Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

Aberdulais Aqueduct

Structural Inspection Report

for

Waterways Recovery Group

Project Number:	10925
Date:	Dec 2021
Rev:	P1

Bath - 7 Old King Street, Bath, BA1 2JW T 01225 464419

Belfast - 9-11 Corporation Square, Belfast, BT1 3AJ T 02890 998670

Content/Quality Assurance

Document issue details:
10925_R_TM_01

Version Number	Issue Date	Issue Status	Distribution
P1	07/12/2021	For Comment	Client
P2	28/01/2022	FINAL	Client

Prepared	Checked	Approved	Date
TM	PR	PR	06/12/2021
TM		PR	28/01/2020

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

1.0 Introduction

1.1 Mann Williams were instructed to undertake a structural inspection of Aberdulais Aqueduct to determine the scope of deterioration since the last condition survey in 2009 and make costed recommendations for its repair.

1.2 The aqueduct is located in Aberdulais northeast of Swansea in south Wales. It is the crossing of the Tennant canal over the river Neath. Upstream from the aqueduct is a partially breached weir, the confluence of the river Neath and river Dulais and the A465 bridge over the river Dulais. Downstream of the aqueduct is a masonry arched rail bridge and a modern road bridge carrying the B4434.

1.3 Immediately to the east is a canal basin and the end of the Tennant canal where it joins the Neath canal. To the west the canal continues through its only locks immediate west of the aqueduct to Swansea and its terminus at Swansea marina.

1.4 The aqueduct was constructed in 1823 and was engineered by William Kirkhouse. It is the longest canal aqueduct in South Wales and a very traditional British narrow-canal type.

1.5 The aqueduct is grade II* listed and a Scheduled Monument. It is currently owned by the Port Tennant Canal Company.

1.6 Recce visits were undertaken on 7th of April 2021, and the 13th of April when the weather was dry and overcast.

1.7 The full inspection was carried out on the 22nd September 2021, the weather was overcast with a very brief shower following an extended dry period. During the inspection touching distance access was gained to the majority of the structure.

1.8 The following page shows a plan and section from the photogrammetric model of the site. These have references A-I for key features of the site which are consistent throughout the report. More detailed areas of each feature have numeric references which are also consistent, ie E3 is the third detail of the aqueduct section canal channel.

1.9 The 3D model can be viewed at:

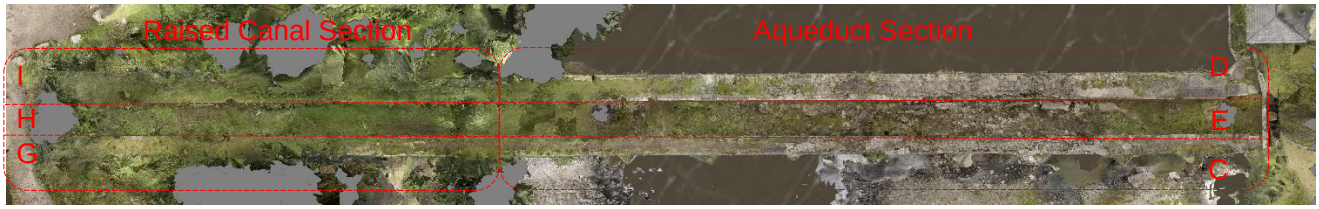
Aqueduct Only

https://skfb.ly/o7TVu

Wider Area

https://skfb.ly/o7TTS

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

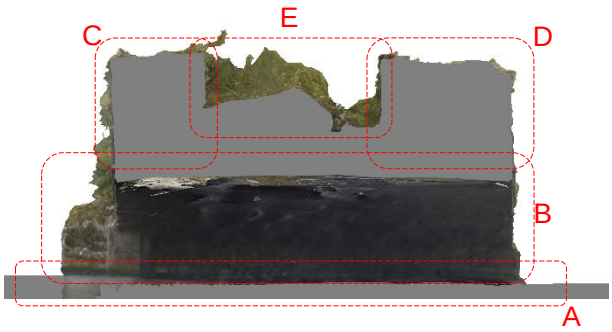


Aqueduct Section

- *A – Apron*
- *B – Arches*
  - *Arch 1-10 (numbered west to east)*
- *C – Upstream channel wall*
- *D – Downstream channel wall*
- *E – Canal channel*

Raised Canal Section

- *F – Arch 11*
- *G – Upstream channel wall*
- *H – Downstream channel wall*
- *I – Canal channel*



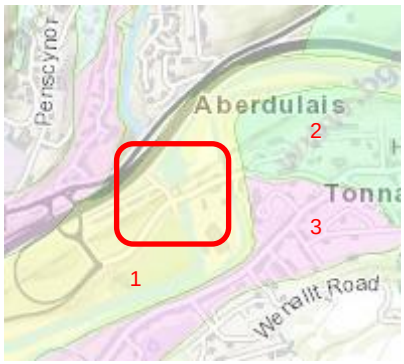
Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

2.0 Desk Study

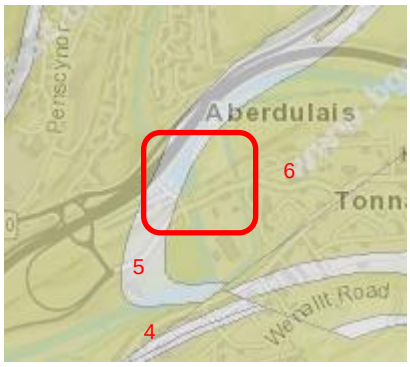
2.1 As part of the desk study for this site historic maps and photographs have been collated and studied as well as online geological information. In addition to these sources the listing text, information from the client and Cadw have all been reviewed.

2.2 British Geological Survey Website

2.2.1 The British Geological Survey website shows superficial and bedrock geology as well as publicly available borehole records.



Superficial Geology



Bedrock Geology

Boreholes

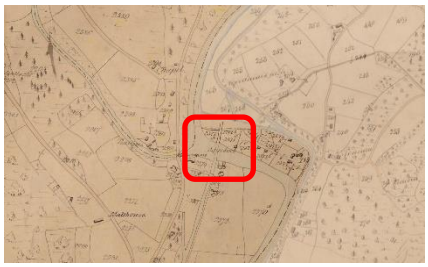
1 – Alluvium, (clay, silt, sand and gravel)
2 – Glacial Deposits (sand and gravel)
3 – Glaciofluvial Sheet Deposits (sand and gravel)
4 – Local Fault Lines
5 - Brithdir Member - Mudstone, Siltstone and Sandstone
6 - Brithdir Member - Sandstone
7 – Boreholes around site from construction of A465 and B4454 bridge show dense sands and gravels with occasional clay layers, one borehole shows sandstone bedrock at -23m AOD.

2.2.2 On site the river channel was formed in rounded gravels and no bedrock was visible.

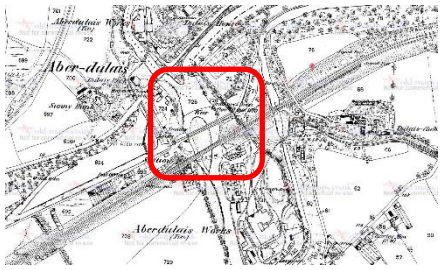
2.2.3 The above shows the dominant ground conditions across most of the area are deep superficial sand and gravel deposits.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

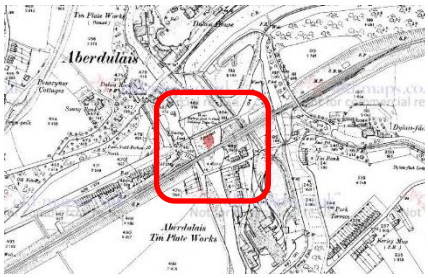
2.3 Historic Map Regression



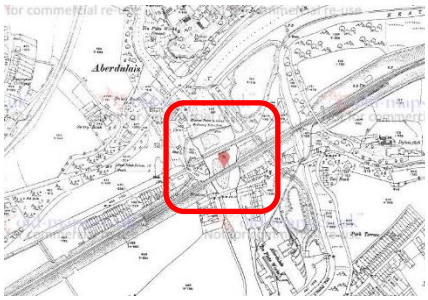
1844 / 46 Combined Tithe Maps
- *Shows Aqueduct in current arrangement*
- *Tinworks shown downstream*
- *Navigable cut to west shown and both Tennant and Neath canals.*
- *Bridge shown over Dulais upstream*



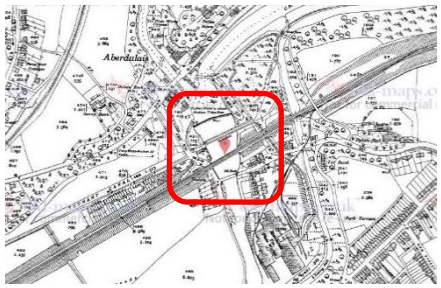
1880 OS Map
- *Railway bridge and weir now shown*
- *Bridge shown over river Neath upstream*



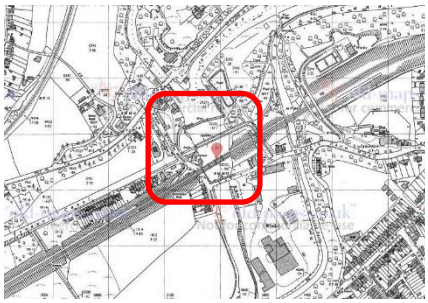
1889 OS Map
- *Road bridge shown downstream of railway bridge*
- *Towns continue to grow*



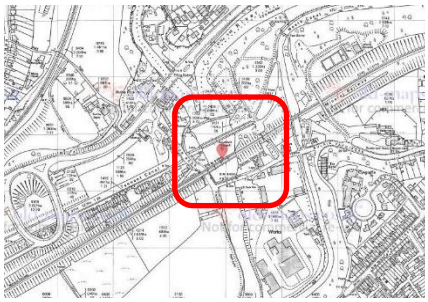
1918 OS Map
- *Towns continue to grow*



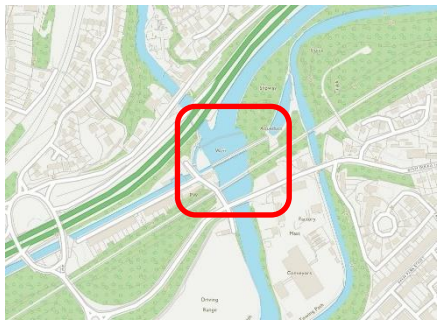
1935 OS Map
- *Station road shown*
- *Towns continue to grow*



1964 OS Map
- *Bridge over river Neath upstream no longer shown*
- *Navigable cut to west no longer shown*
- *End of aqueduct now shown disconnected from basin*



1984 OS Map
- *A465 roundabout and some earthworks shown*



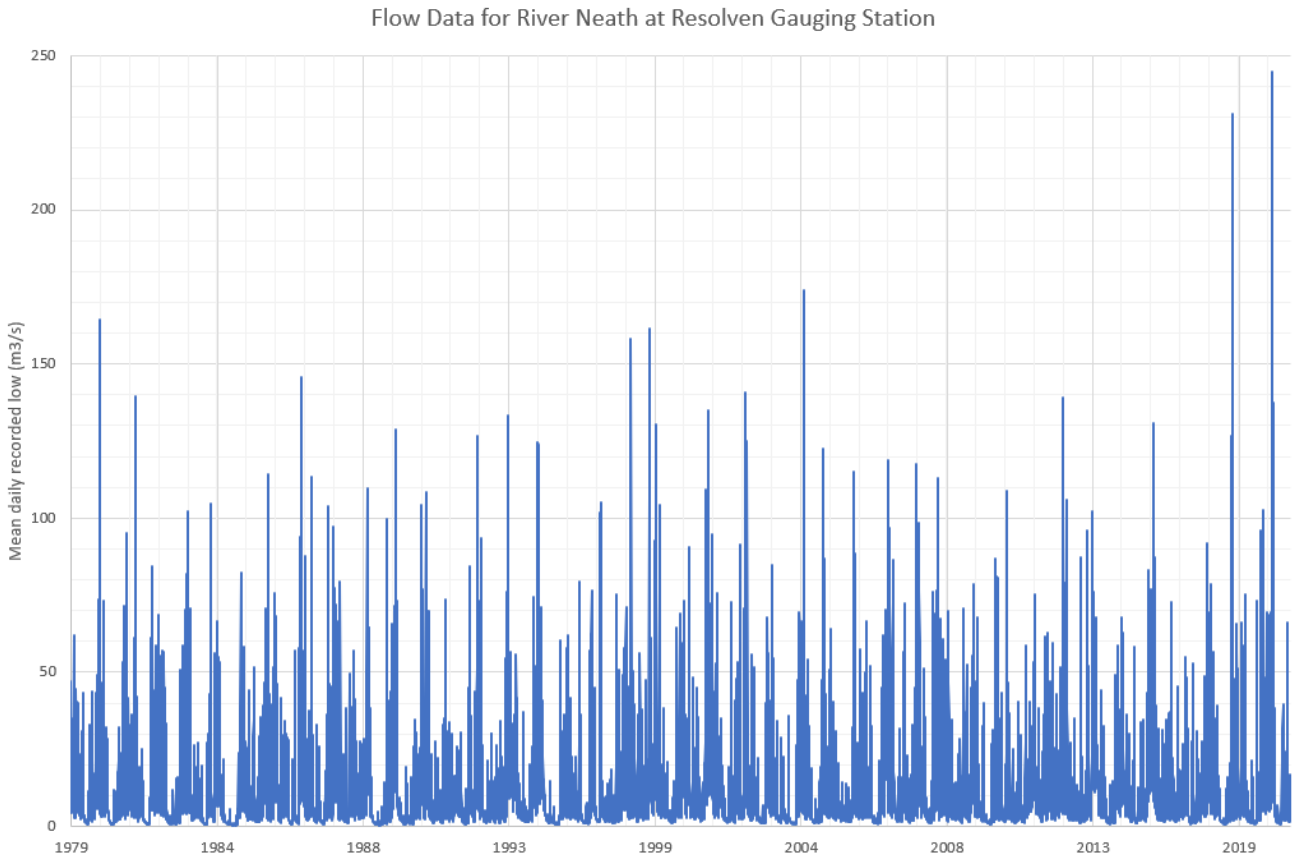
2021 OS Map
- *A465 shown with associated change to river Neath channel*
- *B4434 shown and bridge downstream upgraded.*

2021 OS Map with overlay of 1964 river channel.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

2.4 Hydrological Data

2.4.1 The following graph is produced from flow data from the National River Flow Archive for the River Neath at Resolven. This flow gauging station is 4.5km upstream of the site and therefore does not include flows in the Dulais or any other tributaries in this stretch of the river.



2.4.2 This data shows two very significant recent flood events, around 225m^3/s, in February 2020 and October 2018 and a series of slightly less significant flood events, around 125m^3/s, at regular intervals for the duration of recording.

2.4.3 The station details show the following statistics:

- Mean Flow: 9.566 m^3/s
- 95% Exceedance (Q95): 0.769 m^3/s
- 70% Exceedance (Q70): 2.378 m^3/s
- 50% Exceedance (Q50): 4.278 m^3/s
- 10% Exceedance (Q10): 23.4 m^3/s
- 5% Exceedance (Q5): 35.91 m^3/s

2.4.4 The catchment of the river Neath is approximately 31,652 Ha and the area of the catchment at the gauging station is 19,090 Ha. The catchment at the aqueduct has been estimated as 25,350 Ha suggesting flows would be approximately 30% higher at the site than the gauging station.

2.4.5 The 1979 archive image shows the aqueduct fully inundated in the Dec 1979 flood. This suggests at least three other floods in 2004, 2018 and 2020 will have overtopped the aqueduct.

2.5 Historic Photos

2.5.1 The following images are taken from a variety of sourced including the briefing documents and reports issued with the tender for these works and online images from searches.

1979

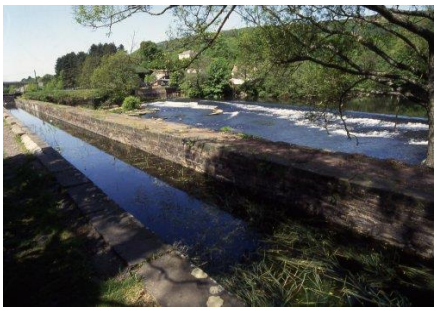
1980

1998

2001

2005

2007



2009

2012

2012

2014

2017

2017

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

2018

2018

2020

2020

2020

2021

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

2.6 2012 Opus Report

2.6.1 This report was commissioned by Neath Port Talbot County Borough Council from Opus in 2012 following previous reports in 2007, 2009 and 2003. The aim of the report was to present a repair scheme to bring the aqueduct and lock back into use and discuss this with the relevant stakeholders.

2.6.2 The 2009 report was also caried out by Opus but for the Port Tenant Canal Company. It included a condition survey and geotechnical investigation works. The conclusions from these are indirectly referenced in the 2012 report. We have not seen copies of the Opus reports other than the 2012 one.

2.6.3 The 2012 report makes the following recommendations for the repair of the aqueduct:

- Repair deteriorated masonry to sides and soffit of arches, including removal of vegetation, replacement of missing masonry and repointing.
- Pressure grouting/consolidation of masonry to be carried out locally where the condition of masonry is loose.
- Excavation of the channel vegetation and accumulated materials.
- Repair the existing pathway, to remove vegetation, concrete and tarmac surfacing. Reinstate the paving using nominally 100mm sandstone paving to match existing.
- Repair scour damage to invert below the arches with new concrete. The existing invert has up to 0.8m scour damage as recorded on the 2009 inspection reports.
- Reconstruct the deteriorated 1.15m high masonry wall at the east end of the Aqueduct, south side.
- The iron trough at the East end of the aqueduct is to be exposed, repaired and repainted.
- Provide a new waterproof lining to the Aqueduct Channel.
- Add various fencing to restrict pedestrian access
- Add removable maintenance bridge to east end

2.6.4 The discussions with the various stakeholders showed:

- While supportive of the scheme the Tennant Canal Company did not have any money for work involved with any restoration work.
- Neath Navigation Canal Company were concerned about water demand for the aqueduct and locks.
- Cadw would have required Scheduled Monument Consent for the works and asked for maximisation of reversible works and justification for all works.
- The Environment Agency (now Natural Resources Wales) required no increase in flood risk with flow modelling a likely requirement to justify this.
- Neath Port Talbot County Council were generally in favour of the scheme.

2.6.5 This report does not provide a detailed condition survey which can be used as a benchmark for the current condition of the monument. This is contained within the 2009 report which has not been made available.

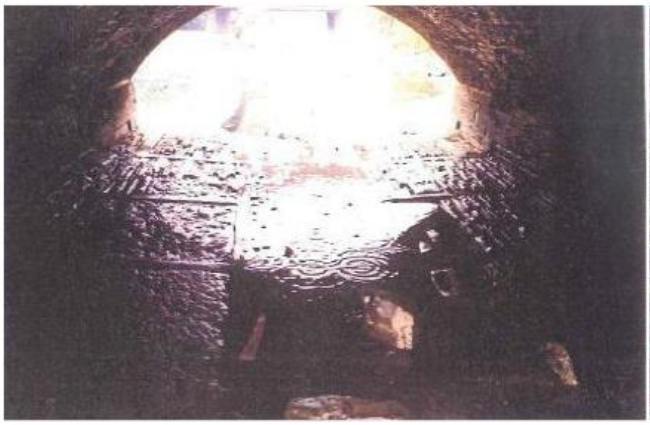
Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

Aberdulais Aqueduct looking East

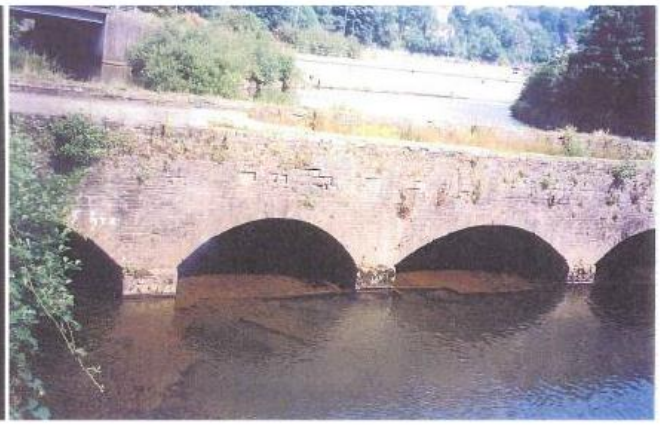
Aberdulais Aqueduct, North side

Aberdulais Aqueduct, East end & wall

Aberdulais Aqueduct, iron trough



Arch 1 stone/timber bed protection



Arches 1-3, deteriorated bed protection

Images reproduced from Opus 2012 report

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

2.7 Site Timeline

2.7.1 Based on the above we have developed a timeline of significant events and changes on the site and in the immediate area.

- 1821 – Tennant Canal construction began
- 1823 – Aqueduct construction began
- 1824 – Tennant Canal opened
- 1934 – Tennant Canal closed to commercial traffic
- Pre 1979 – Downstream parapet wall to toe path removed, reinforcement added to 2 no central arches
- 1979 - Major flood event overtops aqueduct
- 1980 – Aqueduct designated a Grade II* listed structure
- 1997 – Aqueduct designated a Scheduled Monument
- Mar 1998 – Major flood event
- Oct 1998 – Major flood event
- 2001 - B4434 Upgraded
- 2003 – Atkins Flood Alleviation Scheme, Feasibility Report
- Feb 2004 – Major flood event
- 2007 – Hyder Neath and Tennant Canal Restoration: Economic Appraisal Report
- 2009 - Opus Feasibility study for the Rehabilitation of the Aberdulais Aqueduct
- 2012- Opus Feasibility Study and Design Development Report
- 2014-2017 – Weir upstream breached
- Oct 2018 – Major flood event
- Feb 2020 – Major flood event

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

3.0 Inspection Methodology and Access Extent

3.1 During the inspection the monument was inspected from ground level only. The level of access achieved was determined on site based on a combination of the effectiveness of ground level inspection, condition of the area, similarity to other areas, complexity of access and safety of access.

3.2 Finger tip access was gained to the whole of the top of the aqueduct, the upstream face, in the river channel, and the inside of 3-4 of the arches. The following areas were not accessible at this level:

3.3 The downstream face of the aqueduct in the river channel was inspected visually from the shallow section of the river 20m downstream. The river channel closer to the monument was too deep to enable access. Local areas were inspected at touching distance from inside the arches.

3.4 The remainder of the arches were inspected visually from the upstream face. This was a combination of fast river flow making access difficult and apparent consistency between the arches.

3.5 The downstream face of the raised canal section on the east bank was not inspected, it was obscured by vegetation over its whole length.

3.6 The upstream face of the raised canal section on the east bank was partially inspected at touching distance, the remaining 20% was obscured by vegetation.

3.7 The inside of the canal channel was inspected at touching distance over its whole length but much of it was obscured by vegetation, soil and rubble. Approximately 5% of the channel base, 75% of the downstream face and 55% of the upstream face were visible.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

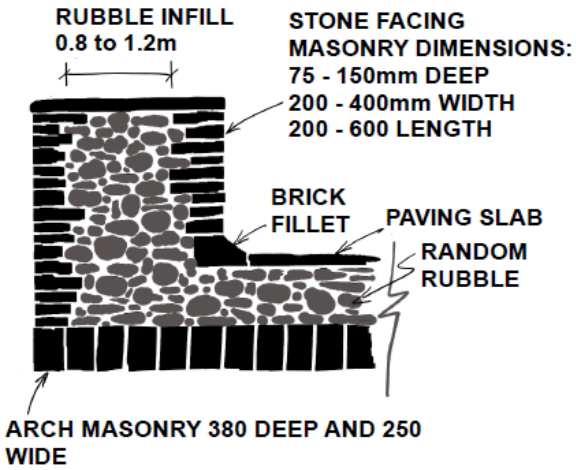
4.0 Structural Form

4.1 The following sections describe the form of the structure during the inspection with some comments regarding the likely original form. Throughout this section areas of the monument are referred to by numbers shown on the key views.

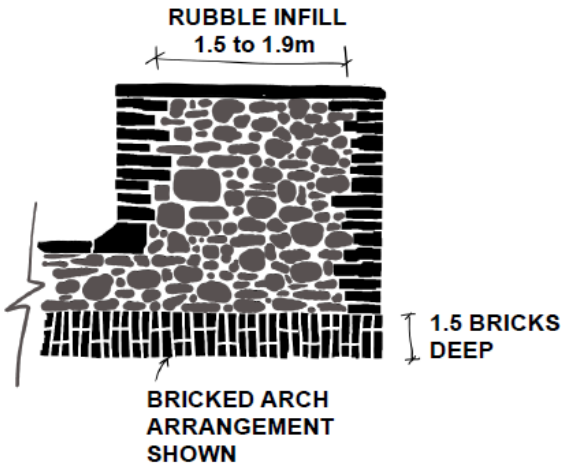
4.2 The monument has been split into two principal sections, the aqueduct section over the river Neath and the raised canal section on the east bank of the river. Each of these have been further split into different construction elements which are similar over the length of the structure.

4.3 The aqueduct section is 65m long, 4m high from the apron and 7m wide. It is formed from 10 arches supporting upstream and downstream channel walls with the canal channel between.

4.4 The raised canal section is 40m long, the same width as the aqueduct section and the height reduces away from the river as ground level raises. It is formed from upstream and downstream channel walls with the canal channel between. At the east end is a single arch (arch 11), crossing a former navigable cut, with a cast iron trough forming the canal channel.



UPSTREAM WALL



DOWNSTREAM TOWPATH

4.5 Aqueduct Section – Apron - A

4.5.1 The Apron was largely obscured by river gravel and water however, the visible areas suggest there is a level concrete apron (A1) beneath each arch (B). The Apron appears to continue approx. 100mm past the downstream face (A2) and finish flush with the upstream face. It continues past the piers on the downstream face (A3) and under the breakwaters on the upstream face (A4). At the downstream face there is a very slight (approx. 50mm) weir effect caused by the apron.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.5.2 This concrete apron is almost certainly not original but no evidence on site or from the desk study suggests when it was constructed (other than pre 1980). The archive photos do suggest the river channel upstream used to also have a concrete apron and that this may have extended from the weir to the aqueduct.

4.5.3 Below arches 1 and 2 the concrete apron does not appear to be present. The 2012 Opus report includes a photo of arch 1 labelled as a timber and stone apron. This appears to show a pitched stone apron with transverse timbers sloping down to the centre of the arch and longitudinal centre and edge timbers. During our inspection, this construction was not visible in arch 1 which was obscured by river debris but was visible in arch 2.

4.6 Aqueduct Section – Arches - B

4.6.1 The aqueduct section is supported on 10 arches (B1) (numbered from west to east) between piers (B2) and abutments (B3). The span of the arches varies (as below) but the springing level crown level and original detailing are all consistent. The springing points are 0.5m above the apron and the arch crowns are 1.6m above the apron.

Arch	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Span (m)	*4.5*	*4.2*	*6.1*	*6.2*	*6.1*	*6.1*	*6.2*	*6.1*	*4.6*	*4.6*

4.6.2 Each arch is formed with a 380mm deep 250mm wide stone facing arch (B4) on the upstream and downstream faces. These are formed with tapered stones, with radial grooved patterning, and no key stone.

4.6.3 Each pier (B2) has a concrete breakwater (B6) on the upstream face which appears to encase a stone breakwater (B7) these obscure the facing arch springing. The concrete breakwaters are of varying size but are consistently wider than the stone pier and return (B8) into the arch. The downstream face of the piers is rectangular with a slight step out on plan (B9) and a single springing stone (B10).

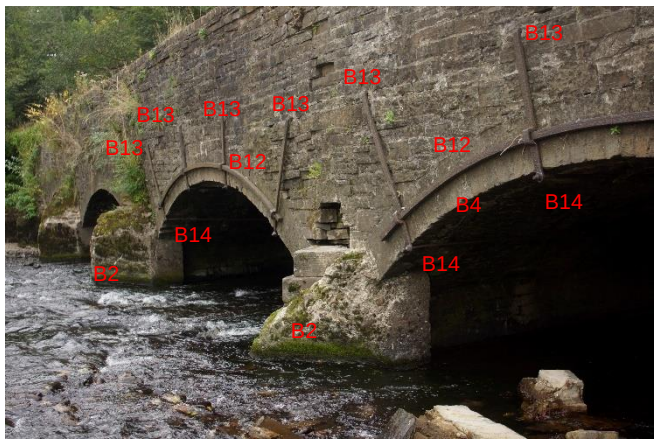
Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.6.4 The inside of the arches (B1) is formed with an arch barrel (B5) of the same shape as the facing arch (B4) and vertical pier (B2) walls. The arch barrel (B5) is roughly coursed rubble stonework partially finished in a smooth render. The pier walls (B11) are constructed from roughly coursed rubble stone with rows of putlog holes at water level through the thickness. The thickness of the facing stone for both was not possible to measure.

4.6.5 The spandrel panel (B12) between arches is a continuation of the channel wall above and is described as part of that.

4.6.6 Arches 6 and 7 have been reinforced with metal straps. These are formed with a 50x50mm curved bar (B12) on each facing arch (B4), 4 No 25x50mm radial bars (B13) on each face and 4 No 20-25mm dia rods (B14) under the arch vault.

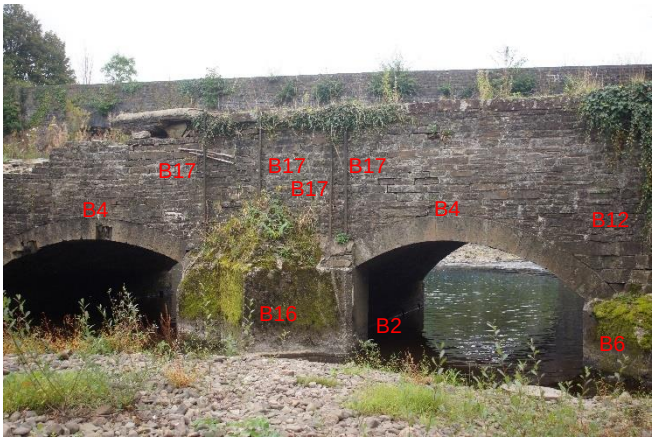
4.6.7 The radial bars (B13) are built into the masonry at the top formed around the curved bars (B12) and bolted to threaded ends of the rods (B14). In theory tightening the rods (B14) will clamp the curved bar against the facing arch but due to the length of the rods it is unlikely any significant force could be generated.



4.6.8 The downstream facing arch of arch 1 (B15) is brick, it is a brick and half deep and 1 brick wide. There is some visible evidence the facing stonework above has been rebuilt with some leachate suggesting this could be in cement mortar. The brick arch appears to be present in archive photos from 1998 and is definitely in photos from 2007.

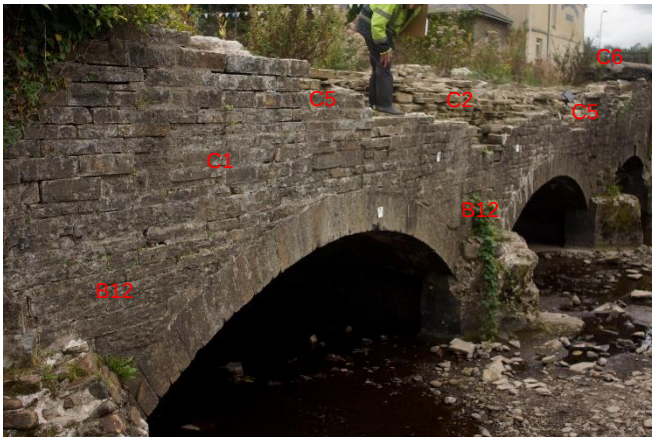
Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.6.9 The concrete breakwater to the pier between arches 2 and 3 (B16) is significantly larger than the other concrete breakwaters (B6). Above the breakwater (B16) there are 4 No irregularly spaced vertical metal rods (B17) against the face of the spandrel wall (B12). These metal rods bend 90 degrees and run over the head of the channel wall. The end of each bar is fixed down with an embedded U bar.



4.7 Aqueduct Section – Upstream Channel Wall - C

4.7.1 The upstream channel wall is 1.6m thick and faced both sides (C1) in well coursed rubble stone. Stone courses vary from 75mm deep to 150mm deep and stones vary in length from 200 to 600mm where measurable the stone thickness is 200 to 400mm. The stonework to both faces (C1) is consistent over the whole length and height including the spandrel panels between arches (B12). Where visible the core material (C2) is roughly coursed stone core-work bound in lime mortar.

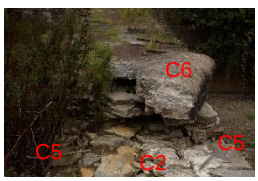


4.7.2 The top of the wall varies significantly over the length of the aqueduct and between the two faces:

- Over arches 1 and 2 the outside and inside faces have a formal, larger format, stone coping (C3) and the wall is capped with concrete (C4) between and flush with the top of the coping stones.
- Over arch 3 the top of both faces is unmade (C5) with exposed core-work (C2) between and a displaced section of concrete coping. Evidence on site and archive images suggest the outside face had an insitu concrete coping (C6).
- Over arches 4-6 the top of both faces is unmade (C5) with exposed core-work (C2) between. There is evidence on site that these were formed as either side but the extent of each is unclear.
- Over arches 7 and 8 the outside face has a yellow brick coping (C7). The inside face has stone coping(C3) and the wall is capped with concrete (C4) between flush with the top of the copping stones.
- Over arches 9 and 10 the outside face has no formal coping (C8), the inside face has a formal, larger format, stone coping (C3) and the wall is capped with concrete (C4) between, flush with the top of the coping stones.

The archive images do not add anything further other than suggesting various phases of degradation and repair with different detailing.

Arches 1-2



Arch 3

Arches 4-6

Arches 7-8

Arches 9-10

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.8 Aqueduct Section – Downstream stream Channel Wall - D

4.8.1 The downstream channel wall is 2.3m thick and faced both sides in well coursed rubble stone. Stone courses vary from 75mm deep to 100mm deep and stones vary in length from 200 to 600mm where measurable the stone thickness is approx. 200mm. There are a handful of distinct deeper courses of stonework including two adjacent courses (D1) at 130 and 170mm deep just above the arch crowns in the outside face. The stonework to both faces is otherwise consistent over the whole length and height including the spandrel panels between arches (B12). Where visible the core material is roughly coursed stone core-work bound in lime mortar.

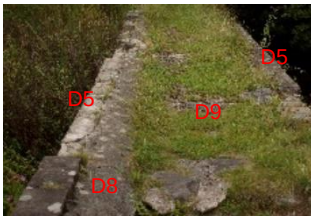
4.8.2 The top of the wall varies significantly over the length of the aqueduct and between the two faces. The outside face has no formal coping over the whole length and the level of the stonework steps.

- Over arches 1 and 2 - the inside edge is variable with 3 bricked up water control features (D2) 2 large coping stones (D3) and some squared concrete slab (D4) over the wall head. The outside face is an even wall head with no formal coping (D5).
- Over arch 3 – the inside edge is an unmade wall head (D6) with chamfered concrete slab (D4) over the inside wall and half of the wall head. The remainder of the wall head is unmade exposed core work (D7). The outside face is unmade (D6).
- Over Arches 4-7 - the top of both faces is unmade (D6) with exposed core-work (D7) between and a small remnant area of concrete slab (D4).
- Over arches 8-10 – the tops of both faces have an even wall head with no formal coping (D5). The inside face is approx. 150mm proud of the remainder with a concrete fillet (D8) behind and thin, patchy concrete over core-work (D9) between the two faces.

Arches 1 and 2

Arch 3

Arches 4-7



Arches 8-10

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.9 Aqueduct Section – Canal Channel - E

4.9.1 The aqueduct channel is 3.2m wide and 1.2m deep, the base (E1) is approximately 850mm thick over the arch crowns. The downstream wall (E2) is approximately 150mm lower than the upstream wall.

4.9.2 The base (E1) of the channel is generally obscured by vegetation, earth or rubble. Where it is visible it appears to be a stone paved surface with a shaped brick fillet (E3) in the corners.

4.10 Retained Canal Section – Arch 11 - F

4.10.1 Arch 11 is located at the east end of the retained canal section. The downstream face of the arch was completely obscured by vegetation and was not located during our inspection. The upstream face was partially obscured by vegetation and difficult to access to inspect effectively.

4.10.2 The form of the arch is different to the aqueduct section arches. There are stone arches supporting the channel walls and a spanning cast iron trough supporting the channel.

4.10.3 The stone arch on the upstream face has a stone facing (F1) arch similar to the aqueduct section arches. The remainder of the upstream channel wall thickness has a stone vaulted soffit (F2) to the cast iron trough (F3) .

4.10.4 The cast iron trough (F3) is visible as a vertical iron face with two horizontal rounded ribs on the outside face and a vertical iron face on the inside face. The soffit appeared to be at the same level as the remainder of the channel base. There is a straight joint between the stonework inside face of the channel walls and the trough.

4.10.5 The channel under arch 11 is now almost completely infilled with only a 50mm gap below the cast iron trough now present.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

4.11 Retained Canal Section – Upstream Wall - G

4.11.1 The upstream wall of the retained canal section is a continuation of the aqueduct section upstream wall (C) with the same dimensions. The outside face (G1) has no formal coping (G2), the inside face has a formal, larger format, stone coping and the wall is capped with concrete but heavily overgrown and obscured by vegetation. The middle section of the outside face (G3) is obscured by vegetation. Along the outside face is a rough unmade channel (G4), near the river bank is a concrete projection (G5) to the wall with a slot which appears to be a sluice of some kind.

4.12 Retained Canal Section – Downstream Wall - H

4.12.1 The downstream face of the raised canal section is heavily obscured by vegetation, none of the external face was visible during the inspection. It is a continuation of the aqueduct section downstream wall (D) with the same dimensions. The outside face extends above the wall head as a 430mm wide 980mm high parapet wall (H1) with dressed stone coping over a length of 5m. The inside face (H2) is flush with the wall head (H3) with stone copings (H4). The wall head (H3) is obscured by vegetation cover.

4.13 Retained Canal Section – Canal Channel - I

4.13.1 The canal channel in the retained section is the same dimensions as the aqueduct section (E). The base of the channel is totally obscured. The earth cover was recorded as 350mm deep very wet silt in one location near arch 11. The base of the channel appears to be at the same level as the aqueduct section.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.0 Structural Condition

5.1 The defects observed on site have been split into general and specific defects and are outlined below. This includes the risks posed to site users and the monument by these defects.

5.2 Where possible comparison has been made to condition in 2009 however as discussed in section 2.6 we have not had access to the 2009 condition report. Any comparisons are limited to items discussed in the 2012 report or visible in the images from that report.

5.3 Specific Defects

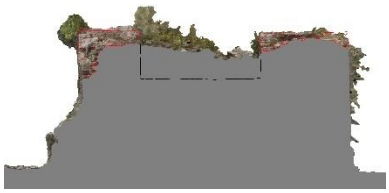
5.3.1 The following sections describe the defects observed on site which are limited to a single location. These include the most critical defects.

5.3.2 Collapsed Sections of Channel Walls

5.3.2.1 The most visually significant defect affecting the aqueduct is the section of broken down masonry over arches 3, 4 and 5. Over this length the upstream and downstream channel walls have lost a proportion of their masonry and the canal channel is full of masonry debris.



5.3.2.2 The upstream channel wall (C) has lost 0.5m height over its full width and 1.25m height of the upstream facing (C1). The downstream channel wall (D) has lost 0.25m height over its full width and 0.5m height of the downstream facing. Both walls (C & D) are affected over a length of 16m with the damage reducing towards both ends and worst at the centre.




5.3.2.3 The exposed top surface of the channel walls (C & D) is exposed core work consolidated in mortar without significant voids. This is not a repair since the section was damaged and is inconsistent with the original construction period. This suggests the channel walls have been dismantled and rebuilt to consolidate the core work at some point.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.3.2.4 The upstream face of the upstream channel wall (C1) is broken down to a lower level than the core work behind and there is a void between the remaining facing stone and core work. This in conjunction with the distortion discussed in section 5.4.5 suggests the facing stone (C1) is not well bonded to the core material and has moved away from it.

5.3.2.5 Although this is a significant defect in the masonry it is not progressive and is unlikely to propagate further deterioration without outside influence.

5.3.2.6 The exposed core work and void behind the facing stone both increase the likelihood and consequence of vegetation growth. The uneven surface and void are likely to collect soil and seeds encouraging plant propagation. The voids and more uneven stonework will allow roots into the masonry and are less robust against the forces generated by this. Combined with vegetation growth the void behind the facing has the potential to cause a larger collapse of the facing masonry.

5.3.2.7 Likewise, the exposed core and void behind the facing increase the vulnerability of this area to hydraulic damage during flood events. The reduced crest height will increase the frequency this area is overtopped and increase the water velocity in this location. In addition, the exposed core work and voided facing stone are less robust against these hydraulic forces.

5.3.2.8 Finally, there does not appear to be a hydraulic or structural reason for the flood damage to have started in this location. It is possible a pre-existing defect or debris impact triggered the initial defect which reduced the robustness of the masonry causing the defect to progressively enlarge. This suggests the defect could have started at any point along the aqueduct and strengthening works may be required along the full length.

5.3.3 Damaged Arch Voussoirs

5.3.3.1 On the upstream face of arch 3 (B), 7 of the facing arch (B4) voussoirs are damaged. Each have lost around half of their face.

5.3.3.2 This defect does not pose a significant immediate risk to the monument but is a general deterioration of the masonry robustness.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.3.4 Missing Area of Stone Breakwater

5.3.4.1 Between arches (B) 6 and 7 the stone breakwater (B7) on the upstream edge is exposed and has lost 2 No stones exposing the core material behind. The stone is exposed due to degradation of the concrete breakwater (B6) as described in section 5.4.4. The top two stones forming the breakwater are still in place but look vulnerable.

5.3.4.2 This defect reduces the robustness of the adjacent facing masonry making it vulnerable to hydraulic action or impact. It poses a risk to the monument of further loss of stonework and potentially a more significant local collapse.

5.3.5 2 No Missing Facing Stones

5.3.5.1 Above arch (B) 5 on the downstream face of the downstream channel wall (D) 2 No facing stones are missing exposing the core behind.

5.3.5.2 This defect reduces the robustness of the adjacent facing masonry making it vulnerable to hydraulic action or impact. It poses a risk to the monument of further loss of stonework and potentially a more significant local collapse.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.4 General Defects

5.4.1 The following sections describe the defects observed on site which are not limited to a single location and apply to larger areas of the monument. Where specific locations are of particular concern or are good examples of the defect they have been noted.

5.4.2 Degraded Pointing

5.4.2.1 The condition of the masonry pointing varies across the monument but is generally in reasonable condition with localised areas of missing pointing. These can be broadly categorised into three conditions:

- Area of general pointing loss where approx. 90-100% of joints have lost the majority of their pointing within a defined area.
- Area of generally reasonable pointing with isolated local loss where approx.. 5-10% of joints have lost their pointing over a more general area.
- Area of generally reasonable pointing with no significant distress

Area of general pointing loss

Area of generally reasonable pointing with isolated local loss

Area of generally reasonable pointing

5.4.2.2 The areas of general pointing loss are limited to areas of the downstream face of the downstream channel wall (D) around the areas where stonework was lost in the recent flooding. This accounts for approx. 25% of the area of this face.

5.4.2.3 The areas of isolated local loss of pointing account for the majority of the remainder of the monument. This accounts for approx. 90% of the outside face of the upstream channel wall (C and G), 15% of the outside face of the downstream channel wall (D) and 75% all of the visible inside faces of the channel walls (C, D, G and H).

5.4.2.4 The remainder of the pointing was in generally reasonable condition. This accounts for approx. 10% of the outside face of the upstream channel wall (C and G), 60% of the outside face of the downstream channel wall (D) and 25% all of the visible inside faces of the channel walls (C, D, G and H).

5.4.2.5 The risks posed to the monument is an ongoing general deterioration of the masonry robustness which will continue to reduce its resistance to hydraulic forces in flood events and increase the risk of damage to the stonework.

5.4.3 Vegetation growth

5.4.3.1 The degree of vegetation growth varies across the monument in extent and severity of impact on the monument structure. Broadly there are four distinct types of vegetation growth on and around the monument which warrant discussion.

- Soft herbaceous vegetation growth from masonry faces and horizontal surfaces.
- Woody vegetation growth, such as saplings, from masonry faces and horizontal surfaces.
- Trees, both mature and growing, adjacent to the structure.
- Growth of invasive species on and adjacent to the monument.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.4.3.2 Soft herbaceous vegetation is growing from the majority of the channel wall heads (C, D G and H), from the inside face of the channel walls (C, D G and H) and to a lesser degree from the outside faces of the channel walls (C, D G and H).

Sparse soft vegetation growth from outside face of downstream channel wall (D).

Dense soft vegetation growth in canal channel (E) and variable growth on downstream channel wall head (D and H).

Dense soft vegetation growth in canal channel (E) and moderate growth on inside face of upstream channel wall (C).

5.4.3.3 The risks posed to the monument is an ongoing process of vegetation growth which will tend to encourage soil deposition and opening of joints increasing the likelihood of woody vegetation growth.

5.4.3.4 Amongst the soft vegetation growth there are some saplings taking root in the channel wall heads (G and H) and channel base (I) of the retained canal section. Most of these are small plants approx.. 600mm high but there was at least one over a metre high.

5.4.3.5 The risks posed to the monument is an ongoing process of root growth opening joints in the masonry, allowing further vegetation growth and displacing and damaging the stonework.

5.4.3.6 Both sides of the retained canal section are mature woodland. There are large trees and shrubs growing close to the monument with branches overhanging it.

5.4.3.7 There are three separate risks posed to the monument by the proximity of the trees. The root zone of the trees almost certainly extends below the monument and may cause swelling or shrinkage of the ground as the trees grow and die. The overhanging branches of the trees will increase the likelihood of woody vegetation growth taking root on the structure. Finally, if any trees fall, they could cause damage to the structure by impact or by disturbing the ground below the monument.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.4.3.8 On and around the retained canal section there are Himalayan Balsam and Japanese Knotweed plants, this is particularly the east end of the canal channel (I) and the downstream channel wall (H). Both plants are listed on schedule 9 of The Wildlife and Countryside Act (WCA) 1981 making it an offence to plant or allow it to grow in the wild. As such landowners have a duty of care to prevent its spread from their property. Himalayan Balsam propagates via seeds which can travel great distances by water so its presence near watercourses is undesirable.

Japanese Knotweed

Himalayan Balsam

5.4.3.9 This defect does not pose a significant immediate risk to site users.

5.4.3.10 Japanese Knotweed possess a risk to the monument as its root growth can be very damaging to structures.

5.4.4 Degradation of Concrete Breakwaters

5.4.4.1 All the concrete breakwaters (B6) to the upstream face have mechanical damage particularly to the corners. The degree of degradation increases for the breakwaters closer to the channel centre. The extent of degradation is significant for 5 of the 11 breakwaters and of these 5 one is almost completely compromised as described in section 5.3.4.

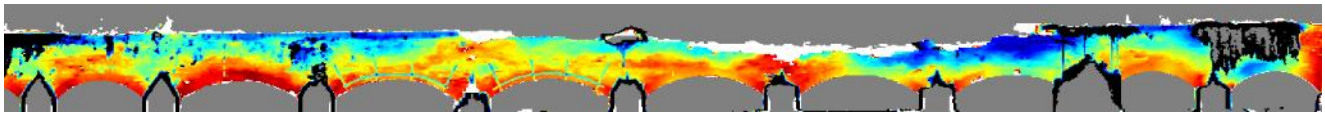
5.4.4.2 This degradation is likely the result of abrasion and collision from debris in flood flows including stones and boulders in the base of the river channel. It is likely the concrete was added to the breakwaters because the stone breakwaters were not performing although we have not seen any evidence of this.

5.4.4.3 The risks posed to the monument is an ongoing deterioration and erosion of the breakwaters until the stone breakwaters underneath are exposed to the same impact and abrasive forces.

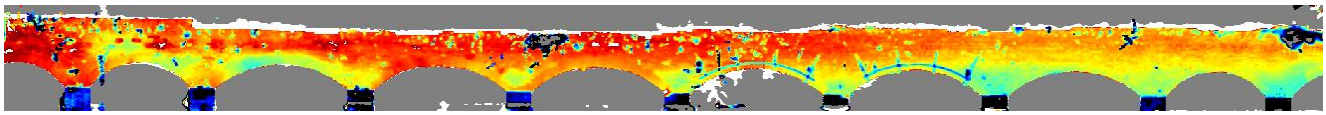
Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.4.5 Masonry Distortion

5.4.5.1 The photogrammetric model has been used to analyse the distortion in the upstream and downstream faces of the channel walls (C&D). The two images below show false colour plots of the distance from the masonry face to a base plane. The base planes have been aligned parallel to the walls on plan, the two walls are not quite parallel to each other, the aqueduct width increases by approx. 50mm over its length. The vertical alignment for the base planes are computed automatically and are parallel to each other but have not been verified as truly vertical.



Upstream Face



Downstream Face

Blue 0mm back  *Red 150mm back*

5.4.5.2 The analysis shows the upstream face of the upstream channel wall (C) to lean out by approx. 130mm from the arch springing to wall top. This is fairly consistent over the length of the aqueduct but is slightly worse in the area around arch 3.

5.4.5.3 In contrast the downstream face of the downstream channel wall (D) is shown to lean in by approx. 50mm from the arch springing to wall top. Although the 50mm lean is fairly consistent over the length the wall does not appear to be straight on plan with the section around arches 4,5 and 6 further back than the remainder.

5.4.5.4 The distortion to the upstream face around arch 3 was noted on site but the other distortions revealed by this analysis were not apparent visually.

5.4.5.5 There are a few ways this data can be interpreted and there is a limit to its certainty based on the variability of stonework, presence of vegetation and modelling accuracies. Based on the data we have come to the following conclusions:

- The plan distortion (two faces not parallel and downstream face not straight) are most likely construction error rather than subsequent movement. We have come to this conclusion because of the lack of distress or causes related to these distortions.
- The vertical lean of both faces in the same direction could indicate either an error in the computation of the vertical planes or a rigid body rotation of the aqueduct with the upstream side sinking and the two faces leaning towards upstream by 50mm. This could be caused by undermining of the upstream face or additional weight of the cocnrete breakwaters on the upstream face.
- The difference in lean between the two faces with distress noted on site suggests the upstream stonework skin of the upstream wall is moving away from the wall by up to 100mm at the wall head.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

5.4.6 Scour / Undercutting

5.4.6.1 This inspection was limited to inspection above the water level however some observations were made on site regarding scour and potential scour impacting the aqueduct foundations.

5.4.6.2 On the upstream face the river bed is relatively level with the apron slab (A1) below the arches (B). In one or two locations the bed level was reduced at the interface with the concrete apron but in no locations was it seen to be undermined.

5.4.6.3 On the downstream face the bed level is reduced and there is a large deep pool downstream of the aqueduct. This prevented access to the downstream face making it difficult to assess the risk of undermining.

5.4.6.4 There is no obvious evidence of distress to the aqueduct which could be attributable to scour and although here is some evidence of distortion it is not severe and may well be historic.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

6.0 Discussion

6.1 The structure of the aqueduct has remained largely unchanged for at least 140 years. Over this period, it appears there have been cycles of deterioration and repair which have aimed to maintain the overall appearance of the structure.

6.2 Over this period of time there have been a number of significant flood events but the largest recorded is the most recent which has caused the current damage to the aqueduct.

6.3 Pointing of Masonry Structures

6.3.1 Pointing has a number of significant functions in masonry structures. It primarily bonds the masonry units together and provides a load spread between units improving the structural efficiency particularly in bending and shear. Pointing also reduces the ingress of water into the masonry while allowing it to breathe reducing the overall moisture content and stopping running water penetrating deeper into the structure and washing out finer core material. Finally pointing acts as a barrier to prevent vegetation growth and the penetration of roots. As pointing degrades it becomes friable, fractures and is dislodged, this allows increasing amounts of moisture and root growth into the masonry and reduces the bond between units. The action of water and roots will then tend to accelerate degradation of the pointing.

6.3.2 The pointing of this monument's masonry is very variable but in most areas there are at least some partially degraded joints. The associated water ingress and root penetration is likely to be allowing more vegetation growth than would otherwise be expected.

6.3.3 One of the key requirements of pointing is that it allows the masonry to breathe and that it encourages water evaporation through the pointing not the masonry units. This is because evaporation causes deposition of salts and consequential expansive forces and degradation. Water will evaporate through the pointing where the porosity of the mortar is less than the masonry units. Typically for stone and softer brick units this will require the use of lime mortars. Where evaporation does occur, it can cause visible salt deposits, delamination of the face or erosion of the face. The aim of the mortar joint is to allow this to occur in the sacrificial mortar which can be periodically replaced rather than causing damage to the masonry units.

6.3.4 Some of the pointing observed on site was almost certainly hard cement which fits with the age of some of the consolidation works. Despite this, minimal evidence of degradation to the stone faces was observed on site. This could indicate the cement pointing is not more impermeable than the stone units, the cement pointing is not extensive enough to cause damage or the stone units are strong enough to resist the expansive forces generated.

6.4 Causes of Deterioration

6.4.1 The most significant cause of degradation for this structure is hydraulic action, particularly during flood events. There are two main causes of deterioration from hydraulic action, pressure forces from the fluid flow and impact forces from debris and sediment in the river. Pressure forces will be greatest wherever the fluid velocity is greatest and will tend to lift stones from the crest. Impact forces will occur from floating debris where the water surface meets the masonry and close to the river bed for rocks in the river flow. This degradation will tend to be abrasion of the surfaces and or impact damage to the masonry.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

6.4.2 When woody vegetation grows on and around masonry structures the roots grow through the joints and then expand as the vegetation grows. This action can be very destructive with very large forces lifting and distorting heavy sections of masonry and prying masonry elements apart. Larger vegetation also acts to increase the wind area of structures which can impart larger wind forces into the masonry, larger vegetation close to structures can also cause impact damage where wind deflections cause it to strike the masonry. Finally larger vegetation is itself subject to failures from disease or wind, such failures can impose very significant forces on masonry either through impact or rotational forces through the root ball.

6.4.3 No evidence on site has been observed of any ground movements, subsidence or scour impacting the structures.

6.4.4 Weathering and water action are also likely causing ongoing deterioration of the masonry structures. However, limited specific evidence of this was observed on site. This is probably attributable to pointing allowing the structures to breathe and the limited locations to hold water and thus promote freeze thaw action.

6.5 Impact of Re-Flooding the Canal

6.5.1 One of the options being discussed for the canal is reflooding it to bring it back into use. There are a number of potential impacts of reflooding the canal including the additional weight of the structure, the lateral pressure on the side walls, waterproofing and seepage of water through the structure.

6.5.2 Although the canal has been dry for a considerable period of time it has not altered significantly in that time. Unlike for buildings being brought back into use the potential uses of the structure and loads imposed by those uses have also not changed.

6.5.3 The as existing mass of the aqueduct channel, above the arch crowns, is 210 kN/m. Based on a water depth of 800mm the reflooded mass would be 235 kN/m an increase of 12%. Once the weight of the piers is included in the original weight this would bring the increase in weight below 10%.

6.5.4 The lateral force imposed by water at 0.8m depth is 3.2 kN/m. By inspection this is easily resisted by the side walls which are both over 1.5m thick.

6.5.5 There is currently no evidence to suggest if the canal had a waterproof lining originally. If it had a clay lining it is feasible this has been totally lost since the canal last held water. Even if the stonework were well consolidated with good joints and kept in a good state of repair it would be relatively porous. Any lost water would go straight into the river below and provide there was sufficient water supply into the canal the water level could be maintained.

6.5.6 A constant flow of water through the aqueduct stonework would have a negative impact on the stonework by washing out joints and fines from the core material. Over time this would erode drainage paths through the stonework increasing the rate of flow and accelerating any damage.

6.5.7 There is some evidence on site and in historic photos of a weir structure on the aqueduct to maintain the water level in the canal. If this were not reinstated flooding or large draught boats could cause the water level to raise imposing greater forces on the structure and risking overtopping.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

7.0 Conclusions

7.1 The main conclusion of this investigation and report is that the condition of the monument is relatively stable in the long term as an ongoing cycle of degradation and repair. No ongoing or progressive deterioration other than the current flood damage, was noted which would make its repair and ongoing maintenance unfeasible.

7.2 The current flood damage makes the structure significantly more vulnerable to further damage in flood events. Left unchecked this damage will be progressive over future flood events potentially to the point of rendering the structure unviable to repair. However, in its current state we believe repair is feasible and should be undertaken as quickly as possible to mitigate further damage increasing the cost and complexity of repairs.

7.3 The monument is susceptible to damage in flood events, and it has been damaged at a number of locations along its span in previous flood events. We do not believe the variation in damage location is caused by pre-existing defects in the masonry but by variations in flow and impact from floating debris. From this we conclude the structure is not sufficiently robust to resist flooding events and will continue to be damaged by them even if it is kept in a good state of repair. Also, any strengthening to make the structure robust enough to resist flooding would be required over the whole length of the aqueduct section.

7.4 In its flood damaged condition, the monument is susceptible to flood damage in smaller flood events and to more damage in each flood event than in its condition immediately prior to the most recent flood damage. This suggests that the most economical way of continuing the current cycle of degradation and repair is to undertake repairs to flood damage as soon as possible following each flood event.

7.5 In addition to the significant area of flood damage a number of defects were noted to the monument which are reducing the robustness of the masonry and increase the risk of further deterioration. Risks from these defects are limited to the historic fabric as the access for site visitors is restricted.

7.6 With some additional works to the existing structure, it would be possible to reflood the canal without detriment to the aqueduct structure. The main additional works required would be a waterproof lining to the canal channel.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

8.0 Recommendations

8.1 Based on the conclusions of this report we recommend a schedule of works is developed based on the recommendations below. These works are likely to involve a combination of consolidation and repair works to protect the monument and works to exclude and protect the public. This full schedule of works will require further design input and potentially further survey work.

8.2 The recommendations have been split into four categories of urgency as follows:

- Immediate / Urgent Works – Works to be undertaken immediately to resolve issues which may cause instability or collapse in the short term and are making the structure unsafe.
- Short Term Works – Works to be undertaken, in the short term, to resolve issues which are currently causing progressive degradation and or damage to the structure.
- Medium / Long term works – Works to be undertaken to halt the progression of issues which may develop given time to cause damage or degradation.
- Ongoing Maintenance Works – Works which will need to be repeated on a regular basis to avoid damage or degradation.

8.3 All of the works proposed below are our best estimate of the required works based on the survey work completed to date. All of these works will be subject to Scheduled Monument Consent and will require justification. This will not only be to justify the requirement to undertake a repair but also for the proposed materials and repair details.

8.4 Immediate / Urgent Works

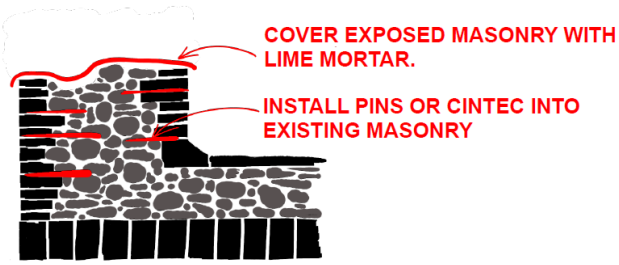
8.4.1 The following works should be undertaken in the short term to mitigate immediate risk to the stability of the structure or its users.

8.4.2 **Fencing and Access** - Although public access to the monument is currently limited it is clear some people are accessing it through some gaps in the existing fencing. We recommend some repairs / additional fencing is provided potentially with signage to discourage access onto the aqueduct. There is one vertical missing to the downstream palisade fencing at the east end. Access is also possible around the palisade fencing on the upstream face of the east end and from the concrete projection in the upstream face.

8.5 Short Term Works

8.5.1 The following works should be undertaken in the short term to stop defects progressing and becoming damaging to the structure or a risk to its users.

8.5.2 **Flood Damage** – As a minimum in the short term we recommend the existing flood damaged area is consolidated by covering the exposed wall head with lime mortar and pinning vulnerable stones back to the core material. This will reduce the impact of future flood events on this damaged area until a more comprehensive repair is undertaken. A more robust solution would be to rebuild the damaged section with stonework and lime mortar to its previous arrangement. Neither of these options would address the underlying lack of robustness against flood damage but would reduce the likelihood of a more significant failure being caused by repeated floor damage to the same area.



Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

8.5.3 **Missing Area of Stone Breakwater** – The exposed core material should be cleaned of any soil or other deleterious materials. The missing areas of facing and stone breakwater should be replaced with new stonework in lime mortar. New stone and mortar should be of similar type, colour and finish to the existing and the size should be to match all available evidence for the original stone breakwaters. Stainless steel pins should be included to strengthen the bond between the breakwater stones and the between he breakwater and facing.

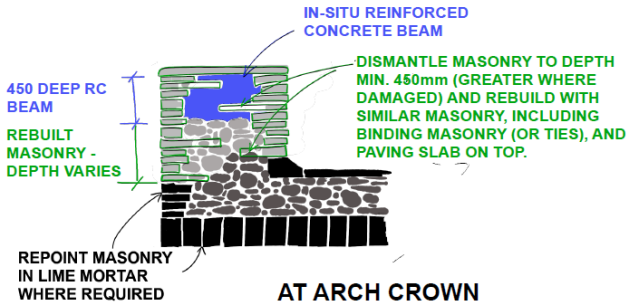
8.5.4 **Vegetation Growth** – Two packages of vegetation works should be undertaken in the short term:

- Soft herbaceous and woody vegetation growth from the monument masonry should be removed, and or poisoned taking care not to disturb the underlying masonry.
- A programme of eradication of Japanese knotweed and Himalayan Balsam should be undertaken. This is likely to require treatment over a number of years to fully eradicate both invasive species from the site.

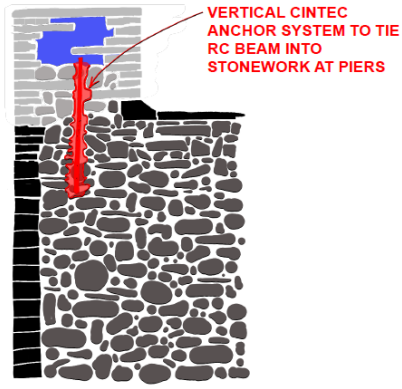
8.6 Medium / Long Term Works

8.6.1 The following works should be undertaken in the medium to long term to halt the progression of issues which may develop given time to cause damage or degradation.

8.6.2 **Flood Damage / Strengthening** – In order to reduce the likely impact of future flood events, on the monument, we recommend a significant programme of strengthening works is undertaken. The detailed design of this is complex and beyond the scope of this report. However, we suggest this could be achieved by dismantling the majority of the upstream and downstream channel walls and rebuilding them with a reinforced concrete core in place of the stone core material. Consideration in the detailed design will need to be given to, thermal movement, weight, tying of masonry to the concrete, specification of cover and reinforcement to avoid corrosion and other interactions between the concrete and masonry. This would be a very significant intervention to a historic structure which would require substantial justification, as part of this we would expect to produce an options appraisal with pros and cons of the different options.



AT ARCH CROWN



AT PIER

8.6.3 **2 No Missing Facing Stones** – The two number missing stones to the downstream face above arch 5 should be replaced with new stones in lime mortar.

8.6.4 **Damaged Arch Voussoirs** – We recommend the damaged arch voussoirs to arch 3 are repaired by carefully removing and replacing the affected stones in lime mortar. New stone and mortar should be of similar type, colour and finish to the existing and the size should be to fit the gap with minimal joints either side.

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

8.6.5 **Degradation of Concrete Break Waters** – The one compromised concrete breakwater between arches 6 and 7 should be repaired. This is likely to comprise breaking out the remainder of the breakwater to a level base and recasting the breakwater to match its original dimensions. Stainless steel dowel bars between new and old concrete would be required to provide a good shear link between them. The inclusion of a stainless steel mesh reinforcement such as D49 wrapping mesh which can be hand bent on site would greatly improve the durability.

8.6.6 **Vegetation Growth** – One further package of vegetation works should be undertaken in the medium to long term:

- A review should be undertaken by an arboriculturist of the trees adjacent to the monument to review the risks they pose to the monument. Any works recommended by this should be undertaken which is likely to include felling trees close to the monument at risk of falling and removing limbs of trees at risk of striking the monument.

8.6.7 **Degraded Pointing** – A programme of repointing works should be undertaken to the whole monument. Loose pointing and any accumulated materials to be removed by hand / brush to maximum depth of 100mm avoiding removing sound pointing wherever possible. Any visible roots to be removed / cut back to the face of good pointing. If resulting joint is deeper than 50mm repoint in lime mortar, joint finish to be reassessed by approx. 10mm to match surrounding pointing.

8.7 Ongoing Maintenance Works

8.7.1 The following are specific ongoing maintenance works which should be undertaken in additional to all normal maintenance and repair to alleviate specific issues related to this structure.

8.7.2 **Vegetation Growth** – Three packages of vegetation works should be undertaken on a regular basis as part of the ongoing maintenance strategy:

- Soft herbaceous and woody vegetation growth from the monument masonry should be removed, and or poisoned taking care not to disturb the underlying masonry.
- The site should be inspected by a suitably qualified person for invasive species and if any are located, they should be treated accordingly.
- A review should be undertaken by an arboriculturist of the trees adjacent to the monument to review the risks they pose to the monument. Any works recommended by this should be undertaken which is likely to include felling trees close to the monument at risk of falling and removing limbs of trees at risk of striking the monument.

8.7.3 **Degraded Pointing** – A programme of repointing works should be undertaken on a regular basis to the whole monument. Loose pointing and any accumulated materials to be removed by hand / brush to maximum depth of 100mm avoiding removing sound pointing wherever possible. Any visible roots to be removed / cut back to the face of good pointing. If resulting joint is deeper than 50mm repoint in lime mortar, joint finish to be reassessed by approx. 10mm to match surrounding pointing. Frequency and extent of works to be developed to suit rate of deterioration and access constraints with preference for “little and often"

Mann Williams Consulting Civil and Structural Engineers
53 Mount Stuart Square, Cardiff, CF10 5LR T 02920 480333

9.0 Costed Schedule of Works

General Notes

Item	Description	Works	Product Examples
G1 - Scheduled Monument			
	This structure is a Scheduled Monument and as such no works should be undertaken other than with Scheduled Monument Consent. During all works care must be taken to avoid unnecessary disturbances to the monument.		
G2 - Structure over Main River			
	This structure crosses a main river at the top of the tidal range and just below the confluence of the Neath and Dulais. Any works impacting the river channel including but not limitted to scaffolding, temporary propping , storage of materials and excavation will require NRW fllod defence consent. River flow varies significantly, during high flow access to the river channel will be restricted. The nearest flow monitoring stations are: Dulais at Celfrew - Upstream - https://rivers-and-seas.naturalresources.wales/Station/4087? Neath at Resolven - Upstream - https://rivers-and-seas.naturalresources.wales/Station/4125? Neath at Neath Tidal - Downstream - https://rivers-and-seas.naturalresources.wales/Station/4112?		
G3 - Masonry Works Generally			
	All masonry works to be undertaken with hand tools only such as toothed masonry chisels, hacksaw blades and bent spikes. Do not use wedge shaped tools, chisels, hacking hammers, mechanical disks or other power tools. Maintain stability of masonry during all phases of all works with temporary works as required, to be designed by contractor Report any new defects or signs of movement that become apparent during the works Avoid disturbance to all masonry outside work areas and all sound masonry adjacent to work areas. Do not use frozen materials or lay masonry units on frozen surfaces, do not undertake masonry or pointing works in cold weather and provide adequate protection from weather during masonry works.		

G4 - Lime Mortar		
All masonry works to be undertaken with lime mortar unless noted otherwise Appearance including colour and finishing to match surrounding unless noted otherwise Trial area to be undertaken to agree mortar appearance and joint finish for each variation Lime mortar to be NHL 3.5 with sand and fines as required for desired appearance unless noted otherwise		
G5 -Small Stumps		
Stumps in masonry with little or no displacement to masonry and minor anticipated root structure.	Cut off stump and any visible roots at face of masonry and chase out of joints to 100mm depth. Avoid removing sound pointing and stone work wherever possible. Repoint patches as piecemeal repointing note G8.	
G6 - Medium Stumps		
Stumps in masonry over 25mm Ø with little or no displacement to masonry but significant anticipated root structure.	Cut off stump as close to wall as possible leaving 40mm length 25mm Ø. Treat with poison plugs such as Eco Plug Max. 12 months later cut off and repoint as small stump (to be undertaken under separate contract, ie do not price for return visit)	https://www.frjonesandson.co.uk/products/ecoplug-max-tree-stump-killer-100-pack/
G7 - Dismantle Facing Masonry		
Loose sections of masonry not possible to consolidate in situ.	Section to be photographed to record existing layout of masonry units, notes and other recording as required to be completed, with consideration for potential time between dismantling and rebuilding, as required to allow walls to be reconstructed in the same character and coursing with stones in the correct courses and with the same facing as the existing. Loose stones / bricks to be carefully dismantled propping masonry above as required. Stone to be stacked neatly and labelled on site adjacent to section, or in secure location as defect note. Stone units to be stored by course with consistent facing to augment recording and labelling. Loose core work & deleterious materials such as roots to be removed as far as possible without removing more face work. All masonry to be left in stable condition with temporary works and propping as required given the time required until rebuilding works.	
G8 - Rebuild Facing Masonry		
Loose sections of masonry not possible to consolidate in situ.	Loose core work & deleterious materials such as roots to be removed as far as possible without removing more face work. If time has past since dismantling any further surrounding loose stonework to be recorded and dismantled as general note G6. Core & face work to be rebuilt in lime mortar as general note G3. Face work to match existing with stone / bricks in same location as existing but made as true & straight as possible to tie into surrounding remaining facing.	

G9 - Piecemeal Exposed Core-work Re-consolidation

Sections of exposed core-work with generally sound masonry with a proportion of missing or loose pointing.	Loose mortar and any accumulated materials to be removed by hand / brush as deep as possible without loosening exposed stones. Any visible roots to be removed / cut back to the face of good mortar. Avoid removing sound mortar wherever possible Resulting joints and voids to be consolidated to approx. 100-150mm from end of projecting stones to provide a solid irregular face with minimal visual impact of mortar. For deeper or wider joints add small coarse stones to mortar mix and tamp mortar solid in layers of maximum 40mm depth. Where gaps have formed in the stone facing new stones to be pieced in to match the character of the surrounding. Photograph is of example of previously consolidated core-work on a different project. Some of this area is now in poor condition with loose stones, vegetation and one area of missing stonework but the general arrangement is a good example of the proposed works	

G10 - Consolidation of Horizontal Surfaces

Larger areas of horizontal core-work with generally sound masonry with a proportion of missing or loose pointing and stones.	Loose pointing, vegetation and any accumulated materials to be removed by hand / brush to maximum depth of 100mm. Any visible roots to be removed / cut back to the face of good pointing. Avoid removing sound pointing wherever possible Loose stones in top course of facing to be lifted and re-bedded on lime mortar bed, filling gaps and crevices to provide solid top surface . Core stones to be re-laid as random surface as existing with minimal projections and general slope over facing. Where possible the pointing and stonework of the top face should promote water shedding from the horizontal surface over the facing stonework avoiding ponding. Resulting joints to be consolidated as note G9

G11 - Scaffolding

As required for access to undertake the proposed repair works	Scaffold is to be designed by others to provide access and material storage required to undertake the proposed works. Where temporary propping of masonry is required this can be provided from scaffolding, but the scaffold must be designed for this purpose No drilled ties to the monument will be permitted, such as resin or mechanically fixed anchors, any areas where the scaffold bears on the monument protection must be provided to the stonework. All scaffold bases should avoid as far as possible any significant disturbance to the ground and any bearings on stonework should be adequately protected to avoid damage To avoid the equiremnt for NRW Flood Defence Consent it is assumed scaffolding will utilise a canalever system from the top of tht aquaduct not scaffold legs into the river chanel.

Ref	Structure	Location	Ref	Proposed Works	Justification for works	Height of works above ground level	Anticipated Access	No	Units	Photo	Estimated Costs
Immediate/Urgent Works											
1	Access to Structure from East bank	Downstream palisade fencing at East bank	IM_1.1	Replace missing vertical in palisade fencing	Discorage public access onto monument	0m	Simple access at ground level	1	No		£1,250.00
		Upstream palisdae fencing at East bank	IM_1.2	Refix existign palisade fencing with 3 No self tapping masonry screws to stonework.				1	No		£99.50
			IM_1.3	2m of additioanl fencing				2	m		£1,770.00
		Upstream Conrete Projection at East bank	IM_1.4	2m of additioanl fencing				2	m		£1,770.00
										Stage Total	£4,889.50

Short Term Works											
1	Flood Damaged Area - Option 1	Upstram and downstream channel walls above arches 3-6.	ST_1.1	Collect surrounding rubble from channel and river bed and store on east bank for future reuse in 1m3 steel gabion baskets.	Increasing robustness against urther flood damage	5m	Working over water on top of aquaduct. Access anticipated by foot along aquaduct and cantalever scaffold solotionfrom aquaduct	35	m3		£9,380
			ST_1.2	Loose and displaced masonry to be lifted and rebedded in lime mortar				5	m3		£17,000
			ST_1.3	Allow for 35 No 600mm long 10mm dia stainless steel pins drilled and grouted into stonework to restrain vulnerable stones				35	No		£5,430
			ST_1.4	Top surface to be consolidated as note G10, vertical surfaces to be consolidated as note G9				75	m2		£6,900
2	Flood Damaged Area - Option 2	Upstram and downstream channel walls above arches 3-6.	ST_2.1	Collect surrounding rubble from channel and river bed for imeidiate reuse.	Increasing robustness against urther flood damage	5m	Working over water on top of aquaduct. Access anticipated by foot along aquaduct and cantalever scaffold solotionfrom aquaduct	35	m3		£14,180
			ST_2.2	Dismantel lose and displaced masonry and store for imeidiate reuse				5	m3		£3,280
			ST_2.3	Rebuild masonry sections using collected and dismantled masonry in lime mortar				40	m3		£57,400
			ST_2.4	Rebuild remaining masonry sections in imported masonry and lime mortar. Facing to be rebuilt as note G8				15	m3		£22,200
3	Stone breakwater	Upstream breakwater between arches 6 and 7	ST_3.1	Area to be cleaned and prepaired for rebuilding as note G8	Increasing robustness against urther flood damage	1m	Working in river channel approx 1m above water level. Anticiapted access by foot across channel	1	m2		£80
			ST_3.2	Missing facing stonework and 2 No shaped breakwater stones to be reconstructed as note G8				0.25	m3		£1,500
			ST_3.3	Allow for 5 No 600mm long 10mm dia stainless steel pins drilled and grouted into stonework to restrain vulnerable stones				5	No		£950
4	General / Whole Site	Whole aquaduct structure	ST_4.1	Significnat soft herbaceous and woody vegetation growth to be removed from channel base and internal walls taking care not to disturb the underlying masonry.	Removing vegtiation to reduce the potential impact on the monument.	5m	Working over water on top of aquaduct. Access anticipated by foot along aquaduct	850	m2		£9,750
			ST_4.2	Accumulated soil and silt within channel should be removed and disposed of on site.				40	m3		£11,320
			ST_4.3	Minor soft herbaceous and woody vegetation growth to be removed from external walls taking care not to disturb the underlying masonry.		0-5m	Working in river channel up to 5m above water level. Anticiapted access by foot across channel and by ladder	700	m2		£6,940

5	General / Whole Site	Areas of east bank arround aquaduct and aquaduct strructure near east bank	ST_5.1	A programme of eradication of Japanese knotweed and Himalayan Balsam should be undertaken. This is likely to require treatment over a number of years to fully eradicate both invasive species from the site.	Removing vegtiation to reduce the potential impact on the monument and reducign the potnetial for spread of invasive species from the site.	0m	Simple access at ground level	400	m2		£4,240
										Stage Total	£170,549.50
										Grand Total	£175,439.00