Jacobs

Trams to Granton, BioQuarter and Beyond

Orchard Brae Corridor
Dean Bridge Structures Report

The City of Edinburgh Council

July 2025

Trams to Granton, BioQuarter and Beyond
Orchard Brae Corridor - Dean Bridge Structures Report

Client name: The City of Edinburgh Council

Project name: Trams to Granton, BioQuarter and Beyond

Client reference: CEC

Project no: B2340264

Document no: REP04_A

Version: P02

Date: 25 July 2025

File name: RP04_A Dean Bridge Structures Report FINAL.docx

Document status: Final

Document History and Status

Version	Date	Description	Author	Checked	Reviewed	Approved
P01	31.03.2025	Draft For Comment	LR	PM	GCD	GKD
P02	25.07.2025	Final	LR	PM	GCD	GKD

Distribution of Copies

Version	Issue approved	Date issued	Issued to	Comments

Jacobs U.K. Limited

160 Dundee Street
Edinburgh, EH11 1DQ
United Kingdom

T +44 (0)131 659 1500
F +44 (0)131 228 6177
www.jacobs.com

Contents

1. Introduction

1.1 Purpose

A north-south tram line is being considered as part of an expansion of the Edinburgh Tram network. In the north of the city, two options are being considered, one via the Roseburn Path and one via Orchard Brae.

Dean Bridge is the primary structure on the Orchard Brae corridor. It is a Category A listed 1820's structure designed by Thomas Telford. This report considers the structural viability of operating trams across Dean Bridge.

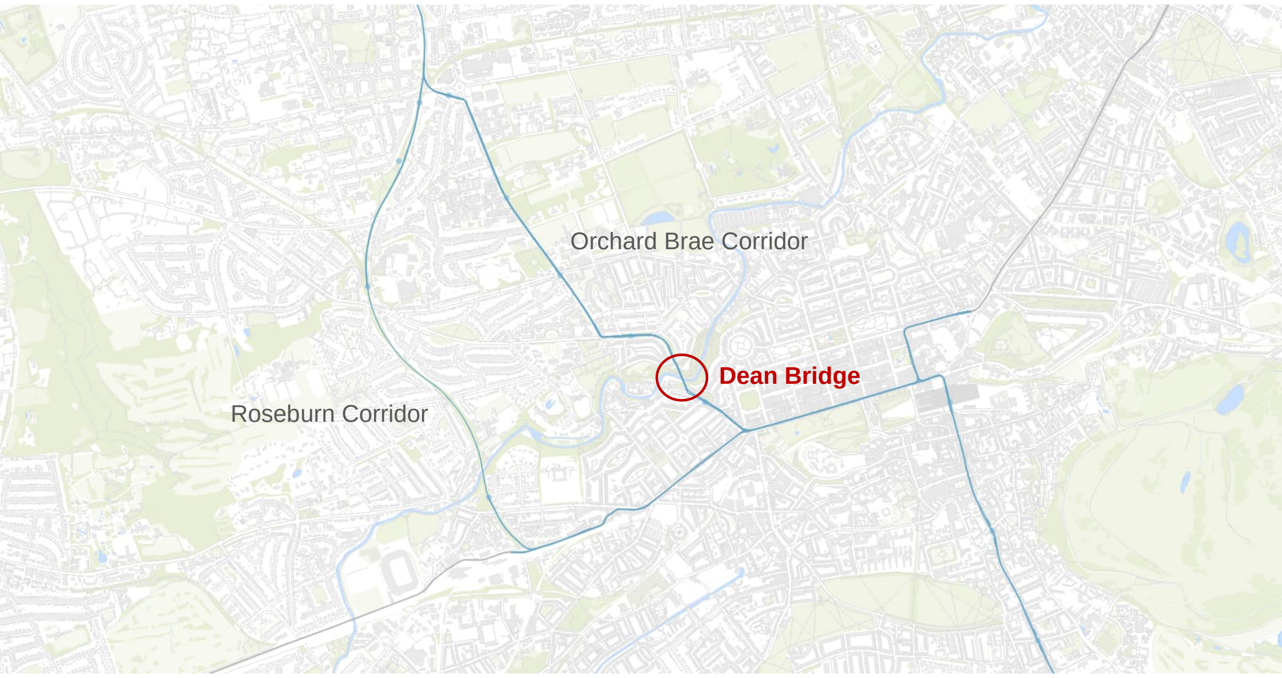
The Trams to Granton, BioQuarter and Beyond project is currently at Strategic Business Case stage and so considerations and recommendations are high level.

1.2 Location

The Orchard Brae corridor and the location of Dean Bridge is denoted in Figure 1.1. The route departs the existing tram route at the west end of Princes Street. From here it follows Queensferry Street towards the Water of Leith before crossing Dean Bridge. The route then follows Orchard Brae, onto Crewe Road South, past the Western General Hospital and down to Crewe Toll roundabout, before heading left to Ferry Road and on to Granton.

The Roseburn Corridor route option leaves the existing corridor at Russell Road and follows the Roseburn Path to Crewe Toll, before heading towards Granton on the same alignment as above.

Figure 1.1: Dean Bridge Location



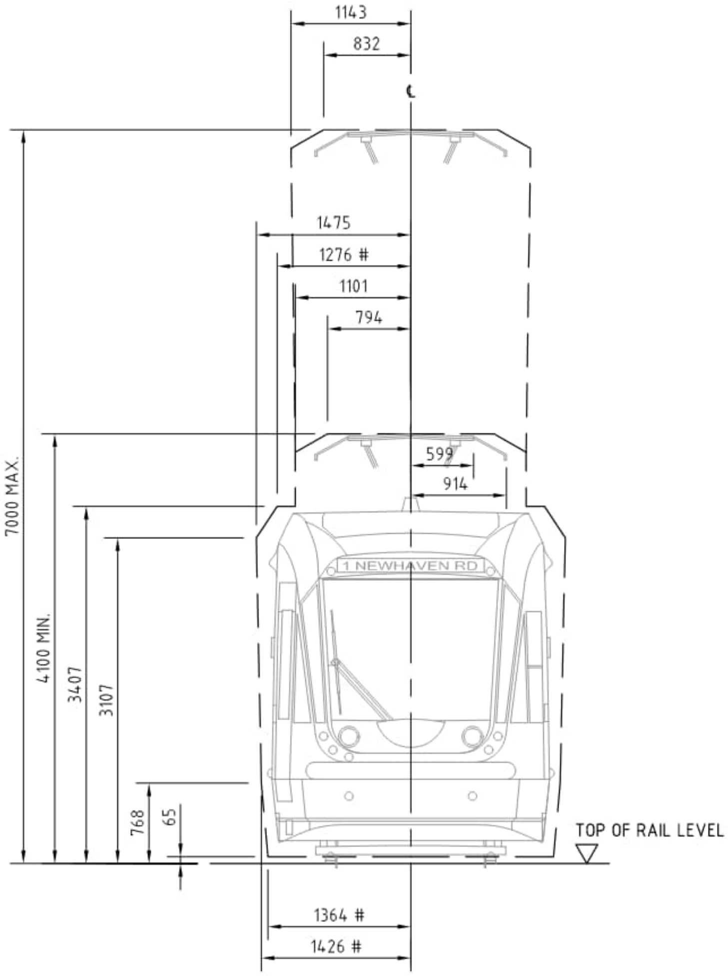
2. Scheme-Wide Considerations

It is anticipated that the proposed Crew Road/Orchard Brae route would align with the City of Edinburgh Council's policies and aims, with the expansion of the Edinburgh Tram network aligning to the Council's Mobility Plan. The following considerations under this section ensure that the proposed scheme meets its safety requirements, whilst its impact on the existing area remains beneficial to local community along the route.

2.1 Tramway Requirements

In keeping with the existing tramway clearances, the proposed scheme considers the dynamic kinematic envelope (DKE) for each tram, described in the Office of Rail Regulation's Guidance on Tramways document. This envelope factors in tolerances in the track gauge and alignment, while also making allowances for the effects of curvature. Clearances to other trams or structures are considered to be between the closets points of these envelopes. The dynamic kinematic envelope is shown in Figure 2.1.

Figure 2.1: Tram Dynamic Kinematic Envelope



2.2 Environmental

The bridge crosses the Water of Leith and there is significant green space and vegetation in the park and riverside path below. Mitigation of any adverse impacts on the river and green space will need to be determined prior to any work being undertaken via an environmental impact assessment on or around the structure.

Across Dean Bridge, the encountered environment may be classified as urban.

2.3 Local Heritage

Dean Bridge is a category A listed structure and has been designated as such since 1965. The listed status protects the aesthetics and position of the bridge as a prominent structure on the approach to the west end of the city. It also recognises the design by Thomas Telford, a seminal figure in engineering innovation and the first president of the Institution of Civil Engineers (ICE).

The Bridge straddles the boundary between the New Town and Dean Bridge Conservation Areas and so is integral to both. It is also located within the UNESCO World Heritage Site as noted later in the Report.

Any changes or proposed works which affect the physical aesthetics of Dean Bridge would require consultation with Historic Environmental Scotland.

3. Historical Data

3.1 Information Sources

As an historical structure there is limited information available on the bridge. Jacobs undertook a thorough investigation to find existing drawings and research its history. The sources replied upon are detailed below:

Surveys and Inspections:

- Dean Bridge Manhole Access survey, 03 February 2022
- British Geological Survey Borehole Logs
- Edinburgh Geological Maps

Drawings:

- Longitudinal and Cross Sections showing Spandril Walls (provided by CEC) - undated
- DC 7920, Plan showing the situation of the proposed bridge over the Water of Leith (superseded), 08 May 1829
- DC 7921, Untitled (Dean Bridge details and section of construction), 08 May 1829
- DC 7922, Cross-section (Dean Bridge cross-section and details of railings and parapet) - undated
- DC 7925, Elevation of the Dean Bridge, Edinburgh, April 1833
- DC 7927 and DC 7928, East Elevation of Dean Bridge, 30 July 1891

Written accounts, literature and images:

- Dean Bridge, Edinburgh - Roland Paxton, Edinburgh History Magazine 1990 (Paxton, 1990)
- Interior view of the Dean Bridge showing internal stairs of archway (McKelvie, 1970)

3.2 Missing Information

The above sources have provided a large amount of information about the structure, however there are still several aspects that remain unknown.

- Jacobs has not been provided with any inspection reports for the structure. Therefore, its existing condition is unknown. For the purposes of this report, it has been assumed that the structure is in fair condition and that there are no known major structural concerns.
- There is no available information on the foundations of the structure or their condition. Public geological maps and borehole logs have been used to give an indication of the expected ground conditions around the structure. However, without a specific geotechnical investigation the exact ground conditions around the foundations remain a projection. In light of Telfords bespoke form of structure, this is a critical gap on the modelling of the soil structure interaction.

4. Existing Structure

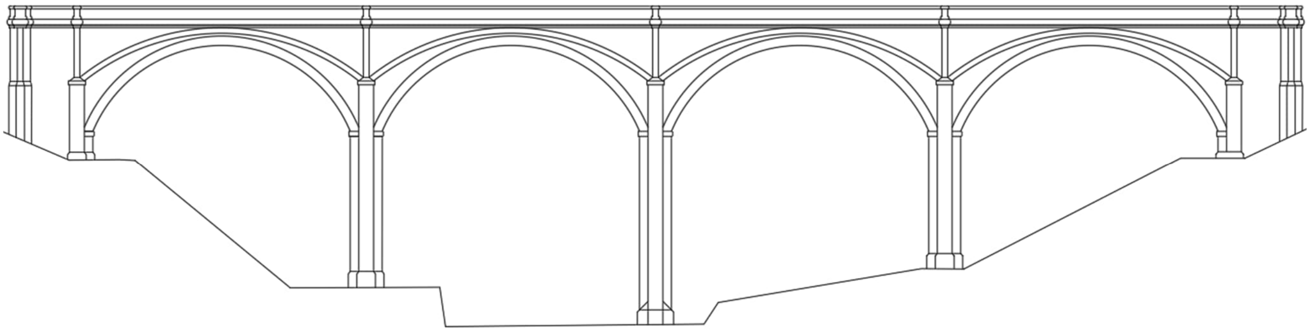
4.1 Overview

Dean Bridge is a four span masonry arch structure, constructed in the late 1820s and designed by Thomas Telford. The crossing is designated a category A listed structure.

The bridge consists of four 27.4 metre main arch spans, which support the roadway. The semi-circular arches have a rise of 9.1 metres from their springing. The arches are not infilled, instead there are four internal spandrel walls spanning longitudinally and perpendicular to the deck. Flat masonry slab covers span the top of the spandrel walls, and supporting the roadway above. Secondary lateral arches sit above the main spans with a slightly longer profile on each elevation. These support the pedestrian walkway and project approximately 1.5 metres beyond the main arches (Figures 4.1 and 4.2).

The piers have a width of approximately 3.4 metres with historical records indicating they have four hollow compartments divided by masonry ties. This approach was deliberate and appears to have been adopted by Telford to reduce the structures overall mass.

Figure 4.1: Sketch of the Dean Bridge Elevation



4.2 Site Description

Dean Bridge carries A90 Queensferry Road over the Water of Leith. The road level sits 32m above the Water of Leith below, and is a major arterial road providing access into the city centre from the north. The carriageway has a width of 7.0 metres. There is a 2.4 metre pedestrian footpath on each side of the carriageway, giving a total deck width of 11.8 metres.

The river lies at the base of a deep gorge, therefore the access to the main arches from below is challenging. Figure 4 shows an ariel view of the bridge and its position above the river. There is a footpath beneath the south side of Water of Leith which provides access to the two southern arches. On the north side a large private park is located by the northern arch and pier, with the central pier sitting within the water course.

Figure 4.2: Ariel View of Dean Bridge from the North (LHS), and from Below (RHS)

4.3 Structural Form

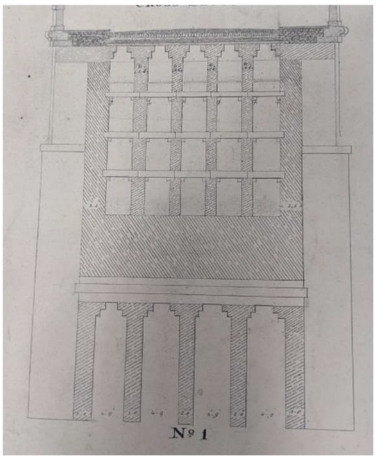
4.3.1 Foundations

There is very limited available information on the foundations of Dean Bridge. From the historical records, it is known that the original design for the bridge comprised three spans. However, this was increased to four following initial excavations, as the rock quality on the south side was found to be poor. The addition of the fourth span, enabled the south abutment to be located upon solid rock (Paxton, 1990).

4.3.2 Piers

Comprising large masonry blocks, the piers are internally hollow, with the external thickness of the pier walls being approximately 0.9 metres. There are four internal rectangular hollow voids within each pier and these extend vertically to support the springing courses of the masonry arch structure above - Figure 4.3 refers.

Figure 4.3: Pier Cross Section

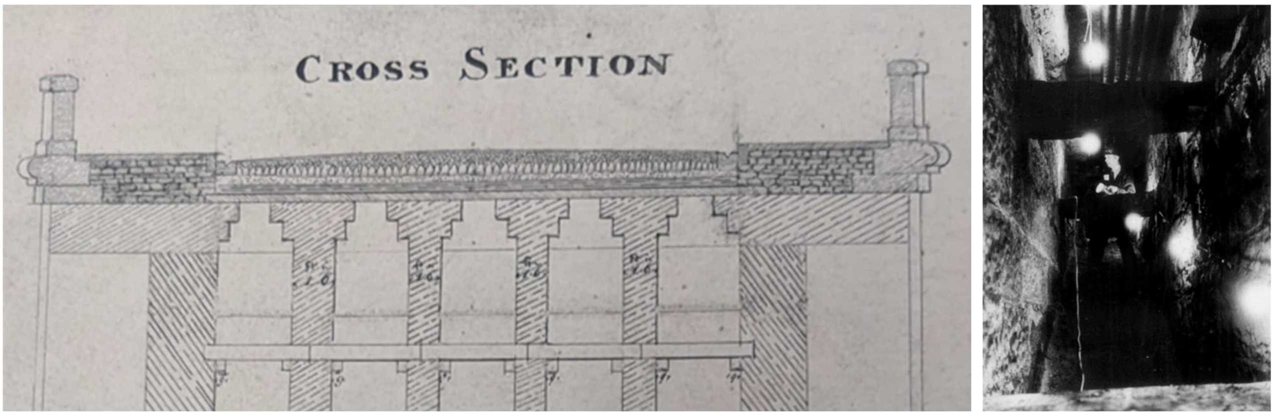


This is not a common approach to pier construction and the technique was most likely adopted by Telford account for the reduced underlying strata layers that was a concern to the structural viability of the original design.

4.3.3 Arches

Unlike conventional infilled arch structures, the arch barrel of Dean bridge supports four internal spandrel walls and two external ones which are orientated longitudinally and perpendicular to the deck. Between the spandrels, at discreet centres, internal ribs comprising masonry blocks are positioned - Figure 4.4 refers. The offset between the internal spandrel faces needs confirming, as the historical drawings were noted to state varying dimensions. It is however estimated from the historical photo below, that the spandrel offset dimension is approximately 1.0 to 1.2 metres apart. Large masonry bridging slabs approximately 150mm thick, span the spandrel roof voids at deck level. This creates a surface to support the carriageway above.

Figure 4.4: Cross Section Denoting Spandrel Ribs (LHS), and Image of a Typical Rib (RHS)



4.3.4 Waterproofing

Visible staining on the arch intrados was observed, and this looks to be a white efflorescence. Without a closer inspection it cannot be determined whether this is natural surface weathering or the result of water ingress to the arch.

In February 2022, a manhole access survey was undertaken and the findings reported a suspected water leak within the first arch, no further information was provided.

There is no evidence to suggest that the structures carriageway has been waterproofed.

4.4 Structural Access

There is limited access to the internal elements of the structure. A series of manholes afford access to the secondary (below footpath) arch on the east side of the structure.

The manhole access survey undertaken in February 2022 noted public utilities ducts in all seven manholes across the structure and these either limited or prevented internal access, as shown in Figure 4.5. The spaces that can be accessed are considered confined and would be restricted to workers with confined space training.

Figure 4.5: Extracts of the Manhole Access Survey Photos Denoting Utilities and Restrictive Access

There is currently no access provided to any of the main arch spans or the internal spandrel walls. This means that inspections of the internal spandrel walls have not been undertaken for some time and their condition is presently unknown. There are options that could be considered to gain further access to the structure for an inspection and assessment. These are discussed in more detail under the Section 6 - Constraints Sections.

4.5 Geotechnical Information

4.5.1 Superficial Deposits

The published geological information (British Geological Survey, 1998) indicates bedrock is 'at or near surface or beneath artificial deposits' within the gorge in the vicinity of Dean Bridge and to the east. The areas north-west and south-east of Dean Bridge are predominantly recorded to be underlain by Glacial Till (Diamicton).

A lens of alluvium is recorded on the southern bank of the Water of Leith beneath the bridge, and larger areas of alluvium are indicated to be associated with the meander features to the west, near Dean Village. The alluvium is indicated by the BGS GeoIndex (British Geological Survey, 2024) to comprise clay, sand and gravel. A small area of Made Ground of unspecified composition is recorded beneath the northern end of the bridge, beneath and adjacent to the church on the corner between Queensferry Road and Belgrave Crescent.

4.5.2 Solid Geology

The solid geology comprises Lower Carboniferous strata of the Gullane Formation in the Strathclyde Group (formerly the Lower Oil-Shale Group subdivision). These strata are recorded to comprise grey mudstones and siltstones with interbedded sandstones, thin limestones, ironstones and coals locally present. The Ravelston Sandstone, annotated as 'massive', is mapped in the vicinity of the Dean Bridge, with a further annotation describing '180 ft (55 metres) bituminous blaes in gorge, below bridge.' (British Geological Survey, 1965) ['blaes' is a Scottish term for shale or mudstone].

More recent mapping from 2000 shows several interpreted NNE-SSW trending bands of sandstone and mudstone/siltstone crossing the gorge (British Geological Survey, 2000) in the vicinity of the bridge. Two sandstone units are indicated to subcrop in the vicinity of the bridge:

(i) The Craigleith Sandstone is indicated to subcrop approximately 25 metres south-east of the bridge, dipping WNW beneath the bridge. The Craigleith Sandstone is described as typically off-white, fine-grained, siliceous, often thickly bedded with some micaceous and carbonaceous material.

(ii) The Ravelston Sandstone is indicated to subcrop beneath the central and northern part of the bridge, dipping WNW. The Ravelston Sandstone is typically brown or black, fine grained, siliceous, often thickly bedded with some micaceous and carbonaceous material.

The strata are recorded as dipping between 15° and 25° to the west, and a NNE-SSW trending fault is recorded just to the south of the southern end of the bridge.

Regionally, ESE-WNW trending quartz-dolerite intrusions are present within the sedimentary strata, with the closest mapped intrusion to the Dean Bridge subcropping approximately 125 metres north-east of the bridge.

The Coal Authority Interactive Map indicates Dean Bridge does not fall within a Coal Mining Report Area.

4.5.3 Ground Investigation Records

No historical ground investigation information is available in the vicinity of the Dean Bridge; however, 14 No. exploratory holes were undertaken at a site approximately 100 metres to the southwest, near Belford Road. These logs provide indicative strengths of the solid strata in the area but due to their distance from the bridge and the associated variation in mapped deposits, the descriptions of the superficial deposits in these logs are not relevant to the assessment of the founding strata of the bridge. Use of the data should therefore be considered a projection.

The historical borehole logs (British Geological Survey, 2024) generally describe the sandstone encountered as “moderately strong to strong”, whereas the mudstone and siltstone are generally described as “weak to moderately weak”. Logging standards have changed since the boreholes were undertaken and the equivalent strength terms in accordance with current standards would now be classified as be “moderately weak to strong” for the sandstone and “very weak to weak” for the mudstone and siltstone. Many of the strata are logged as being heavily fractured, with some sub-vertical fractures, iron-staining and clay infill recorded.

An overarching review of this geotechnical information is provided under Section 6.3.4 Commentary on Founding Strata.

Table 4.1: Summary Existing Ground Conditions near Dean Bridge

Exploratory hole	Ground Level (Mod)	Location	Layer Description	Thickness of Layers (m)
NT27SW9730/1 BH1	48.65	120m from abutment, Belford Road	MADE GROUND (sand and sandy silty clay with gravel and cobbles)	0 - 6.90
			Brown silty CLAY	6.90 – 8.40
			Weathered grey MUDSTONE with bands of sandstone	8.40 – 9.60
			Grey SANDSTONE	9.60 – 10.60
NT27SW9730/2 BH2	48.25	120m from abutment, Belford Road	MADE GROUND (sand and sandy silty clay with gravel, cobbles and boulders)	0 – 5.90
			MUDSTONE with bands of sandstone	5.90 – 8.0
NT27SW9730/7-9 BH7, 8 and 9	42.35/42.6 0 /43.6	120m from abutment, Belford Road	MADE GROUND (top soil overlying ash, gravel and masonry rubble)	0 – 1.40 to 2.90
			SANDSTONE with bands of mudstone	1.40 to 2.90 – 3.40 to 4.90
NT27SW9730/12 BH12	45.85	120m from abutment, Belford Road	TOPSOIL containing gravel and cobbles	0 – 1.60
			Brown clayey sand SILT containing gravel, cobbles and boulders	1.60 – 8.90
			Slightly weathered light grey fine grained moderately strong occasionally strong micaceous SANDSTONE. Occasional laminations of mudstone. Generally very closely spaced fractures.	8.90 – 9.20
NT27SW9730/14 BH14	45.70	120m from abutment, Belford Road	MADE GROUND (sandy silty clay containing gravel)	0 – 0.50
			Sandy silty CLAY containing gravel	0.50 – 1.10
			Sandy silty CLAY containing gravel, cobbles and boulders	1.10 – 5.05
			Highly weathered light grey fine grained SANDSTONE	5.05 – 5.55
			Slightly weathered light grey fine grained moderately strong micaceous SANDSTONE. Thin band of moderately weak mudstone at 6.15m.	5.55 – 6.25
			Slightly weathered light grey fine grained moderately strong and strong SANDSTONE. Thin band of mudstone at 7.30m.	6.25 – 7.30
NT27SW454	26.80	250m west along river	MADE GROUND (concrete block and cobbles)	0 - 0.70
			GRAVEL	0.70 - 1.20
			GRAVEL and MUDSTONE	1.20 – 2.30
			moderately strong thickly bedded dark grey MUDSTONE with occasionally carbonaceous patches. Fresh occasionally clay smeared medium spaced planar rough sub horizontal fractures and subvertical joints	2.30 – 4.90

4.6 Utilities

There are a number of existing utilities beneath the east footpath of the secondary arch. It has not been determined what specific services are held with these ducts.

There are four historic lamp-posts on the bridge, of a similar style, to the historic images of the bridge. It is assumed that they are covered by the listed status, is so they would need to be retained.

4.7 Drainage

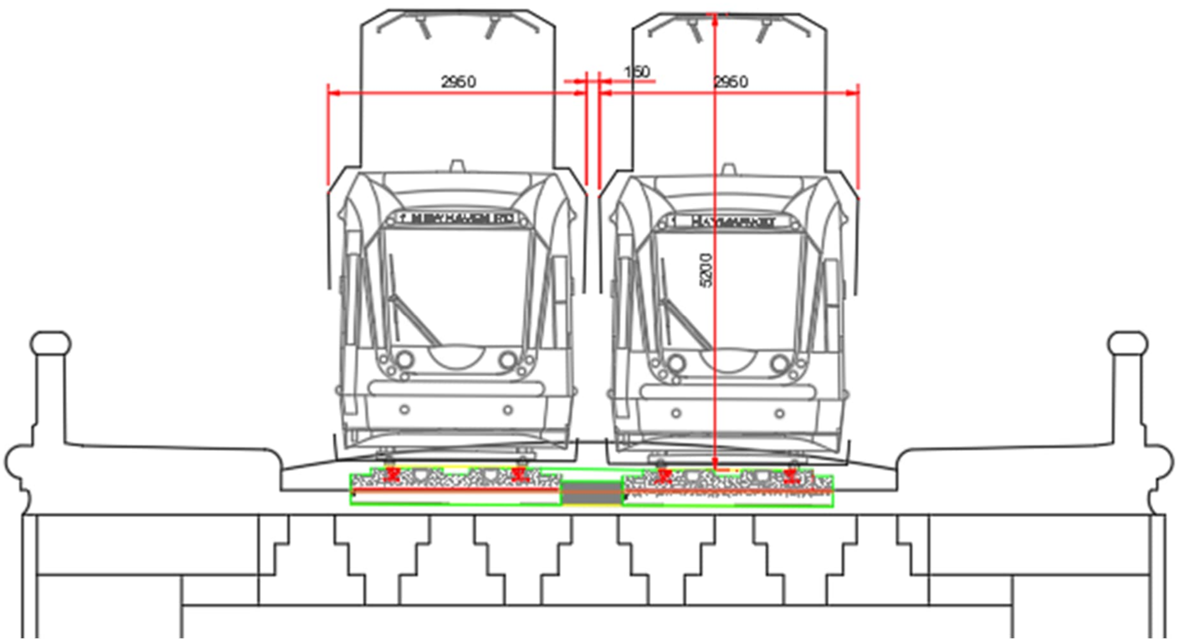
The structure does not appear to currently have any drainage gullies for the carriageway or the footpath. Moreover, no drainage is denoted on any of the available drawings, suggesting positive flows have been designed into the structures vertical alignment. A single drain gully was observed on both the structures approaches, outwith the structural extents.

5. Tram Proposal

The intent is for Dean Bridge to support two tram tracks in addition to existing traffic, under a dual use solution, Figure 5.1 refers. The tram tracks will run centrally along the deck to ensure an even distribution of the loading into the spandrels and arches. The horizontal alignment of the tracks would remain straight across the bridge to minimise centrifugal forces.

The current footpath over the bridge will need to be retained, with Cycling provision either on the roadway or shared with pedestrians. If shared with pedestrians a restricted width of 2.4 metres is available on each footpath.

Figure 5.1: Proposed Carriageway Cross Section



5.1 Structural Form

The intention is for the existing structure to carry trams along the existing carriageway deck. The current road surface would be excavated down to the masonry capping slabs above the external and internal spandrel walls, and a new carriageway make up formed incorporating a track bed with a trackform.

5.2 Proposed Dean Bridge Track bed and Track form

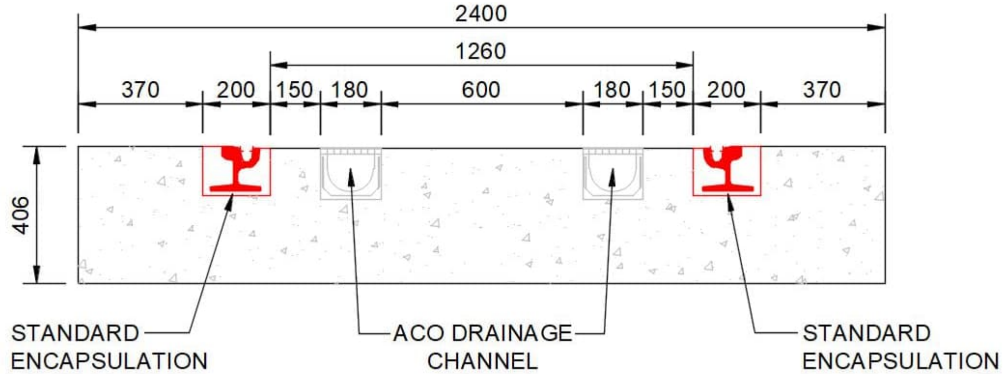
The tramway across the structure would consist of a double track line, with each track facilitating travel in one direction. These tracks would be standard gauge, with the tramway utilising approximately 6.5 metres of the 7.0 metre deck width. The rails would be secured within reinforced concrete track form, with the track bed most likely being structurally separate from the superstructure below. The first stage of the track bed construction would be the formation of a reinforced concrete pour across the whole width of the deck to act as a blinding layer to create a flush surface. A separation membrane would be laid and the second stage reinforced concrete trackform poured with rails encapsulated, to provide vertical and lateral support to accommodate dynamic loading from the trams.

Two slabs may be poured in tandem each with a width of 2.4 metres and a tarmac road surfacing formed. Alternatively, the whole width of the deck may be covered in the second stage concrete pour, with this concrete making up the road surfacing. Both of these approaches have been implemented on the current tram network between Leith and Newhaven. A minimum combined depth of track slab would be approximately 405mm.

Longitudinally, between the rails, ACO drainage channels will channel water off the structure while also doubling as derailment channels. An indicative track form is illustrated in Figure 5.2 and would need to be refined based upon the highway alignment, the P-Way design and the depth of deck above the masonry slab covers.

From historical drawings, a depth of 0.5 metres is indicated from the surface of the roadway to the top of the masonry slab covers. Therefore, there appears to be is sufficient depth for the track bed and track form to be accommodated. A spray applied waterproofing layer would most certainly be included in any future deck reconstruction.

Figure 5.2: Indicative Track Form Cross-Section



5.3 Structure Use

Dean Bridge would remain a multi use structure for pedestrians, cyclists, highway traffic and trams.

5.4 Parapets / Guardrails

The historical records advise that in 1888, the parapets were raised to deter suicides on the bridge. An adjustment to the parapet height may need to be made to accommodate any change in the vertical carriageway profile. The height would seek to satisfy the recommendations of Cycling by Design for a 1.5 metre high parapet. The aesthetic implications of this on a listed structure would need to be considered and approved by Historic Environment Scotland. One option to minimise any aesthetic impact, would be to modify the height with a like for like masonry block.

5.5 Proposed Construction Sequence

Due to the width restriction on the bridge, it would be challenging to complete the construction work whilst maintaining the bridge open. Therefore, it is proposed that a diversion would be established for the duration of the works. On the basis there were no structural concerns, the following consequence would be proposed.

1. Set-up site compound and install the required road diversions
2. Ensure no utilities lie under roadway and divert if necessary. For known utilities running under the pedestrian footpath, ensure these are protected prior to any resurfacing
3. Remove existing deck surfacing and excavate to required track slab depth, taking care not to damage underlaying masonry slab covers
4. Construct the track bed; the waterproofing; the separation membrane; the track form; lay the tracks and re-profile the surfacing
5. Reopen the bridge.

Based on the options considered under Section 7, this sequence would be modified accordingly.

5.6 Design Loads

To remain in accordance with the design loads used for the rest of the tram structures on the network. The design actions for Dean Bridge would be applied according to the amendments to BD 37/01 detailed in Sections 3.71 to 3.76 of Structures and Civil Engineering Requirements Specification for the Edinburgh Trams Network. This specifies that 0.5 of the Type RL loading model given in the now withdrawn BD 37/01 be used for the tram design.

This is recommended as no equivalent load model to RL is provided in the Eurocodes. This design load model will be subject to approval from the TAA and a departure from standard required.

It should be noted that traction and braking forces are much more significant in rail loading models, compared to similar vehicle models. This may result in tension and other unexpected secondary actions upon the bridge. A mechanism analysis would need to be undertaken to understand the failure of the structure under tram loading. This may show that the current structure in conjunction with the ground analysis model is not suitable to carry tram loading without additional works and strengthening. Potential strengthening options are explored further under Section 7.

The key documents to be used for design are:

- BD 37/01 Loads for Highway bridges
- ULE 90130-SW-SW-SPN-00049 V2 (Structures and Civil Engineering Requirements Specification for the Edinburgh Trams)

BS EN 1317 and CD 377 would be consulted for the parapet design.

In addition to the above, the design for Dean Bridge shall comply with the relevant parts of:

- Eurocodes and associated UK National Annexes
- British Standards
- Execution or Product Standards referenced in British Standards or Eurocodes
- Published Documents (PDs)
- The Design Manual for Roads and Bridges (DMRB)
- The Manual Contract Document for Highways Works (MCHW)
- CIRIA
- Disability Discrimination Act (DDA) 1995/Equality Act 2010
- Cycling by Design 2021
- Office of Rail Regulation Guidance on Tramways
- Edinburgh Tram Design Manual

5.7 Third Party Interfaces

The following Third-Party Interfaces have been identified:

- City of Edinburgh Council
- Transport for Edinburgh
- Dean Village Association (DVA)
- Historic Environment Scotland
- Key stakeholders such as land / property owners around Dean Bridge
- Utility companies
- Scottish Environment Protection Agency (SEPA)
- Nature Scot
- Sustrans

5.8 Checking Level

It is considered that due to the relative complexity of this form of structure, a full independent Category 3 level check would be required. This shall be confirmed by the TAA prior to commencement of the detailed design stage.

6. Constraints

Carrying trams across Dean Bridge would result in additional loads being applied to the structure, for which it was not originally designed. This raises various concerns about the condition, capacity and behaviour of the structure once modified and in service.

6.1 Gap Analysis

The current condition of the structures internal elements and foundations are presently unknown. Antidotally CEC have reported that only an external visual inspection has been undertaken in recent years which noted the bridge to be in good condition. Dimensional information on the structure has been obtained from limited historical drawings available which has been obtained from Historical Environment Scotland. This data has been helpful to build a picture of the main geometries of the structure and the make up the deck, there remain key details which need determined. These are:

- Detail of all material strengths
- Details of the foundations, these are only indicated as an extension of the piers in one drawing, but no sizes or depths are provided
- Details showing the internal masonry at the top of the piers are not specific and so it is unclear exactly how the main arch springer courses are formed
- Details of the underlying soil strata layers by the structures foundations
- Details of internal ribs between the spandrels.

6.2 Access

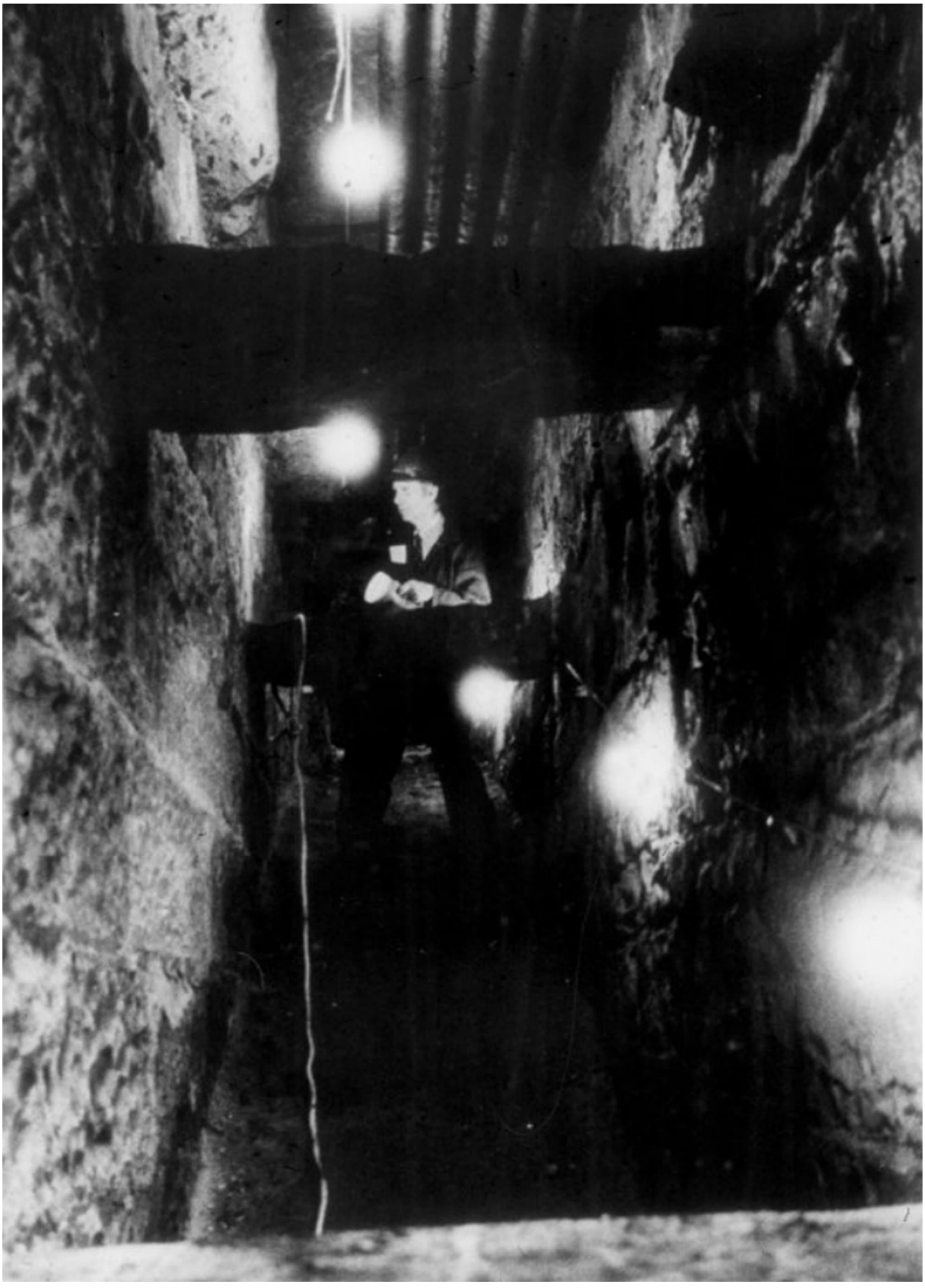
The bridge crosses a steep gorge, therefore access for geotechnical testing plant into the gorge will be challenging. Whilst two of the piers are accessible from the footpath and local park, the third sits in the watercourse and would be difficult to access for a 'with-in touching distance' inspection. Access to the underside of the arches would likely need to be obtained from above by an underbridge unit.

The lack of information for the bridge is a significant limitation to assessing the structural viability. Concerns centre around the condition of the internal spandrel walls of the main arches which are inaccessible and crucial to the load path of the bridge. The image shown in Figure 6.1, shows a workman inside a hollow arch spandrel of the secondary arch in circa 1970 indicating that internal access in the past has been possible. The literature suggests that the cavities are interconnected through access holes, however, no details of these nor further evidence has been found on the historical drawings in support. Access to the internal spandrels for inspection would be essential to any meaningful assessment of the structure.

One access option would be to temporarily restrict use of the bridge to single lane traffic. The carriageway surfacing in a few selected areas could then be removed to uncover the masonry slab covers below. If one slab was lifted by the crown then the spandrel and void below could be accessed, mapped and inspected. By carrying out this procedure at multiple locations on the deck a thorough inspection of the spandrel and internal elements could be undertaken. Following the inspection the slab would be replaced and the surfacing reinstated.

An alternative option would be to open up an access through the side of the external spandrel walls in each of the spans. This would afford access to the outer most void. Should the internal access cavities between the internal spandrels not be located, or if found to be too narrow, additional access points would be required to be installed through the internal spandrels to permit a full inspection for assessment to be undertaken within touching distance. The holes would need to be large enough permit an inspecting engineer to enter with sufficient space to provided should a rescue be required. It should be remembered that inspecting engineers would be entering a confined space environment and as such the associated health and safety hazards would need to be addressed and mitigated.

Figure 6.1: Interior View Between Two Dean Bridge Spandrels, c.1970



Access to the internal hollow piers is also a challenge with the historical records indicate the presence of four separate vertical chambers within each pier. An external access point would need to be created with internal access to the separate chambers formed. As with the superstructure, these voids would be classed as a confined space environment and as such the associated health and safety protocols would need to be observed. Care is required for both the deck spans and the piers when selecting access locations, so as not to inadvertently weaken the parent structure.

6.3 Structural Behaviour

6.3.1 Arches

The arches of the structure act in compression. They are voided with internal spandrel walls following the profile of the arches and extending the length of the span, and are assumed to be continuous. The unknown behaviour of both the spandrels and arches under additional tram loading, in particular traction and braking forces, is a significant constraint. Any introduction of tension forces into the masonry may lead to deterioration and localised failures. The spandrels transfer the load from the deck into the arch barrel, and from the arch barrel into the piers and abutment foundations. Therefore any failure would result in the development of out of plane forces that could create significant strain and change the load path through the structure.

Additionally, the internal voids present areas where current defects may not be easily identified. Currently, these areas are inaccessible, and any potential deterioration would be difficult to monitor and repair, especially when tram are operational.

6.3.2 Piers

The piers like the internal spandrel walls are hollow, this means that any service life defects may be hidden, leading to the same concerns around structural behaviour and deterioration before consideration of additional tram loading. The horizontal traction and breaking forces will introduce higher shear and flexural forces into the pier. A condition inspection would need to be completed of the piers similar to the arches, due to there being four separate voids in each pier.

6.3.3 Foundations

From the historical records the chosen structural form as designed appears to have been developed to reduce the overall mass of the structure. This suggests that the bearing pressure under the foundations was limited in the original design and therefore any additional loading could result in failure within the underlying strata layer.

Additional loading should therefore not be placed on the structure until the ground conditions and founding strata for each pier are thoroughly investigated and a robust ground model created relative to the reactions arising form the structural model.

6.3.4 Commentary on Founding Strata

The available information suggests that the piers of the Dean Bridge are founded on sedimentary strata of the Gullane Formation. The bearing capacity which may be provided by these strata is expected to be variable, reflecting the presence of sandstones, mudstones and siltstones within the sequence and recognising the effects of the thicknesses of individual strata. For example, while the sandstones are described nearby as being moderately weak to strong and, indeed, historical quarries are recorded nearby where the material was extracted for building stone, a foundation placed too close to the base of a sandstone layer may fail by ‘punching through’ if the mudstone or siltstone beneath it has insufficient strength to support the applied load. Imagery available online indicates the presence of mudstone exposures present beneath the bridge, although a site inspection has not been undertaken so further comment is not possible at this time.

The ground conditions beneath the abutments have not been assessed, other than to draw attention to the difference in superficial deposits within and adjacent to the gorge, and the recorded presence of made ground beneath the northern end of the bridge. The location of the abutment foundations in relation to rockhead and the various solid and superficial strata is not known.

It is understood that records suggest the form of the Dean Bridge and the presence of hollow elements may be due in part to concerns about the competency of the strata beneath the structure. This is supported by the published geological information which indicates that some of the founding strata may be of low strength.

A more detailed assessment of the ground conditions would be required if additional loading were to be applied by the structural design, either by in-filling of the hollow structural elements or by application of dynamic loading to the road; however, it is considered likely that strengthening of the existing foundations would be necessary. This is likely to be challenging due to the nature, age and scale of the existing structure, and the difficult access to the base of the piers and abutments.

Ground investigation would be required to inform the design of foundation solutions which could involve underpinning, installation of mini-piles or a caisson-type arrangement, pinned into the existing structure and/or its foundations. Access for the required plant and equipment would likely prove challenging, with the potential for associated environmental and ecological impacts. Ground investigation would also need to take cognisance of heritage impacts with the Dean Bridge classified as a listed building and the site lying within a UNESCO World Heritage Site.

6.4 Tram Utilities

Trams presently require Overhead Line Equipment (OLE) to provide power with communication and signalling ducts also needed. These can be accommodated across Dean Bridge either by the track form or within the adjacent pavement. The OLE requires additional vertical and lateral clearances, which can be accommodated on the structure although the means of fixing the poles will need to be determined. One concern is that the OLE may impact the visual aesthetic of the listed Dean Bridge.

An option may be the introduction of battery technology to replace and remove the need for additional overhead infrastructure to support the trams. The feasibility of this should be investigated along with the additional mass associated with batteries, were this options consider reasonable.

The existing utilities on Dean Bridge would remain.

6.5 Future Maintenance

Future access and maintenance is considered a challenge for this structure. As detailed previously, there is currently no access to the internal load carrying piers or spandrel structural elements. Were a concrete track form to be laid for operational trams, this element would inhibit access to the structure from above. An alternative access would be required. Additionally, as the voids in the arch and piers present a confined space, any maintenance or repair could become a significant undertaking. At this juncture the possibility of restricting the in-service use of the tram should not be ruled out.

Future access should be considered in the design of the track slab, and may involve the inclusion of maintenance hatches and/or access holes for more regular inspections. The use of modern inspection techniques such as 3D Lidar drones should be leveraged to avoid the need for inspection staff needing to regularly enter the structure.

7. Potential Structural Options

As emphasized, the location and chosen structural form of Dean Bridge was deliberate due to the founding strata. Alteration of the structure should not be considered in isolation of the ground profile, as one is directly proportional to the other. This section of this report considers proposals to accommodate trams across Dean Bridge and their associated strengths and weaknesses.

A condition inspection and assessment is required to fully understand the present condition of the structure and its capacity to accommodate trams, in conjunction with the development of a robust ground model.

7.1 Structural Options

7.1.1 Infill of Arch and Piers

Proposal summary:

Infill the structures hollow internal spandrel and pier voids. The proposed infill material would likely be low density concrete, with the overall aim being to mimic a conventional arch.

Strengths:

- Lightweight infill material with low density
- Would mimic a conventional infilled arch simplifying analysis and maintenance
- Provides additional strength to the structure
- Creates more load paths more evenly distributing the deck actions through the structure
- Encapsulates the existing spandrel walls reducing the likelihood of deterioration
- External aesthetic of the structure unchanged.

Weaknesses:

- Adds additional self-weight to the structure, increasing foundation loading
- Would most likely need the foundations to be underpinned including the river span
- Complicated ground investigation will be required
- Access for initial inspection and maintenance repair will be required
- Removes the possibility of future internal access for inspection

7.1.2 Reinforce & Infill Arch and Pier

Proposal summary:

Similar to the Infill of the Arch and Piers with the exception that reinforcement is installed between the hollow spandrels and the pier voids, with dowels drilled into the masonry and the structure infilled with low density concrete.

Strengths:

- Ties the arch elements together, increases the tensile strength
- Would mimic a conventional infilled arch simplifying analysis and maintenance
- Provides additional strength to the structure
- Creates more load paths to more evenly distribute the deck actions through the structure
- Encapsulates the existing spandrel walls reducing the likelihood of deterioration
- External aesthetic of the structure unchanged.

Weaknesses:

- Adds additional self-weight to the structure, increasing foundation loading

- May need the foundations to be underpinned including the river span
- Complicated ground investigation will be required including the river span
- Access for initial inspection and maintenance repair will be required.

7.1.3 Deck Replacement

Proposal summary:

Existing deck and masonry spandrel slabs would be removed, and a reinforced concrete deck would be cast in place.

Strengths:

- Enables the tram loads to be distributed more evenly between more spandrels
- Removes all the individual spanning masonry spandrel slabs
- External aesthetic of the structure unchanged.

Weaknesses:

- Adds additional self-weight to the structure, increasing foundation loading
- Would most likely need to be undertaken in combination with underpinning
- Complicated ground investigation will be required including the river span
- Access for initial inspection and maintenance repair will be required
- Does not change access and future confined space access concerns
- Ongoing requirement for internal maintenance and inspection will remain.

7.1.4 Replacement Spandrels and Deck

Proposal summary:

Replace existing internal masonry spandrel walls with new reinforced concrete or equivalent mass concrete ones with a reinforced deck.

Strengths:

- Removal of existing, potentially deteriorating, internal masonry spandrel walls
- Enables the tram loads to be distributed more evenly from the deck to the existing arch barrel more robustly
- Removes all internal masonry elements
- Future internal access provision can be designed in
- External aesthetic of the structure unchanged.

Weaknesses:

- Hollow piers would need to be strengthened
- Adds additional self-weight to the structure, increasing foundation loading
- Would most likely need to be undertaken in combination with underpinning
- Ongoing requirement for internal maintenance and inspection will remain.

7.1.5 FRP Strengthening of Internal Spandrels

Proposal summary:

Fibre reinforced polymers (FRP) would be used to strengthen the internal spandrel walls and piers of the structure. The choice of wrapping and method would be targeted depending upon the structural behaviour required.

Strengths:

- Minimal addition to the structures self-weight
- Increased tensile strength in the spandrel walls and piers with reduced crack propagation
- Soil strata strengthening such as underpinning could be avoided
- External aesthetic of the structure unchanged.

Weaknesses:

- Access for initial inspection and maintenance repair will be required
- Limited examples of similar work, therefore would need extensive design and testing to find most effective solution
- Any future damage or deterioration to the spandrels would be harder to identify as the FRP would obscure the deteriorated element
- Bonding of the FRP to the parent masonry could be challenging.

7.1.6 Underpinning

Proposal summary:

Construction of new encompassing substructure around the existing foundations of Dean Bridge, to transfer the applied reactions to deeper strata layers. Comprising at depth reinforced concrete bored piles and a pilecap foundation extension, this proposal may be applied in isolation or in combination with other strengthening methods.

Strengths:

- Increases the load carrying capacity of Dean Bridge, overcoming the original design capacity limitations
- Mitigates the apparent weakness in the underlying soil strata, designing out the possibility of differential settlement.

Weaknesses:

- Access to foundations including the in water pier is challenging, complicating construction
- Pilling adjacent to existing structures is a highly specialist activity
- Existing foundations unknown, this method requires the bridges foundations to be excavated and a physically connection made, which could be challenging due to the form of structure
- Potential for foundations not being suitable, requiring an increase in foundation size proportional to the required increase in bearing capacity.

7.1.7 New Structure

Proposal summary:

Construct a new crossing either online or by the existing bridge location.

Strengths:

- New structure would have no limitations on its load carrying capacity
- Would be designed for a 120-year design life

- New structure would not be hindered by limitations in founding strata, as geotechnical technology exists to pass weak strata layers
- If an offline solution was progressed the existing operational use of Dean Bridge would remain unaffected.

Weaknesses:

- If online, demolition of the existing Category A listed structure may not be permitted
- Aesthetic of the nearby conservation area would be changed with possible negative public reaction
- Highly constrained site would complicate construction
- Lease cost effective of all the solutions

7.1.8 Alternative Route

Proposal summary:

Avoid Dean Bridge by routing trams via the alternative Roseburn Corridor.

Strengths:

- Mitigates all known concerns identified in respects of modifying or replacing Dean Bridge
- Cost effective in so far as not committing resources in favour of lower risk routes
- Option with the least associated risk
- Increased certainty of accommodating trams on the Roseburn Corridor structures compared to Dean Bridge.

Weaknesses:

- Alternative route may not be preferred from a transport modelling perspective.
- Alternative route may not be preferred from stakeholder perspective
- Environmental impact around flora and fauna, and visual impact

7.2 Ongoing Concerns

A number of viable options have been presented, many of which involve strengthening to accommodate tram loading or to secure the existing structure for said loading. However, whilst these are all feasible solutions there still remains a number of significant concerns.

7.2.1 Constructability and Contractor Engagement

Dean Bridge has a complex internal structure with challenging access requirements and is situated in a constrained site. All of the proposed solutions would require significant structural intervention, which should not be underestimated in terms of complexity and cost. Moreover, considerable care would need to be taken to avoid the introduction of out of balance forces, tension or deformations of the arch barrel, as even a small amount of deformation could create a mechanism leading to structural failure. Therefore, a suitable contactor with demonstrable experience and expertise in arch modification and temporary works should be engaged.

In light of the apparent risks, a suitable professional indemnity level shall be required. It is not unreasonably to anticipate tendering contractors pricing this risk into their returns, resulting in increased tender costs compared to conventional structures. This could may reduce the number of potential tenderers as the risk may be deemed to be too high.

7.2.2 Maintenance

The Section 6.5 concerns pertaining to Future Maintenance remain relevant. For the chosen proposal monitoring, inspection and maintenance should be established early in the process and designed into the preferred solution. Alongside the economic and social impacts, frustration and reputational damage relating to the potential long-term closing of the tramline needs to be considered should any future repair or maintenance upon Dean Bridge be required.

7.3 Cost and Duration

The costs for each solution have not been calculated as there is insufficient data available at this stage for the structure or temporary works required to provide an indicative value. Additionally, until an internal condition inspection has been undertaken the extent of works required remains unknown. Therefore, scaled cost relative to each proposal has been indicated. At this stage and scope of work, costs could alter once the existing condition is determined, resulting in either higher or lower estimates.

If it were determined that the foundation strata accommodated the operational running of a new track form, this would be deemed a cost effective implementation and align to the basic construction sequence outlined under Section 5.5. However, once in service any repairs or upkeep of the structure may result in a disruption to the operational running of the trams over Dean Bridge. The duration would depend upon the works required, extending from as little as off peak night shifts, to a full day or a number of weeks.

8. Evaluation of Potential Structural Options

The following chapter seeks to assess the Section 7 options against one another for a range of parameter's. Based upon the data obtained at the time of writing, the scoring may change as more robust data comes to the fore. The scoring should therefore be considered informative.

8.1 Structural Options

Option 1: Infill of Arch and Piers

Infill the structures hollow voids, between the internal spandrel walls and the piers. The proposed infill material would likely be foamed concrete, with the overall aim being to mimic a conventional arch.

Option 2: Reinforce & Infill Arch and Pier

Similar to the Infill of the Arch and Piers with the exception that reinforcement is installed between the hollow spandrels and the pier voids, with dowels drilled into the masonry and the structure grouted up.

Option 3: Deck Replacement

Existing deck and masonry spandrel slabs would be removed, and a reinforced concrete deck would be cast in place.

Option 4: Replacement Spandrels and Deck

Replace existing internal masonry spandrel walls with new reinforced concrete or equivalent mass concrete ones with a reinforced deck.

Option 5: FRP Strengthening of Internal Spandrels

Fibre reinforced polymers (FRP) would be used to strengthen the internal spandrel walls of the structure. The choice of wrapping and method would be targeted depending upon the structural behaviour required.

Option 6: Underpinning

Construction of new encompassing substructure around the existing foundations of Dean Bridge, to transfer the applied reactions to deeper strata layers.

Option 7: New Structure

Construct a new crossing either online or by the existing bridge location.

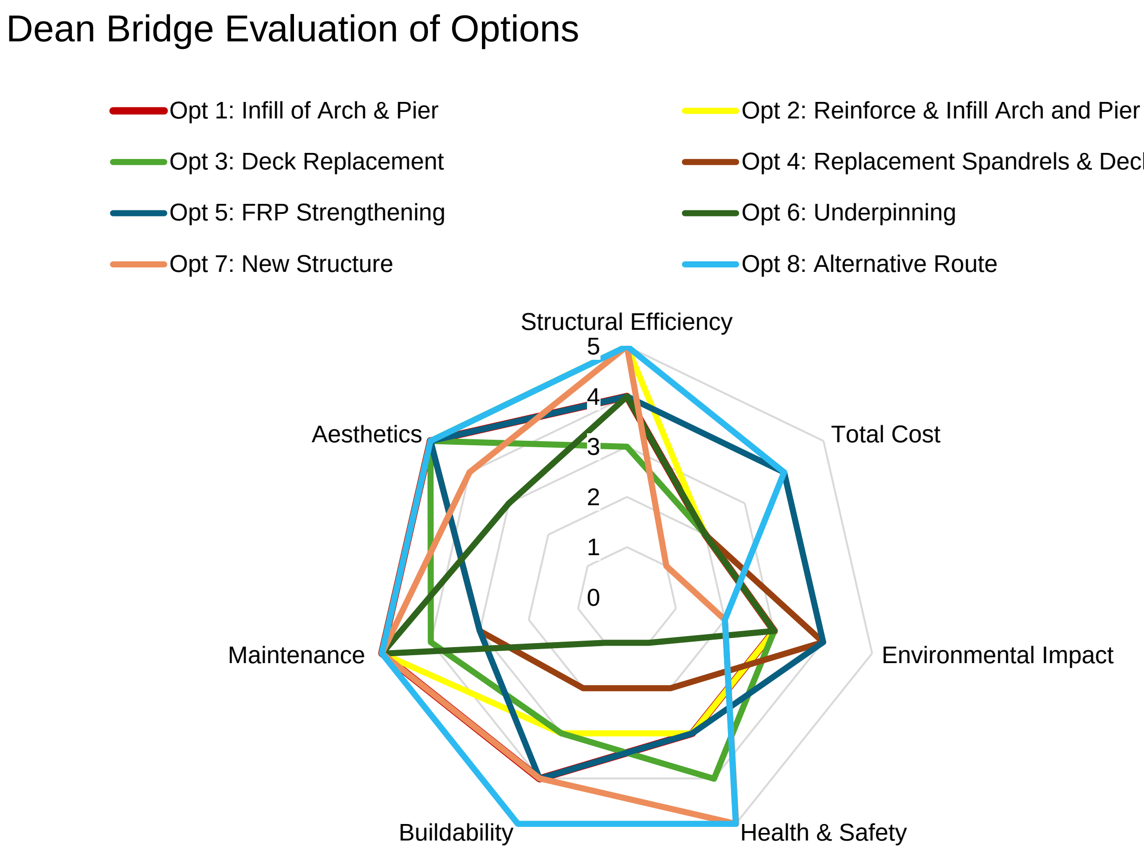
Option 8: Alternative Route

Avoid Dean Bridge by routing Trams via the alternative Roseburn Corridor

8.2 Evaluation of Options

Each of the options has been considered and evaluated against several factors; Structural Efficiency, Total Cost, Environmental Impact, Health and Safety, Buildability, Maintenance and Aesthetics. The options have been qualitatively scored on a rising scale of 1 to 5, with 1 deemed poor and 5 deemed good. The findings of this evaluation are illustrated in Figure 8.1 as a spider diagram and Table 8.1 below.

Figure 8.1: Evaluation of Options Based on Option Scoring Summarised in Table 8.1



Option 6 Underpinning scores poorly in respects of buildability, H & S and total cost, and environmental impact and aesthetics not much better. This option requires a modification to the existing foundation to support and transfer the full mass of Dean Bridge into the underlying strata and should be considered a significant alteration to the existing bridge. Given Option 1: Infill of Arch & Pier and Option 2: Reinforce and Infill Arch and Pier, Options 4: Replacement Spandrels and Deck, Option 3: Deck Replacement would in ascending order, increase the mass of the associated structure, it is not surprising these are ranked after Option 6 in the overall order. Buildability and future maintenance being the primary differentiators.

Option 5: FRP strengthening scores well across the parameters although the requirement to install FRP within confined spaces, along with the identification of future defects in the parent masonry, places this option in second place.

By far, Option 8: Alternative Route scores the best as it mitigates the concerns pertaining to operating trams across Dean Bridge and is considered a less risky option. Assuming the alternative route is via the Roseburn corridor, it scores less strongly against environmental criteria.

Nevertheless, based upon the forgoing, Option 8 is recommended over the other choices evaluated.

Table 8.1: Basis of Option Scoring

Structure Options	Structural efficiency	Score
Infill of Arch & Piers	Allows loads to be distributed directly through the structure into the foundations.	4
Additional Arch Barrel Reinforcement	Allows loads to be distributed directly through the structure into the foundations.	5
Deck Replacement	Allows tram loads to be distributed directly into the masonry spandrels. The existing piers would still be used, and self-weight would be increased.	3
Replacement Spandrels & Deck	The deck and internal spandrels would function as existing albeit more durable.	4
FRP Strengthening of Internal Spandrels	Increased strength in the spandrel walls and reduction in crack propagation. Different wrap methods possible.	4
Underpinning	Will prevent and settlement due to increased loading. May be paired with strengthening methods that increase the self-weight of the structure.	4
New structure	A new structure will be of modern design and therefore be efficiently designed.	5
Alternative Route	No structural intervention is involved.	5
Structure Options	**Total Cost**	**Score**
Infill of Arch & Piers	This would have reduced construction costs as no formwork would be required. However, it would need to be coupled with underpinning increasing cost significantly.	2
Additional Arch Barrel Reinforcement	This would have reduced construction costs as no formwork would be required. However, the additional reinforcement option would need to be coupled with underpinning increasing cost significantly.	2
Deck Replacement	This would be relatively expensive as there would be complicated sequencing required to ensure that the arch remains stable. However, it may need to be coupled with underpinning increasing cost significantly.	2
Replacement Spandrels & Deck	This would be relatively expensive as there would be complicated sequencing required to ensure that the arch remains stable. However, it would need to be coupled with underpinning increasing cost significantly.	2
FRP Strengthening of Internal Spandrels	This would be a relatively cost effective option as there is little interference with the existing structure, removing the need for additional formwork and support.	4
Underpinning	There would be significant temporary works and complex construction techniques driving the cost of this option up.	2
New structure	This would be the most expensive option as a complete new substantial structure would be required to span the gorge. The cost of this would be high, especially as the aesthetics would likely need to be a significant consideration.	1
Alternative Route	This is the most cost effective option as it involves no structural intervention on Dean Bridge and the pro-rata cost per structure on Roseburn would be reduced compared to Dean Bridge.	4
Structure Options	**Environmental Impact**	**Score**
Infill of Arch & Piers	High carbon content Large amounts of foamed concrete would be required to fill the volume of voids in the structure.	3
Additional Arch Barrel Reinforcement	Reinforcement would be in the form of steel bars	3
Deck Replacement	Large amounts of concrete would be needed to construct the concrete saddle, this would result in higher embodied carbon.	3
Replacement Spandrels & Deck	This option would use less concrete than either infilling or saddling, therefore have a lower embodied carbon.	4
FRP Strengthening of Internal Spandrels	FRP has a higher strength to weight ratio than steel, therefore a lower weight is required. This means it will have less embodied carbon than any of the equivalent steel or concrete strengthening options.	4
Underpinning	This would require significant disturbance of area around the foundations of the bridge, one of these is by the river. Significant prevention would be required to avoid detrimental effects to the watercourse.	3
New structure	This option would have the largest material usage and therefore the most embodied carbon.	2
Alternative Route	No impact on existing structure. Impact on Roseburn corridor to be mitigated through design development, including local single track running.	2

Table 8.2: Basis of Option Scoring (Continued)

Structure Options	Health and Safety	Score
Infill of Arch & Piers	Demolition and working at height. Out of plane stability concerns and construction loading on the arch barrel and piers.	3
Additional Arch Barrel Reinforcement	Demolition and working at height. Out of plane stability concerns and construction loading on the arch barrel and piers.	3
Deck Replacement	Demolition and working at height. Stability concerns and construction loading on the arch barrel. Removal of existing structural member.	4
Replacement Spandrels & Deck	Working at height. Demolition of existing deck and internal spandrels. Stability concerns about loading on the arch barrel.	2
FRP Strengthening of Internal Spandrels	Working at height and within confined spaces, to apply the system to all vertical faces.	3
Underpinning	Piling and excavation of existing foundations on land and in water. Forming physical structural connection to main structure.	1
New structure	Working at height in constrained site, possible controlled demolition or offline construction of new structure.	5
Alternative Route	Conventional structures on alternative route, well understood with minimal health and safety risks.	5
Structure Options	**Buildability**	**Score**
Infill of Arch & Piers	Once voided areas access is secured, straight forward process to install concrete in a balanced manner.	4
Additional Arch Barrel Reinforcement	Once voided areas access is secured, straight forward process to install rebar, create a positive fix and install concrete in a balanced manner.	3
Deck Replacement	Demolition of existing deck requires care, formation of new deck upon permanent formwork between spandrels creates secure working area and avoids instability due to casting of concrete deck and track form.	3
Replacement Spandrels & Deck	Demolition of existing deck and removal of internal spandrels requires care, formation of new reinforced concrete spandrels requires care. Use of permanent formwork between spandrels creates secure working area and avoids instability due to casting of concrete deck and track form.	2
FRP Strengthening of Internal Spandrels	Working in confined spaces requires working platforms to securely attach the FRP.	4
Underpinning	River working required with at depth reinforced bored piles around existing foundations. Creation of a physical connection to existing foundations could prove challenging, but required for the new reinforced pile cap to be poured.	1
New structure	Challenging site constraints above and within the gorge. Composite construction can simplify buildability. At depth reinforced bored piles, piers and abutments, to support prestressed concrete or steel deck.	4
Alternative Route	Construction options established and straight forward minimising risk. Composite construction can simplify buildability.	5

Table 8.3: Basis of Option Scoring (Continued)

Structure Options	Maintenance	Score
Infill of Arch & Piers	Reduced likelihood of deterioration, due to structure voids being infilled. Regular routine inspections would continue.	5
Additional Arch Barrel Reinforcement	Reduced likelihood of deterioration, due to structure voids being infilled with rc concrete. Regular routine inspections would continue.	5
Deck Replacement	New rc deck would have a 120-year design life, and would have a reduced maintenance, but the remaining existing elements would still require ongoing maintenance which would be a challenge.	4
Replacement Spandrels & Deck	With a 120-year design life, the new elements would have a reduced likelihood of deterioration and require less maintenance. However, access for maintenance would still be a challenge.	3
FRP Strengthening of Internal Spandrels	Deterioration of the FRP would not be anticipated however any underlying defects in the parent masonry would not be identified through routine touching distance inspections.	3
Underpinning	Deterioration would not be expected with a design life of 120-years but would be identified through routine inspections, future maintenance would be anticipated to be minimal.	5
New structure	New structure would be required to have 120 year design life, therefore would reduce amount of anticipated maintenance. Additionally, maintenance and monitoring procedures could be designed in.	5
Alternative Route	Deterioration would not be expected for the new structures, with those modified subject to routine inspections, future maintenance would be anticipated to be minimal.	5
Structure Options	**Aesthetics**	**Score**
Infill of Arch & Piers	No impact on aesthetics of the structure, all strengthening works hidden.	5
Additional Arch Barrel Reinforcement	No impact on aesthetics of the structure, all strengthening works hidden.	5
Deck Replacement	No impact on aesthetics of the structure, all strengthening works hidden.	5
Replacement Spandrels & Deck	No impact on aesthetics of the structure, all strengthening works hidden.	5
FRP Strengthening of Internal Spandrels	No impact on aesthetics of the structure, all strengthening works hidden.	5
Underpinning	Underpinning works depending upon the depth the existing foundations, may be visible within the Leith Water gorge.	3
New structure	Noticeable impact on the aesthetics, to be agreed with stakeholders and planners, however a new structure could mimic the original or with architectural input made to suit its environment.	4
Alternative Route	No impact on aesthetics of the structure. Alternative route structures would be subject to separate aesthetic considerations.	5

9. Recommendation

9.1 Recommendation

This report has considered the viability of taking trams across the historic Dean Bridge. The study has considered the publicly available historic drawings, structural form and geometry of the structure and available existing geological records.

This historic category A listed structure has a unique form of construction with principal internal elements designed hollow (piers and arch spans), by Thomas Telford to reduce the total mass of the structure, relative to the bearing capacity of the underlying strata layers. The proposal to increase the mass of Dean Bridge by various options to accommodate tram loading, may well affect the structural viability of the original design, which was not designed for rail loading.

Based upon the considered information, it is strongly recommended that an alternative route be taken forward in lieu of the Dean Bridge routing proposal, as this would mitigate the concerns pertaining to modifying the structure to accommodate trams and their operation.

9.2 Future Structural / Geotechnical Inspection

Consideration of the structural viability is limited by a lack of available information regarding the existing structure, its current internal condition and the underlying strata layers.

Should the option to proceed with Dean Bridge be progressed, it is recommended that an inspection for assessment be undertaken. All external and internal elements of the structure should be fully accessed to within touching distance. Access should be gained to all the hidden confined spaces of the structure. This should also be combined with a full 3D dimensional survey to confirm the external and internal structural dimensions.

Intrusive coring and strength testing for the internal and external element is also recommended, to determine the material strengths of each masonry component.

Upon receipt of the gathered data, a full assessment of the bridge is recommended. The assessment would consider the short and long-term effects of applying the design tram loads to the structure. Additional load cases such as effects of traction and braking forces should be modelled and considered. A mechanism analysis of the external and internal spandrel walls would be appropriate. In addition to section capacity checks for the piers. An assessment of the foundations should also be undertaken.

Furthermore, a Geotechnical Investigation is required. This report has raised concerns surrounding the strength of the founding strata Section 4.5 and 6.3.4 and subsequently the bearing capacity of the foundations of the structure. Given the limited information available on the foundations it’s expected that this would also involve at depth boreholes to enable the creation of a robust ground model for Dean Bridge.

Inter-discipline analysis should also look at the interaction between the structure and the soil to assess and determine the limiting capacity, respective to the adoption of any proposed option.

It was also identified that there are a number of services running under the structures footpath within a structural void. A survey should be undertaken to establish the service providers and ensure there are no further services located in other areas of the deck. The available space should also be established as services may need to be moved to accommodate tram utilities if they cannot be incorporated into or alongside the track form.