, £25.61 million is likely to represent an upper-bound figure.

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2 This figure excludes drainage, M&E (mechanical and electrical), site setup/management, surfacing and design costs, as well as excavation of the approach cuttings and the disposal of arisings.

Key points

Without insight into the specific design approach taken by Jacobs (which has been requested but not received at the time of publication), it is not possible to make unequivocal statements about the legitimacy of its 2016 repair costing for Queensbury Tunnel. However it can be stated that:

- £35.38 million represents a 2,850% increase on the lining repair cost put forward by the same consultant in 2009
- Jacobs' costing suggests that £15,470 of repairs are required per linear metre of Queensbury Tunnel (despite 89% of it being in 'fair' condition); this is 24%/29% higher than HS2's indicative per-metre cost for driving and lining a new single bore
- a secondary spray concrete lining could be provided through the entire length of Queensbury Tunnel for between £5-10 million, depending on its thickness (150-300mm)
- a new Queensbury Tunnel of the same dimensions as the existing one could be excavated and lined for an indicative cost of £25.61 million.

An overview of the projects examined for this report are summarised below. Further information about each one is provided in Section 3.

Tunnel/project	Type	Source	Date	X-sectional area	Excavation cost/m³	Cost/lin m	Length	Project cost	See section
Queensbury Tunnel (disused rail)	Repair	BRB(R)/Jacobs	2009	46m²		£525	2,287m	[A] £1.2M	3.1
Queensbury Tunnel (disused rail)	Repair	QTS engineering team	2016	46m²		£1,229	2,287m	£2.81M	3.2
Queensbury Tunnel (disused rail)	Repair	HRE/Jacobs	2016	46m²		£15,470	2,287m	£35.38M	3.3
Bressay-Lerwick link (sub-sea road tunnel)	New (drill & blast)	Shetland Islands Council/ Donaldson Associates (Norwegian contractor)	2016	70m²	£130	£9,100 [B] £7,280	1,200m	£10.9M	3.4
		Shetland Islands Council/ Donaldson Associates (UK contractor/100mm lining)	2016	70m²	£175	£12,250 [B] £9,800	1,200m	£14.7M	
Stromeferry link - On-line route (road tunnel)	New (drill & blast)	Highland Council/URS (Norwegian contractor)	2014	60m²	£185	£11,100 [B] £10,360	1,500m	£16.65M	3.5
		Highland Council/URS (UK contractor/500mm lining)	2014	130m²	£200	£26,000 [B] £11,200	1,500m	£39.09M	
Stromeferry link - North Shore route (sub-sea road tunnel)	New (drill & blast)	Highland Council/URS (Norwegian contractor)	2014	60m²	£185	£11,100 [B] £10,360	2,700m	£29.97M	
		Highland Council/URS (UK contractor/750mm lining)	2014	150m²	£211	£31,650 [B] £11,816	2,550m	£80.71M	
HS2 (rail tunnels)	New (TBM-bored)	HS2	[C] 2015	61m²		[D] £11,000/ £12,500			3.6
Queensbury Tunnel	New (drill & blast)	Stromeferry/On-line route (UK contractor/500mm lining)		[E] 56m²	£200	£11,200	2,287m	£25.61M	3.7

A this figure is a sub-cost of the overall £1.975 million project cost, accounting specifically for lining repairs

B cost per linear metre assuming same cross-sectional area as Queensbury Tunnel (56m² bored face)

C uses baseline cost estimates established in the second quarter of 2011

D based on the cost for a twin-bore tunnel and depending on the type of TBM (Slurry/EPB) used

E to deliver a tunnel with a 46m² cross-sectional area, 56m³ of material must be excavated per linear metre to account for the lining (assumes 500mm lining, no structural invert, 7.9m internal width at invert level)

3.1 Queensbury Tunnel repair (BRB(R)/Jacobs, 2009)

In 2009, British Railways Board (Residuary)[3] commissioned Jacobs to undertake a *Feasibility Study of Future Asset Management* options for Queensbury Tunnel.

The tunnel's condition was recorded as being "fair to poor", noting "large sections of brickwork loss. These defects are being exacerbated by continual moisture ingress, perishing mortar and freeze thaw attack. Sections of brickwork appear to be failing in large areas and falling in sheets with other more localised defects exposing the bored rock face."

The report considered three broad approaches to future management of the tunnel:

- securing all access points, leaving the tunnel in its existing condition and thereafter allowing it to fail (referred to as the "do nothing" option)
- continuing a regime of annual examinations and associated maintenance which would require the completion of lining repairs and the provision of permanent pumping facilities[4]
- infilling of the tunnel at both entrances for 150m and its seven shafts.

Jacobs recommended the third option (abandonment) at an estimated cost of £5.125 million.

In relation to the second option, the reports stated that "onerous traditional masonry and brickwork repair schemes" would be required to permit safe entry into the tunnel for examination purposes and suggested that "if this option is chosen, a spray applied concrete repair [should] be seriously considered" as this is more cost effective for large areas of repair and has the advantage of being applied remotely using robotic plant.

The overall remedial works - including the management of the floodwaters at the southern end of the tunnel and forced ventilation - was costed at £1,975,000. This was based on a 15-week programme of works and included an allocation of £1.2 million for "repairs to defective lining".

Repair cost: £1.2 million   Length: 2,287 metres   **Average cost per linear metre: £525**

3 British Railways Board (Residuary), BRB(R), was incorporated in 2001 as a wholly-owned subsidiary of the Strategic Rail Authority. Part of its role was to examine/maintain those non-operational structures that had not already been transferred into private ownership. BRB(R) was abolished on 30th September 2013, since which time these functions have been carried out by Highways Agency/Highways England's Historical Railways Estate.

4 A combination of the tunnel's 1:100 gradient (falling to the south), high levels of water ingress and a substantially infilled southern approach cutting typically results in ~35 feet of floodwater accumulating at the south portal, extending into the tunnel by ~1,167 yards. However the flooding is currently being managed through the installation of long-term pumping equipment.

3.2 Queensbury Tunnel repair (QTS engineering team, 2016)

In the summer of 2016, the Queensbury Tunnel Society asked a specialist engineer to inspect the tunnel on its behalf, accompanied by representatives from a civil engineering contractor. Thereafter, a report was produced which provided an overview of the tunnel's condition and a remediation plan, including a programme of works and associated costing.

The report stated that "whilst some parts [of the tunnel] 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."

It went on, "Between tabs[5] 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."

A visual representation of the tunnel's condition is provided below:

The overall remedial works were costed at £2,814,425, based on a 44-week programme. Included within this figure were:

- principal examinations of the tunnel and shafts, and preparation of condition drawings
- investigations (brickwork coring, finite element analysis of collapsed sections, mining report)
- 20% project contingency.

This represented an increase of 135% over Jacobs' 2009 figure, due in part to:

- a deterioration in the tunnel's condition over the intervening seven years[6]
- the effect of inflation on materials and labour costs, adding in the region of £135,000
- a longer delivery time (44 weeks against 15 weeks).

Repair cost: £2.81 million Length: 2,287 metres **Average cost per linear metre: £1,229**

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5 Queensbury 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 Partial collapses occurred in 2013 and 2014, the repair cost of which is identified as ~£275,000.

3.3 Queensbury Tunnel repair (HRE/Jacobs, 2016)

In 2015, the Historical Railways Estate commissioned Jacobs to undertake a high-level assessment of options for the closure or repair of Queensbury Tunnel.

The report recorded the tunnel's condition as being fair to poor, stating that the lining is "currently unstable and in the process of progressive failure due to overstressing of the brickwork. It is inevitable that further collapses will occur in the central and southern sections unless major works are carried out to repair and strengthen the lining."

The report considered three options for the tunnel:

- securing the portals and allowing the tunnel to collapse of its own accord
- partial or complete infilling of the tunnel and shafts
- repair of the tunnel.

The latter option was developed in response to the public campaign for the repair/reuse of Queensbury Tunnel and a site visit by Robert Goodwill, then Minister of State at the Department for Transport, who asked for an estimate of likely costs.

In relation to repair for public use, the reports stated that "all the risks associated with the tunnel, shafts and mine workings [would need] to be either fully mitigated or reduced to within acceptable levels. It is anticipated that the tunnel would require:

- Repointing of sections exhibiting minimal defects.
- Reconstruction and strengthening of the lining in those sections that have either collapsed or are in a severe state of deterioration. The lining would initially be strengthened by the application of steel fibre sprayed concrete and would then be injection grouted to deal with significant voids. The lining would be restored to its original thickness, or thicker, to counteract the high stresses resulting from the depth of the tunnel.
- Complete reconstruction and relining of the section of tunnel that has collapsed. This would require the procurement and use of a shield to support the strata while the brickwork lining is removed and replaced with a precast segmental concrete lining. The voids behind the segments would then be grouted.
- A minimum of two shafts would require reopening to ventilate the tunnel[7]. The shafts would require those repairs necessary to make them safe and mitigate the risk from falling masonry.

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7 Specialist tunnel engineers disagree with this statement, asserting that Queensbury Tunnel will naturally ventilate (due to the difference in pressure/temperature between the two ends of the tunnel) if/when the floodwater is removed, effective water management arrangements are installed and the collapses are repaired. It should be noted that Combe Down Tunnel on Bath's Two Tunnels Greenway is more than one mile in length, has a smaller cross-sectional area than Queensbury Tunnel (due to it being built for one track) and has never had ventilation shafts.

- The existing or a new drainage system would be required to remove the water entering the tunnel portals.
- The tunnel lining and shafts would require sealing and water management to minimise future degradation.
- Improved access to the southern portal, including access for emergency services.
- The installation of a roadway, lighting and emergency communication system within the tunnel."

In addition, the report stated that there would be a need to carry out:

- principal examinations of the tunnel and shafts
- site investigations (coring, full ground investigations)
- preliminary repairs to make the tunnel safe for construction staff
- investigations to confirm the extent of voids around No.3 Shaft and identify whether others exist elsewhere in the tunnel.

The overall remedial works were costed at £35,381,000, based on a 104-week programme of works. This figure was described as "an order of magnitude estimate", with an accuracy level of ±40%. It is not clear whether all items in the bulleted lists above are included, however the items highlighted in green are thought to be *excluded*.

The figure of £35.38 million represented an increase of 2,848% over the repair figure from 2009, produced by the same engineering consultant, and is 1,157% more than the remediation cost put forward by the Queensbury Tunnel Society in 2016.

Repair cost: £35.4 million   Length: 2,287 metres   **Average cost per linear metre: £15,470**

3.4 Bressay-Lerwick link (Shetland Islands Council/Donaldson Associates, 2016)

In December 2014, stakeholders formed a partnership to jointly consider ferry replacement issues in Orkney and Shetland, gathering evidence to support future funding and investment decisions in line with Transport Scotland's established methodologies.

The Shetland Inter-Island Transport Study (SIITS) was developed to meet these requirements and, as part of Phase 1, Donaldson Associates Limited (DAL) was commissioned to review all previous tunnel studies covering links between the Mainland-Bressay/Yell/Whalsay, as well as Unst-Yell.

As part of this work, one UK and one Norwegian contractor agreed to provide new 'bottom-up' cost estimates for the Bressay tunnel based on a design produced by DAL in 2008 which remains compliant with UK standards.

In spring 2010, a series of meetings were held to seek an understanding as to why UK and Norwegian bored-tunnel construction costs differed so widely. It was found that:

- Norwegian tunnelling projects benefit from a highly-skilled, productive, efficient and experienced workforce, using dedicated, modern equipment
- 'real time' design decisions are taken 'at the face' to ensure quick and efficient progress
- competition is high whilst profit margins are low (2-3%)
- secondary linings are rarely provided, instead relying on spray concrete over rock bolts with a waterproof membrane to create a water seal
- no *separate* provision is made for pedestrians or cyclists, resulting in a smaller cross section and lower excavation requirement
- the contractual and regulatory culture is less onerous
- the UK applies taxes to excavated rock if taken off site, sold as aggregate or put in landfill.

The Bressay tunnel would be 1,200 metres in length with a cross-sectional area of approximately 70m^2 and constructed using mechanised drill and blast techniques. In view of the anticipated rock mass strength and the low in-situ stress, a simple D-shaped profile was considered appropriate, providing a carriageway width of 6.5 metres and a clear height of 5.3 metres, together with a footpath/cycleway 2.0 metres wide plus additional carriageway width of 1.05 metres to be used as a hard shoulder.

To grout ahead, excavate the tunnel and support it with a primary lining of 100mm fibre-reinforced spray concrete and rock bolts at 2m centres, the following costs were established:

UK CONTRACTOR

Cross-sectional area: 70m^2 Excavation cost per cubic metre: £175
Average cost per linear metre: £12,250 Length: 1,200 metres Cost: £14,700,000

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £9,800
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (37% more)

NORWEGIAN CONTRACTOR

Cross-sectional area: 70m^2 Excavation cost per cubic metre: £130
Average cost per linear metre: £9,100 Length: 1,200 metres Cost: £10,920,000

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £7,280
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (53% more)

These costs excluded any secondary lining, drainage, M&E, excavation of the approach cuttings and road surfacing, as well as design and client costs.

3.5 Stromeferry link - North Shore/On-line routes (Highland Council/URS, 2014)

In 2013, URS was asked to provide tunnelling advice relating to the proposed diversion of the A890 Stromeferry bypass which has historically suffered from rock/other debris landing on the carriageway, necessitating repair work and road closures. Tunnelling formed a key part of two identified options, namely a 'North Shore route' - passing beneath Loch Carron at Strome Narrows - and an 'On-line route' taking the road further inland. Both options were subsequently rejected.

Completed in 2014, URS' report reviewed design guidance and regulations relevant to UK highway tunnels and provided budget cost estimates for construction work based on both UK and Norwegian practices.

It was envisaged that the tunnels would be horseshoe in profile and excavated using drill and blast techniques at a rate of 2 linear metres per day. The cross-sectional areas were 130m^2 for the 'On-line' tunnel and 150m^2 for the sub-sea tunnel, recognising that the latter could require a waterproof barrier and thicker lining to resist anticipated water pressures.

The design specified two compartments separated by a full-height concrete wall with fire doors, the larger one accommodating two lanes of traffic. The carriageway width was 6.0 metres, flanked on both sides by hard strips and a single footway for emergency use, sufficient to allow traffic to pass a stranded vehicle. The total headroom was 5.4 metres. The smaller compartment housed a pedestrian path/escape route.

To excavate the sub-sea tunnel, support it with a 750mm concrete lining and rock bolts, and provide a structural invert, the following costs were established:

UK CONTRACTOR

Cross-sectional area: 150m^2 Excavation cost per cubic metre: £211
Average cost per linear metre: £31,650   Length: 2,550 metres   Cost: £80,707,500

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £11,816
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (24% more)

NORWEGIAN CONTRACTOR

Cross-sectional area: 60m^2 Excavation cost per cubic metre: £185
Average cost per linear metre: £11,100   Length: 2,700 metres   Cost: £29,970,000

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £10,360
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (33% more)

To grout ahead, excavate the 'On-line' tunnel and support it with a 500mm concrete lining and rock bolts (no structural invert), the following costs were established:

UK CONTRACTOR

Cross-sectional area: 130m^2 Excavation cost per cubic metre: £200
Average cost per linear metre: £26,000 Length: 1,500 metres Cost: £39,000,000

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £11,200
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (28% more)

NORWEGIAN CONTRACTOR

Cross-sectional area: 60m^2 Excavation cost per cubic metre: £185
Average cost per linear metre: £11,100 Length: 1,500 metres Cost: £16,650,000

Cost per linear metre if same cross-sectional area as Queensbury Tunnel (56m^2 bored face): £10,360
Jacobs' 2016 Queensbury Tunnel repair cost per linear metre: £15,470 (33% more)

These costs excluded any drainage, M&E, excavation of the approach cuttings and road surfacing, as well as design and client costs.

3.6 HS2 tunnels (HS2, 2015)

In 2015, HS2 published a *Guide to Tunnelling Costs* in response to a request from the House of Commons Select Committee for the High Speed 2 (London-West Midlands) hybrid Bill. The guide provided a general description of the principal cost elements for bored tunnels constructed using either an Earth Pressure Balance (EPB) machine (likely to be used in London and Birmingham) or a slurry machine (likely to be used through the Chilterns).

It noted that the indicative costs generated using the guide sit within a range of potential outcomes. They were based on cost estimates prepared in support of the *Estimate of Expense* that formed part of the HS2 Phase 1 hybrid Bill submission in November 2013 and reflected costs determined at the project base date in the second quarter of 2011. It is also made clear that HS2's designs - and the associated cost estimates - were at an early stage of development and therefore relied on many assumptions. The actual costs for specific tunnels will ultimately depend on variables such as length, topography, ground conditions and logistics.

Each of HS2's bored tunnels will comprise two bores, circular in profile and with an internal diameter of 8.8 metres. These will be driven approximately 20 metres apart (centre line to centre line) using tunnel boring machines (TBM) and lined with 400mm-thick precast concrete segments. The bores will be connected together by cross passages every 380 metres and ventilation shafts every 3 kilometres.

A generic unit price for tunnel construction was established covering:

- the excavation of material from the face of the bores and its removal
- the cost of the precast concrete lining segments, their transportation to site and installation
- cleaning and stripping out temporary construction equipment upon completion of the bores
- installation of a concrete base, drainage, an evacuation walkway and a maintenance walkway
- the construction of cross passages linking the two bores.

On this basis, the rate for tunnel construction was established to be:

- £25,000 per route metre of **twin tunnel** using a slurry machine
- £22,000 per route metre of **twin tunnel** using an EPB machine.

Therefore, for a **single** bore of 8.8 metres in diameter, the rate can be estimated at:

£11,000 per linear metre (EPB machine)/£12,500 per linear metre (slurry machine)

These indicative costs excluded:

- fixed cost elements (i.e. the cost of the machines - £45M for a slurry machine/£35M for an EPB machine)
- time-related elements (labour costs for management, supervision and general site-based labour, hired plant and equipment servicing the site, security, cleaning and maintenance costs - £1.1M per week)
- disposal of excavated materials (commercial tip - £4,500 per route metre/sustainable placement - £3,000 per route metre)
- tunnel portals (£20-65M, depending on topography)
- ventilation shafts with cross section on plan of 45m x 25m, located every 3km (£10-30M each, depending on location)
- mechanical and electrical systems (M&E)(£4,000 per route metre).

3.7 A new Queensbury Tunnel

Using the indicative unit prices established in Sections 3.4 and 3.5, a cost can be estimated for excavating and lining a new Queensbury Tunnel using drill and blast techniques, and of dimensions identical to the existing one. As well as taking account of its intended use, the design for any such structure would be largely dependent on the local geology which, according to the British Geological Survey (1 :50,000 scale Solid & Drift Sheet 77, Huddersfield), are the Lower Coal Measures (Westphalian A Group), comprising a sequence of interbedded strata of the Elland Flags and various coal seams.

In relation to the On-line route for the Stromeferry link, URS stated that:

- published geological data shows that the rock [through which the tunnel would be driven] is primarily gneissic and schistose[8]
- it is likely that advance grouting would be required to prevent excessive water ingress into the tunnel during driving and operation
- although the majority of the alignment will be constructed in competent rock, there will be significant areas of faulting and fractured rock mass
- it is likely that a structural invert would not be required unless the rock mass was heavily weathered or fragmented
- a drainage layer would be incorporated behind the internal lining to take seepage water from the rock mass to drains at the base of each sidewall
- rock support would be installed, as required, as the tunnel advances, (rock bolts, sprayed concrete, steel mesh/fibre reinforcement etc), followed by the permanent structural lining.

Of the three schemes examined in Sections 3.4 and 3.5, it is considered that the conditions outlined above - and their implications in terms of design and construction - would most closely align with those anticipated at Queensbury. This means that the following costing for a new tunnel assumes the structure would have:

- a primary lining 500mm in thickness
- no structural invert
- a cross-sectional area of 56m^2 (bored face) to deliver an internal cross-sectional area of 46m^2 (identical to the existing tunnel to invert level)
- a width of 7.9 metres (identical to the existing tunnel)
- a formation layer 0.6 metres deep, providing a height of 6.4 metres from floor to crown.

8 A schistosity plane often forms a discontinuity that may have a large influence on the mechanical behaviour of rock masses in tunnel construction.

The cost of a tunnel to this general specification can be estimated as follows:

UK CONTRACTOR

Cross-sectional area: 56m² Excavation cost per cubic metre: £200
Average cost per linear metre: £11,200 Length: 2,287 metres Cost: £25,614,400

NORWEGIAN CONTRACTOR

Cross-sectional area: 56m² Excavation cost per cubic metre: £185
Average cost per linear metre: £10,360 Length: 2,287 metres Cost: £23,693,320

Taking the UK figure, this would represent a saving of 28% over Jacobs' 2016 repair cost for Queensbury Tunnel of £35.38 million. However it must be noted that this figure excludes drainage, M&E (mechanical and electrical), site setup/management, surfacing and design costs, as well as excavation of the approach cuttings and the disposal of arisings.

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A multi-boom machine drilling holes in a tunnel's working face.

Tunnel engineering specialists advise that the more favourable ground conditions at Queensbury would likely provide improved excavation rates over those through the hard rock at Stromeferry, resulting in a lower unit cost. Hence, £25.6 million is likely to represent an upper-bound figure.

It should also be recognised that if a new tunnel was to be driven for the purposes of accommodating a cycle path, it is likely that a smaller cross-sectional area would be specified[9], thus further reducing the cost.

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9 Devonshire Tunnel on the Two Tunnels Greenway in Bath has a typical cross-sectional area of 19m². Allowing for a 500mm lining but no structural invert, an excavation requirement of 25m³ per linear metre would be required. This would reduce the cost to £11.4 million (using a UK contractor working to UK standards).

In February 2005, local campaigners joined together to promote the idea of a new foot and cycle path into Bath from the south, occupying the former trackbed of the Somerset & Dorset Railway and passing through Combe Down and Devonshire tunnels. The route cost around £4.2 million to build and was opened as the Two Tunnels Greenway in April 2013. In its first year, it was used by more than 250,000 people.

At 1,672 metres in length, Combe Down Tunnel was identified from the outset as the key honeypot attraction. Driven mostly through sandstone with oolitic limestone forming the roof, the tunnel was largely unlined when the railway opened in 1874. Major repair work was required following a collapse that blocked the tunnel four years later. Subsequently, discrete collars of brickwork were inserted as part of the ongoing maintenance regime, together with longer sections through the curves at both ends.

Hundreds of members of the public gathered at the south portal of Combe Down Tunnel in June 2009 when Wessex Water and the Two Tunnels Group arranged an open day, offering the opportunity to walk through the tunnel in its 'disused' state.

Despite being disused since 1966, it was generally accepted that the tunnel was in exceptionally good condition. Wessex Water, its then owner, allowed several hundred adults, children and dogs to walk through the tunnel as part of an open day in June 2009, organised by the campaigning and community-based Two Tunnels Group to highlight its cause. The only stipulation was that some form of protective headgear should be worn.

If the Two Tunnels project was to go ahead, issues surrounding the future ownership of Combe Down Tunnel would have to be addressed. To fully understand the tunnel's condition and its associated liabilities, Bath & North East Somerset (BANES) Council, the local authority, commissioned Mott MacDonald to undertake an inspection.

Completed in August 2009, the resulting report states that "The tunnel has been in place for over 130 years and was found to be in a stable condition with no evidence of any recent collapse, despite having received little or no maintenance for many years. Although the aspirations of opening the tunnel for use as a public cycleway are entirely achievable, further investigation and monitoring, together with the development of remedial measures will be required in order to mitigate risks to the tunnel's long term stability and to the health and safety of the general public when it becomes operational."

The south portal of Combe Down Tunnel following its conversion to host the Two Tunnels Greenway.

The report contained a budget cost for the recommended remedial works of £923,000. This was far in excess of everyone's expectations and had a significant impact on BANES' approach to the scheme, to the extent that the Council came close to withdrawing its support. Mott MacDonald was asked to look again at its specification of works and came back two months later with a revised programme costed at £105,495, a reduction of 89%. This was accepted, the structure's ownership was transferred and substantive delivery work got underway in 2010.

The proportion of the £4.2 million project cost eventually spent on *structural* repairs to Combe Down Tunnel cannot currently be confirmed, but was reportedly in the "tens of thousands".

It should be noted that the repair costing developed by the Queensbury Tunnel Society's engineering team - which involved specifying a method of remediation for every recorded defect - is 92% less than that put forward by Jacobs. As one member of the Society commented, "There is a very real sense of history repeating itself."

Queensbury
TUNNEL SOCIETY

Cost Comparisons (February 2017)

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queensburytunnel.org.uk

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