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County Council
Comhairle Contae Chorcaí

Cork to Kinsale Greenway Chetwynd and Halfway Viaducts - Inspection and Assessment

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Cork to Kinsale Greenway

Chetwynd and Halfway Viaducts - Inspection and Assessment

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EXECUTIVE SUMMARY

Cork County Council appointed RPS Consulting Engineers to carry out an inspection and assessment of Chetwynd and Halfway Viaducts as part of the proposed Cork to Kinsale Greenway.

Chetwynd Viaduct is generally in reasonably good condition. A structural assessment has shown that the structure has sufficient capacity to support the loading imposed during its proposed reuse as a pedestrian/cycle bridge. A number of key measures including the replacement of missing lateral bracing members will be required in advance of deck construction. The preliminary cost estimate for the rehabilitation of Chetwynd Viaduct for its proposed reuse as a pedestrian/cycle bridge is approximately €1,257,172 excluding VAT (€1,426,890 including VAT). Should it be deemed necessary to repaint the existing structure, the preliminary cost will increase by approximately €1,113,970 excluding VAT (€1,264,356 including VAT), thereby resulting in a total rehabilitation cost of €2,371,142 excluding VAT (€2,691,246 including VAT).

Halfway Viaduct is generally in good condition. A structural assessment has shown that the structure is capable of supporting 5 or 6 axle Heavy Goods Vehicles (HGVs) with a Gross Vehicle Weight of 44 tonnes. The bridge can support single axle loads of 21 tonnes. Accordingly, the bridge can comfortably carry the loadings imposed during its proposed re-use as a pedestrian/cycle bridge. It is also feasible to cross the bridge with a maintenance vehicle, if required. The preliminary cost estimate for the rehabilitation of Halfway Viaduct for its proposed reuse as a pedestrian/cycle bridge is approximately €119,526 excluding VAT (€135,662 including VAT).

1 INTRODUCTION

1.1 BACKGROUND

RPS Consulting Engineers is providing engineering consultancy services to Cork County Council in relation to the inspection and assessment of Chetwynd and Halfway Viaducts. The two bridges are located on the old Cork – Kinsale railway, an abandoned route which forms the proposed 36 km Cork to Kinsale greenway. This report provides information on the inspection and assessment of the viaducts and makes recommendations regarding their structural adequacy, required remedial works and preliminary costings for their proposed re-use as pedestrian/cycle bridges.

Chetwynd Viaduct (Figure 1.1) is a four span cast iron under-arch railway bridge which spans over the N71 Cork-Bandon Road. A location map for the bridge is provided in Appendix A.



Figure 1.1: Chetwynd Viaduct

Halfway Viaduct (Figure 1.2) is a three span masonry arch railway bridge. A location map for the bridge is provided in Appendix A.



Figure 1.2: Halfway Viaduct

1.2 THE BRIEF

The inspection and assessment were carried out by a Chartered Engineer with substantial bridge design, inspection and assessment experience. The inspection and assessment was carried out to the advice notes and directives supplied in the relevant documents of the NRA and UK Design Manual for Roads and Bridges and EIRSPAN System Manual No. 3 Revision C.

2 CHETWYND VIADUCT

2.1 LOCATION

Chetwynd Viaduct is a listed heritage structure and is located on the abandoned Cork-Bandon and South Coast Railway. The viaduct is located approximately 5 km south of Cork City and spans over the N71 Cork-Bandon Road and a local watercourse. The viaduct was opened in 1851 (Figure 2.1). The rail line was officially closed on the 31st of March 1961. A location map for the bridge is given in Appendix A.

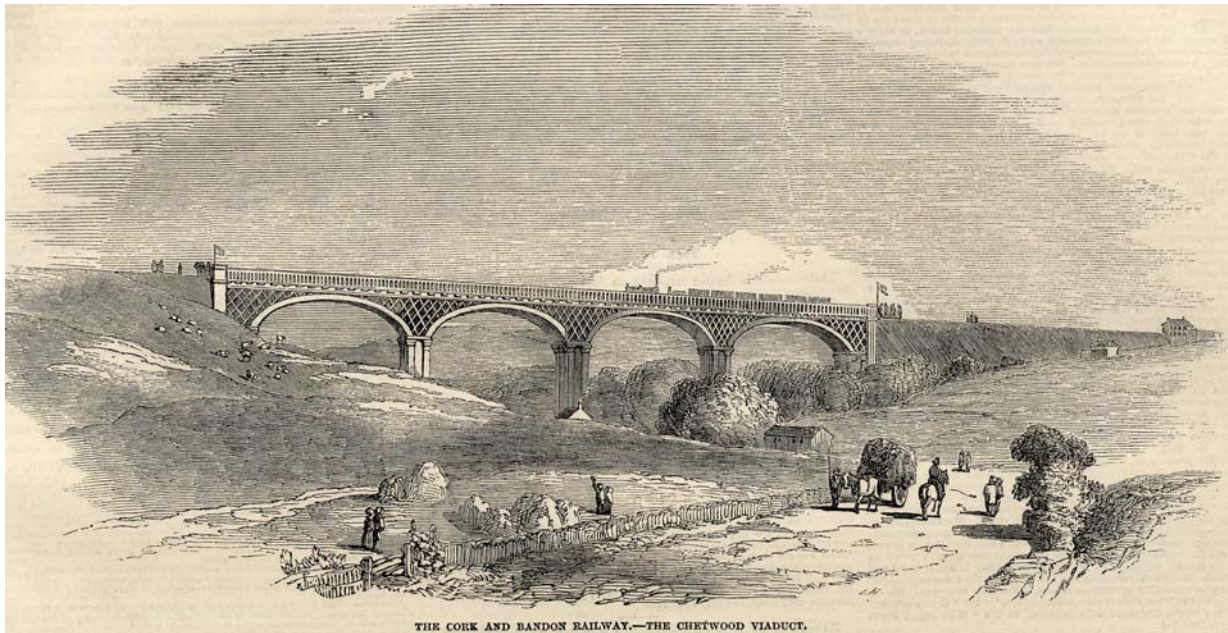


Figure 2.1: Chetwynd Viaduct circa 1851 (Illustrated London News, 1851)

2.2 DESCRIPTION

Chetwynd Viaduct, opened in 1851, is a four span cast iron under-arch railway bridge supported on tall masonry piers and abutments. Latticed spandrel walls are connected to each arch to support the deck and give the structure enhanced strength. Wrought iron ties connect the node points of the latticed spandrel walls at mid-height. This form of hybrid construction involving combining cast and wrought iron components was common at the time of construction as the limited tensile capacity of cast iron became recognised. Wrought iron elements, which have a much higher tensile capacity, would commonly be substituted to serve as tension members. The overall length of the structure, including abutments and wing walls, is 180.33 m. Since the closure of the rail line, the entire decking, parapets and a large proportion of the lateral bracing has been removed from the bridge.

A full structure inventory is given in Table 2.1.

Table 2.1: Chetwynd Viaduct Inventory

Inventory Item	Dimension/Remark
Number of spans	4
Minimum span length	34.5m (clear)
Maximum span length	34.5m (clear)
Overall length	180.33m
Width out-to-out	6.315m
Area	1138.78m ²
Minimum parapet height	0.00m
Skew	0.00°
Bridge curved (Y/N)	N
Skew	0.00°
Span length: Span 1	34.5m (clear)
Span length: Span 2	34.5m (clear)
Span length: Span 3	34.5m (clear)
Span length: Span 4	34.5m (clear)
Standard design (Y/N)	N
Design of cross-section	Cast iron arch
Design of elevation	Arch, one or more spans
Material of primary members	Cast iron
Number of arches	4
Rise of arch at centre	6.10m
Height of piers	21.33m

2.3 HISTORICAL INFORMATION

A description of the construction of the railway is given in Figure 2.1 below (www.corkheritage.ie).

Apart from the Cork Blackrock and Passage Railway, which linked the city to Cork Harbour towns by rail, another railway company operated a line connecting the south-west of the county to the city. Charles Vignoles first proposed the idea of a railway that would connect Cork to Bandon in the Railway Commissioners report in 1837-38. However, in 1843, this idea was promoted strongly by Edmund Leahy (Cork County Surveyor) who had just completed a county survey of the area and by local solicitor, J.C. Besnard. Consequently, in 1844, a provisional Bandon and Cork Railway Committee was established.

Charles Vignoles was appointed as the consulting engineer to survey and give his ideas on how to approach the proposed line. Besnard and Leahy became acting engineers and in 1845, the legislation was passed authorising the development to go ahead. In the same year work began on the Bandon to the Ballinhassig section. In July 1846, Leahy was dismissed for not ordering the right rails. Subsequently, Charles Nixon was appointed as acting engineer who had previously worked under an eminent British architect, Isambard Kingdom Brunel. A young Cork engineer named Joseph Philip Ronayne assisted Nixon. One of Nixon's first proposals involved the adoption of cast-iron instead of

timbers on the proposed Chetwynd Viaduct. He also proposed that tunnels should be bored at Goggin's Hill and Kilpatrick instead of the deep cuttings.

The construction of the line was divided into six sections. Each section was the responsibility of different contractors. In 1849, due to financial difficulties, a decision was taken by company to open the Bandon–Ballinhassig line as fast as possible. Subsequently, it was opened in June 1849. In September 1849, the company chose a tender of £87,000 for the Cork-Ballinhassig section of line. The contractors chosen were Sir Charles Fox (Founder of Hyder consulting) and John Henderson.

The Cork Bandon Railway Project was an enormous undertaking. The main parts included; the longest railway tunnel in Ireland at Goggin's Hill; The Chetwynd Viaduct; a short tunnel bridge under old Blackrock road near the Albert Quay Terminus; 21 cuttings; 19 embankments and 15 road bridges.

One of the greatest problems was the construction of the Ballyphehane embankment. It was just over nine metres high and crossed the Tramore River's floodplain. The track crossed the river initially on a wooden bridge, which in time was replaced by a stone culvert. On the southern approach to the city, it became necessary to cut deep through and into the limestone bedrock. The line also cut across three south-eastern approach roads which led into the city itself.

The entire stretch of line between Cork and Bandon opened to the public on 6 December 1851. The Cork terminus for the Cork Bandon and South Coast Railway was also completed in this year at Albert Quay. The main building is now the parking fines office on Albert Quay, next to City Hall. The old terminus had three passenger platforms, a carriage storage area, and sidings into the Cork Corporation's stone yard and into the corn market. In 1869, a goods siding was added and in 1875, a siding for carriage repairs added. However, it never had locomotive sheds until later years. Feeder lines were also added in the early twentieth century to the roller-milling complex on Victoria Quay and to the Ford tractor works on the Marina.

The first locomotive to operate on the Ballinhassig-Bandon line was manufactured by W.B. Adams of the Fairfield Works, Bow in London. On the Cork –Ballinhassig line, the Vulcan foundry of Newton-Le-Willows in Britain provided the first locomotive. Between 1852 and 1894, a further 25 engines were acquired by the company. Between 1851 and 1893, the mileage of the West Cork Line extended from 20 to 94 miles. Many West Cork Towns attained their own railway stations; Kinsale (1863), Clonakilty (1866), Dunmanway (1866), Skibbereen (1877), Bantry (1881), Timoleague and Courtmacsherry (1890), Bantry Bay (1892), and Baltimore (1893).

In 1898, the Cork and Bandon Railway, the Cork and Kinsale Junction Railway and the West Cork Railway amalgamated together to form the Cork, Bandon and South Coast Railway. This company further amalgamated with the Great Southern and Western Railway in 1925. The last passenger service to West Cork ceased in 1961. In 1979, the track bed approaching the city was widened for construction of the South Link Road as far as the former Macroom Junction in Ballyphehane.

Figure 2.2: Historical description of rail line (www.corkheritage.ie)

There are reports of the Chetwynd Viaduct being damaged (and subsequently repaired) by an attack during the Civil war in 1922 (Ronald Cox and Michael Gould, 2003). Observations during the Principal Inspection confirm that the viaduct has suffered damage and has undergone repairs.

Additional historical information is given in Figure 2.3, with particular attention paid to Chetwynd Viaduct. It is confirmed that the information (spans, dimensions etc.) contained therein is accurate.

OPENING OF THE CORK AND BANDON
RAILWAY.

IN our Journal for Sept. 27, 1845, we illustrated the commencement of this line of railway, by the Earl of Bandon formally cutting the first turf; and we have now much pleasure, by aid of our correspondent at Cork, in recording the opening of the line from end to end.

Few railways have had so hard a struggle for existence as this Bandon line; yet, notwithstanding the period of the famine, the total prostration of the speculative energies of the country, and the disagreements between the contractors and the company, the directors have every cause to congratulate themselves upon the way in which they have executed the arduous trust reposed in them, their whole aim and ambition having been from the commencement to encourage local industry, at the same time that they were laying a line of railway surpassed by few in the country.

The works were of no ordinary description, having to be made along the face of the highest range of hills in the district; thereby entailing the necessity of one continued series of cuttings, embankments, tunnels, and viaducts, the nature of which will be well understood from the accompanying Sketch of the Chetwynd Viaduct, which rises from the level of the Bandon road, over which it passes, to within a few feet of the same elevation as the Great Tubular Bridge; and shows the masterly manner in which Mr. Nixon as engineer, and Messrs. Fox and Henderson as contractors, have executed their work. This vast structure, considered the largest of its kind in Ireland, measures 500 feet from abutment to abutment, and is about 100 feet above the level of the valley; it is divided into four spans of 100 feet each by two abutments and three massive outline stone piers, 70 feet high; the ornamental pilasters and bold projecting cornices giving the whole structure an appearance of great strength and solidity. The upper portion is composed of wrought and cast-iron, and weighs about 1000 tons. Each span consists of four cast-iron arched ribs, three feet in depth, 110 feet span, with a rise of 20 feet in the centre, and running right across from pier to pier. They are retained in their places by cast-iron braces and wrought iron tie-rods, and connected on the top by the roadway formed of cast iron covering plates, flanged and bolted together; the whole finished by a neatly-cast handrail and projecting cornice.

The works throughout the line are now in such a state of forwardness as to have elicited the warmest praise from the Government inspector, who went over the line on Wednesday fortnight, and declared it fit for public traffic.

On Saturday week the deferred excursion to the shareholders, the directors, and their friends took place; and, were the loudly-expressed opinions of those favoured with an invitation to be taken as a guarantee for the welfare of the company, little doubt can be left of its ultimate success. There are two classes of people to whom this railway must be a great boon: these are the widely spread people of the western district of the country whose business or pleasure may lead them into the city, and the tourist who seeks to enjoy the beauties of the west: to the latter it opens up a new district of country; whilst it at once takes them from a road heretofore looked on as one of the most unattractive, leading for some fifteen or sixteen miles out of the city. The excursion was made in and out in capital style, and much to the enjoyment of those who partook of it. The journey outwards; owing to the directors' wish to allow their friends to see the country, occupied about three hours; but home the speed was at the rate of over forty miles per hour.

We have to express our thanks to Mr. Ronayne, one of the resident engineers, for his obliging attention to our Artist.

[Taken from *Illustrated London News*, Vol. XIX, 1851, p.733]

Figure 2.3: Extract from Illustrated London News, 1851

2.4 PRINCIPAL INSPECTION

2.4.1 Inspection Methodology

The bridge inspection system used is the National Roads Authority (NRA) Irish Structure Management System (EIRSPAN).

A condition rating is assigned to the structure and each of its components based on the observed degree of distress or deterioration. The condition is registered by means of a rating from 0 to 5. A description of each of the condition ratings is given in Table 2.2. Based on the condition ratings of each of the individual components, the overall structure is also assigned a condition rating.

Table 2.2: Extract from NRA Eirspan Manual No.3 Principal Inspection (Revision C)

Condition Rating	Description
0	No or insignificant damage.
1	Minor damage but not in need of repair.
2	Some damage, repair needed when convenient. Component is still functioning as designed. Observe the condition development.
3	Significant damage, repair needed very soon, i.e. within the next financial year.
4	Damage is critical and it is necessary to execute repair works at once, or to carry out a detailed inspection to determine whether any rehabilitation works are required.
5	Ultimate damage. The component has failed or is in danger of total failure, possibly affecting the safety of traffic. It is necessary to implement emergency temporary repair works immediately or rehabilitation works without delay after the introduction of load limitation measures.

The Principal Inspection of Chetwynd Viaduct was carried out on 26th September 2013.

2.4.2 Bridge Surface

In the intervening years since the closure of the rail line the entire bridge deck has been removed to prohibit pedestrian access (Figure 2.4). The original decking comprised cast iron plates spanning between transverse intermediate beams (Figure 2.6). Earlier construction drawings show timber deck members but this was not the as-constructed detail (Figure 2.5). During deck removal intermediate transverse steel beams (Universal Beams) were retrofitted to provide lateral restraint to the spandrel walls and arch ribs (Figure 2.4)



Figure 2.4: Current condition of bridge surface

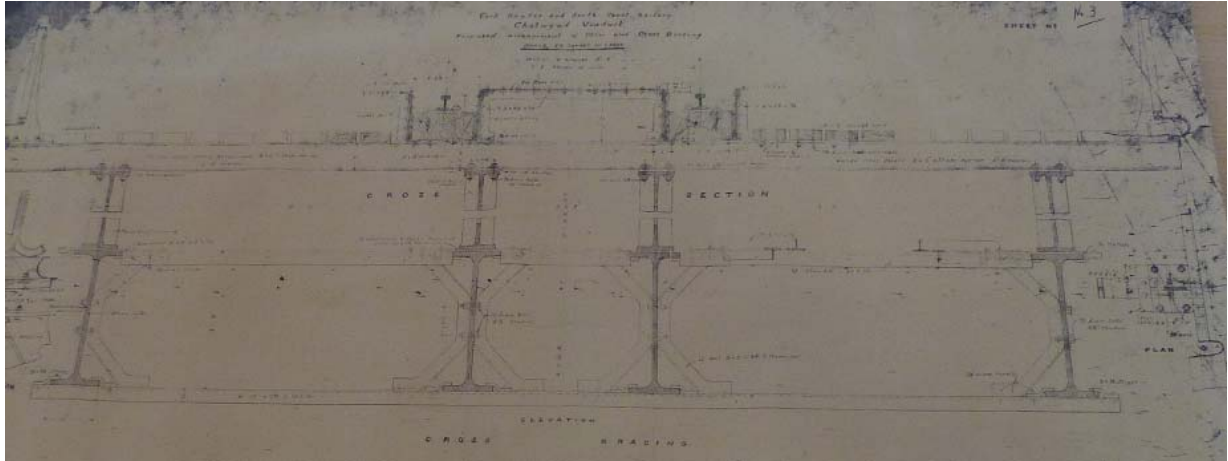


Figure 2.5: Construction drawing of bridge deck



Figure 2.6: Bridge deck partly removed, circa 1970

2.4.3 Arch Ribs

Four cast iron arched ribs are present in each span and comprise of I-sections. Each arch rib consists of four sections which are connected with in-line bolted splice connections (Figure 2.8). The arch ribs have a clear span of 34.5m and an overall depth of 0.914m. The rise of the arch at the centre is approximately 6.1m. Generally, the arch ribs were observed to be in good condition. There is evidence of previous repairs in span 3 (Figure 2.9). These repairs consist of solid spandrel infill plates, additional stiffeners and gusset plates. It is reported that these repairs were undertaken as a result of an attack on the bridge in the 1922 Civil War. It is likely that the repair work was carried out using mild steel and is showing signs of corrosion. Localised rust spotting on the arch ribs indicate localised failure of the paint system.



Figure 2.7: Cast iron arched ribs



Figure 2.8: In-line bolted splice connections (note localised failure of paint system)



Figure 2.9: Repaired sections of arch and spandrel wall in span 3 (solid spandrel infill plates, additional stiffeners and gusset plates)

2.4.4 Spandrel Walls

The spandrel walls consist of cast iron latticed cruciform members (Figure 2.10). The spandrel walls are prefabricated in X-shaped panels and are bolted together and bolted to the top flange of the arch ribs (Figure 2.11). The spandrel walls are generally in good condition. As outlined in Section 2.4.3, repair works have been undertaken on sections of the spandrel walls in span 3. The repair work consists of solid spandrel infill plates, additional stiffeners and gusset plates. A recessed spandrel wall expansion joint allows for movement of the structure at the bridge abutments. The expansion joint was observed to be functional at the time of inspection (Figure 2.13).



Figure 2.10: Prefabricated cast iron latticed spandrel walls at pier



Figure 2.11: Prefabricated spandrel wall bolted to top flange of arched rib



Figure 2.12: Repairs to spandrel walls in span 3



Figure 2.13: Recessed spandrel wall expansion joint detail at abutments

2.4.5 Parapets

The parapets have been completely removed from the bridge. Details of the original parapets are shown on the construction drawings given in Figures 2.14 – 2.16. It appears that the parapets were removed before the 1890s (Figure 2.16). New parapets were subsequently installed before the line was closed in 1961 (Figure 2.17). It is likely that heritage requirements will require similar parapets to be installed in conjunction with the bridge rehabilitation. Parapet infill is recommended in order to make them un-climbable and to prevent debris falling from deck level onto the live carriageway below. As the bridge will also be used by cyclists a minimum parapet height of 1.40m will be required.

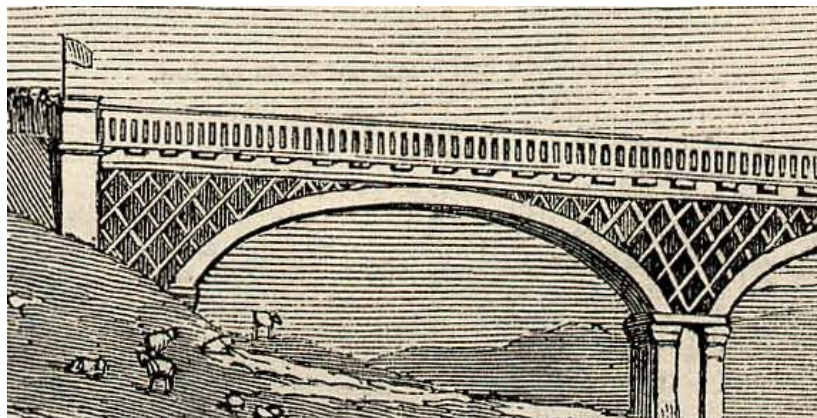


Figure 2.14: Bridge parapet circa 1851 (Illustrated London News, 1851)

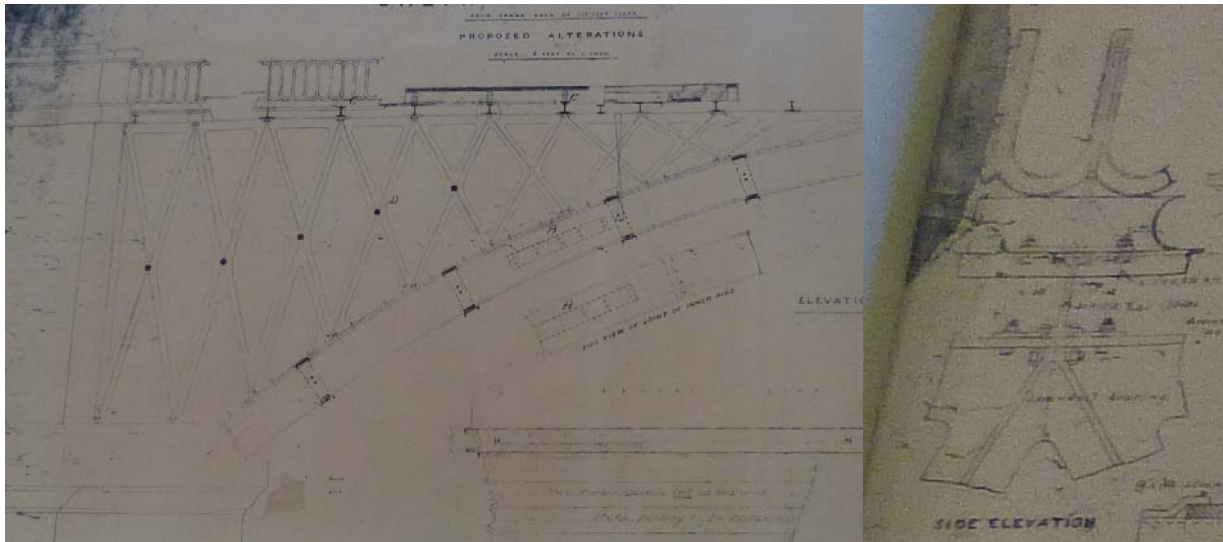


Figure 2.15: Bridge parapet detail (courtesy Cork City and County Archives)

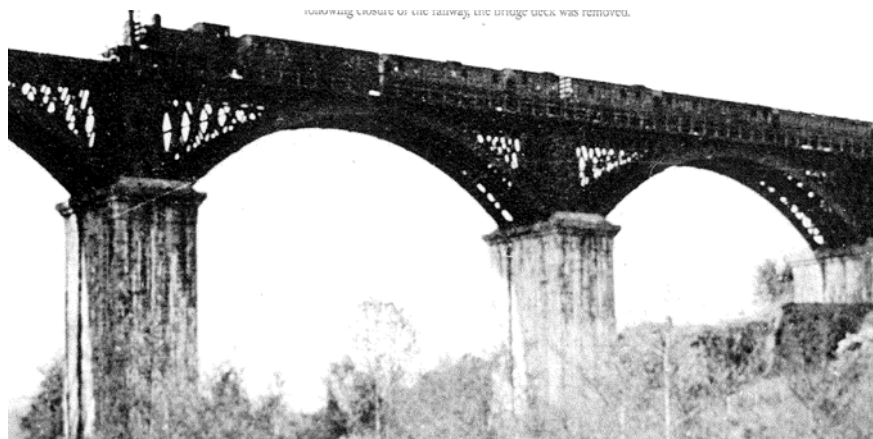


Figure 2.16: Photograph of Chetwynd Viaduct in service circa 1890, note no parapet present (Ronald Cox & Michael Gould 2003)



Figure 2.17: Photograph of parapet on the bridge at the time of deck removal, circa 1970

2.4.6 Lateral Bracing Members

Two types of lateral bracing members are present on the bridge. The extract given in Figure 2.3 refers to lateral “*cast iron bracing*” and “*wrought iron tie rods*”. The cast iron bracing is the X-shaped cruciform bracing which serves to provide lateral restraint to the arch ribs and transfer lateral loads to the substructure. The wrought iron tie rods are the circular hollow sections that provide lateral restraint at the node points of the latticed spandrel walls at mid height. A photographic comparison given in Figure 2.18 shows that an extensive proportion of the cast iron bracing has been removed. A number of wrought iron tie rods are also missing or have failed (Figure 3.22). Rehabilitation works will require complete replacement of the lateral bracing members in order to provide the required wind-bracing and to ensure adequate out-of-plane stability of the primary members.



Figure 2.18: Existing condition of bracing members (left) and previous bracing members (right) during deck removal (circa 1970), note a large proportion of lateral X-shaped cast iron bracing has been removed



Figure 2.19: X-shaped cast iron bracing and transverse wrought iron tie rods



Figure 2.20: Failed wrought iron tie rods



Figure 2.21: Underside of bridge deck (note absence of lateral bracing along length of arch ribs)

2.4.7 Piers

The piers are part constructed from ashlar masonry rising 21.34 m above the carriageway. The piers are in good condition with only minor defects present. Staining, localised mortar loss and localised vegetation growth was observed. Two of the piers are inscribed with the date and the name of the Engineer and Contractor.



Figure 2.22: Vegetation growth on top of pier



Figure 2.23: Staining on pier



Figure 2.24: Details of Engineer and Contractor inscribed on piers

2.4.8 Abutments

The abutments are generally more overgrown than the piers. However, structurally they appear to be in good condition. It is worth noting that significant portion of the approach embankment behind the eastern abutment has been removed (Figure 2.27).



Figure 2.25: Minor vegetation growth from abutment



Figure 2.26: Abutment overgrown with vegetation



Figure 2.27: Large excavation of embankment on approach to eastern abutment

2.4.9 Riverbed

A watercourse is located at the base of the eastern central pier. The banks of the watercourse appear to be eroded. Consideration should be given to the provision of scour protection measures (such as mass concrete infill or the provision of geotextiles overlain with large boulders) at the base of the pier.



Figure 2.28: Localised erosion to the banks of the watercourse at the pier base

2.4.10 Summary and Condition Ratings

A summary of the primary defects observed during the Principal Inspection are as follows:

- Bridge deck and parapets have been completely removed;
- A large proportion of the lateral cast iron X-bracing has been removed;
- A number of wrought iron tie rods have failed;
- Failure of paint system;
- Potential for scouring from watercourse at one of the pier bases;
- Localised loss of mortar from joints;
- Large section of eastern approach embankment has been removed;
- Minor vegetation growth.

Table 2.3 provides the condition rating for the bridge and each of its components.

Table 2.3: Condition ratings for Chetwynd Viaduct

Element	Condition Rating
Bridge Surface	5
Arch Ribs	3
Spandrel Walls	3
Parapets	5
Lateral Bracing Members	4
Piers	2
Abutments	2
Riverbed	3
Structure in General	3

2.5 3D LASER SCAN

Due to difficult and restricted access, Murphy Surveys were appointed to carry out a full three-dimensional laser scan of Chetwynd Viaduct. The survey provided a detailed geometric 3D output of the structure including accurate member sizes and dimensions. Dimensions were confirmed as being accurate using on-site measurements. The scan was capable of picking up geometric imperfections in members (crookedness, member bow etc.) and details of damaged and repaired sections. The output was also imported to the structural analysis program to conduct the structural assessment.



Figure 2.29: 3D laser scanning of Chetwynd Viaduct in operation

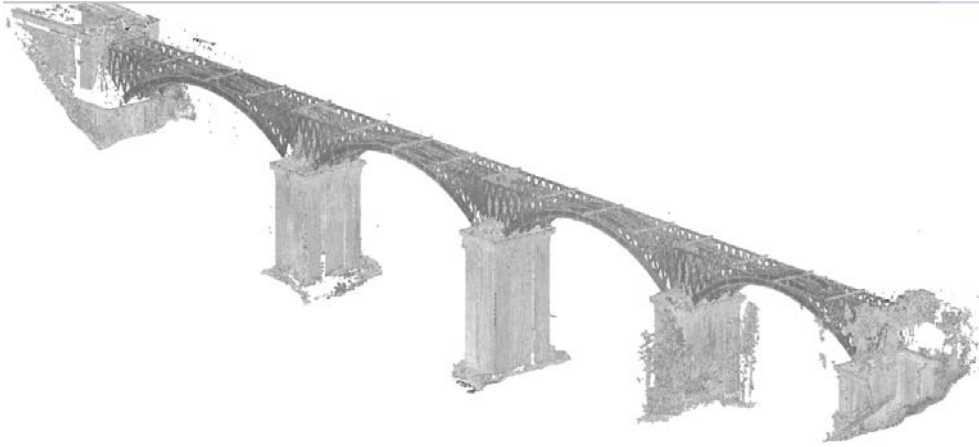


Figure 2.30: 3D point cloud from 3D laser scan

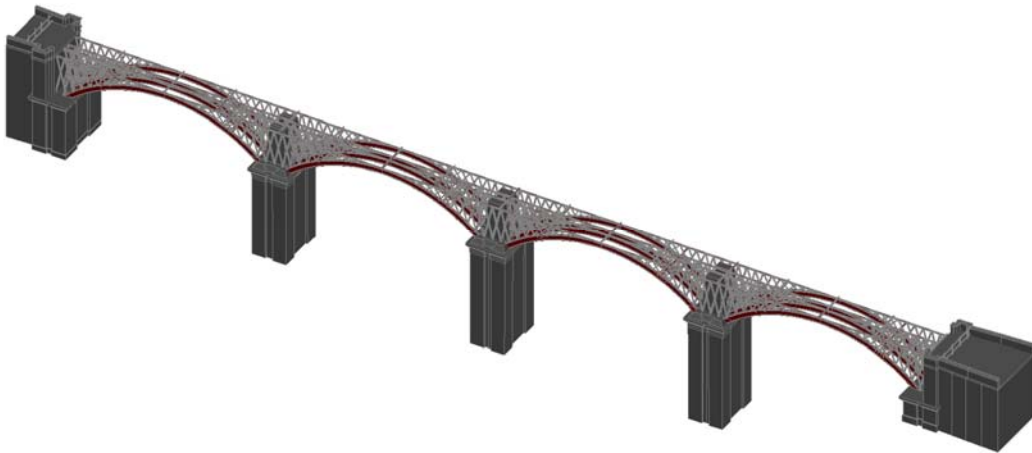


Figure 2.31: Fleshed 3D view of Chetwynd Viaduct from 3D laser scan

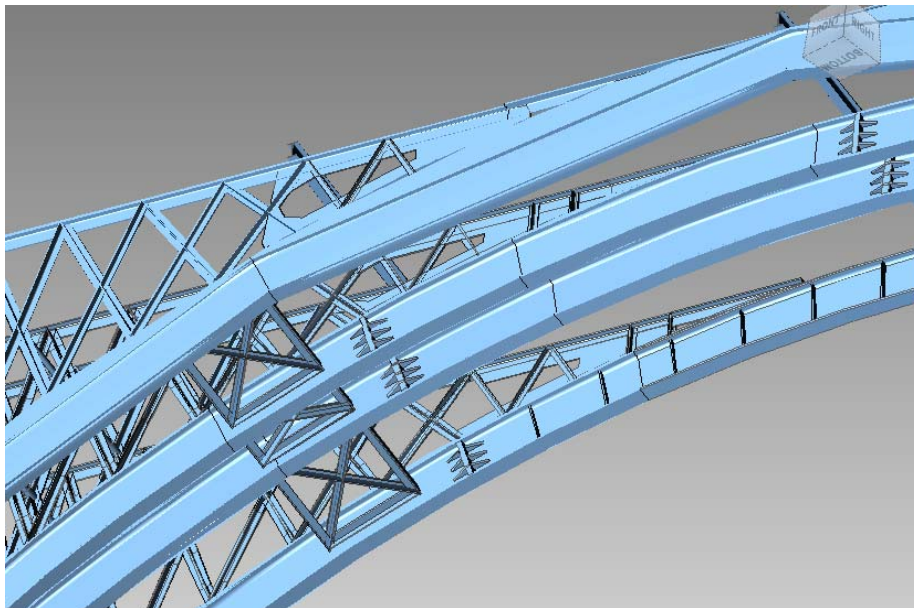


Figure 2.32: Fleshed 3D scan showing details of the repaired section on span 3

2.6 ASSESSMENT

2.6.1 Basis of Assessment

The structural assessment of the superstructure was carried out in accordance with BD21/01. For the cast iron components, a permissible stress assessment (Serviceability Limit State) was carried out with unfactored loading in accordance with BD 21/01. For the wrought iron components an Ultimate Limit State (ULS) approach was adopted in accordance with BD 21/01. A full three-dimensional model was used for the assessment, with the geometry directly imported from the 3D laser scan.

2.6.2 Material Properties

Table 2.4 gives the material properties adopted for the assessment in accordance with BD 21/01.

Table 2.4: Material properties used for assessment

Material property	Cast iron components	Wrought iron components
Material partial factor	1.0	1.20
Unit weight	7200 kg/m ³	7700 kg/m ³
Modulus of elasticity	105000 N/mm ²	200000 N/mm ²
Coefficient of thermal expansion	10.2 x 10 ⁻⁶ C ⁻¹	12.0 x 10 ⁻⁶ C ⁻¹
Compressive stress limit	154 N/mm ²	N/A
Tensile stress limit	-46 N/mm ²	N/A
Shear stress limit	46 N/mm ²	N/A

2.6.3 Loading

The loading applied was in accordance with BD 21/01. Additional members were applied to the model to replicate the loading imposed by a replacement deck. Conservative deck loading associated with a steel deck replacement comprising a stiffened steel deck plate and intermediate transverse beams (see Figure 2.37) was applied. Although alternative decking, such as timber, is feasible, a steel deck was chosen for assessment due to its more onerous self-weight compared to a timber alternative. The loading imposed by pedestrians/cyclists was represented by a uniformly distributed load of 5 kN/m² applied at deck level.

2.6.4 Structural Analysis Model

A full three-dimensional linear elastic finite element model was developed for Chetwynd Viaduct using LUSAS Finite Element Software. The webs and flanges of the arch ribs were modelled using thick shell elements. All other members were modelled using thick beam elements. Member stiffnesses were based on gross section properties. Member imperfections and failed/damaged/repairs sections were imported from the 3D laser scan and incorporated in the structural model. Since a large proportion of the lateral bracing has been removed from the bridge, a linear eigenvalue buckling analysis was conducted in order to assess the out-of-plane stability of the structure to applied loading.

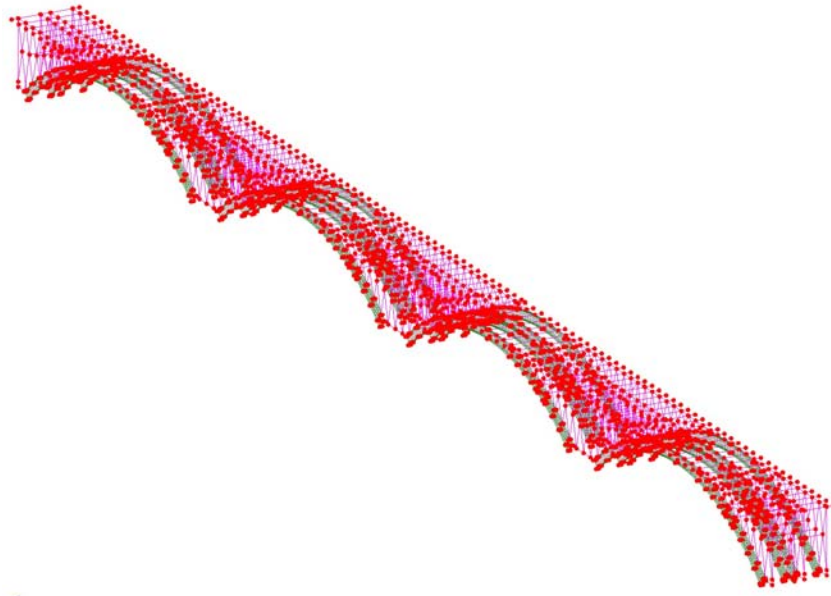


Figure 2.33: 3D finite element model of Chetwynd Viaduct

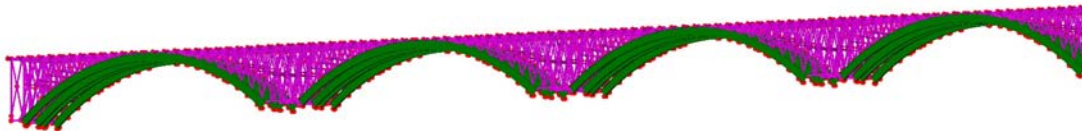


Figure 2.34: Fleshed view of model

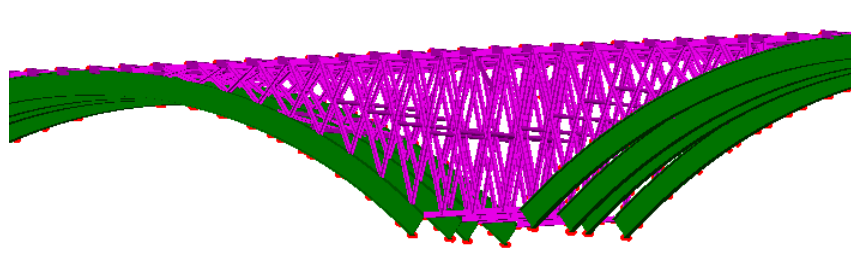


Figure 2.35: Close-up fleshed view of model

2.6.5 Assessment Results

The assessment stresses for the cast iron components is given in Table 2.5. All of the stresses are relatively low and are within the limits stipulated in Table 2.4 and BD 21/01. Accordingly, the cast iron components pass assessment for the applied loading.

The wrought iron components have sufficient capacity to pass assessment for the applied loading at Ultimate Limit State (ULS).

Table 2.5: Assessment stress summary for cast iron components

Member	Compressive stress (N/mm ²)	Tensile stress (N/mm ²)	Shear stress (N/mm ²)
Arch rib	17.0	-2.5	8.0
Spandrel lattice (cruciform member)	26.0	-14.0	5.0
Spandrel lattice (top tee member)	19.0	-12.0	4.0
X-bracing	6.0	-4.5	2.0

A linear-eigenvalue buckling analysis with the current provision of lateral bracing was carried out. Figure 2.36 shows the observed mode of out-of-plane buckling of the arch ribs in the absence of sufficient lateral bracing. It is therefore recommended that the missing lateral X-bracing be replaced in conjunction with the bridge rehabilitation in order to prevent out-of-plane buckling and to provide sufficient wind bracing.

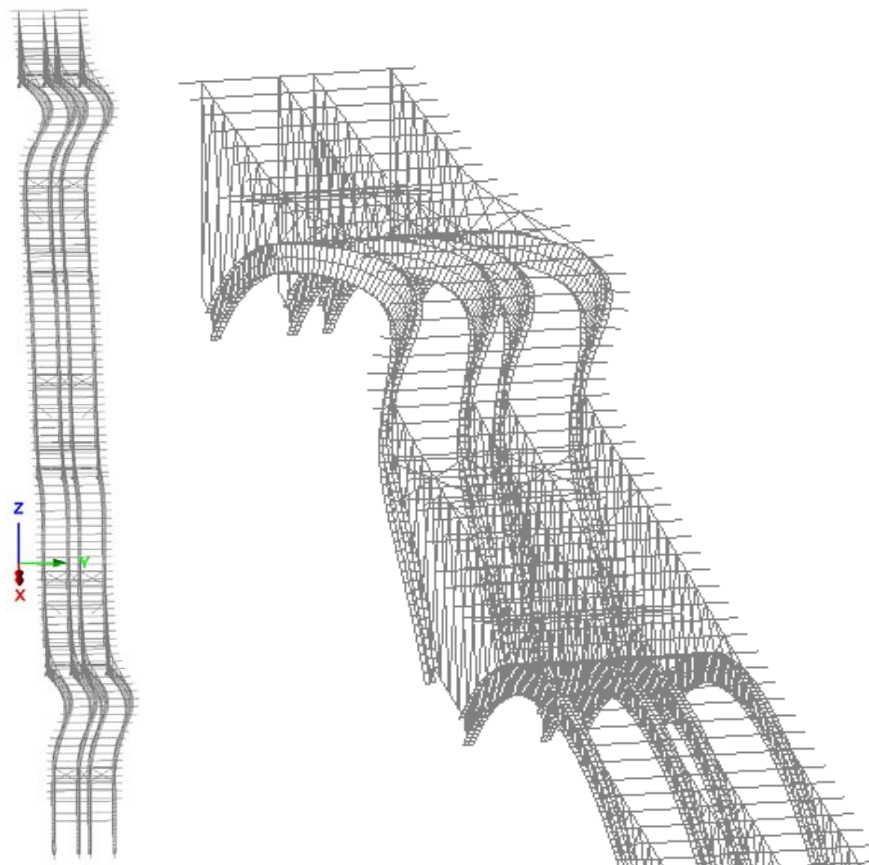


Figure 2.36: Observed mode of out-of-plane buckling of arch ribs in absence of sufficient lateral bracing

2.7 PRELIMINARY REHABILITATION COST ESTIMATE

A preliminary cost estimate for the rehabilitation of Chetwynd Viaduct for its proposed reuse as a pedestrian/cycle bridge is given in Table 2.6.

The form of deck assumed for the cost estimate is a stiffened steel deck plate supported on transverse steel Universal Beams. A preliminary cross section of the assumed form of deck structure is given in Figure 2.37. It is noted that an alternative comprising timber decking supported on transverse steel beams would provide a more cost effective solution.

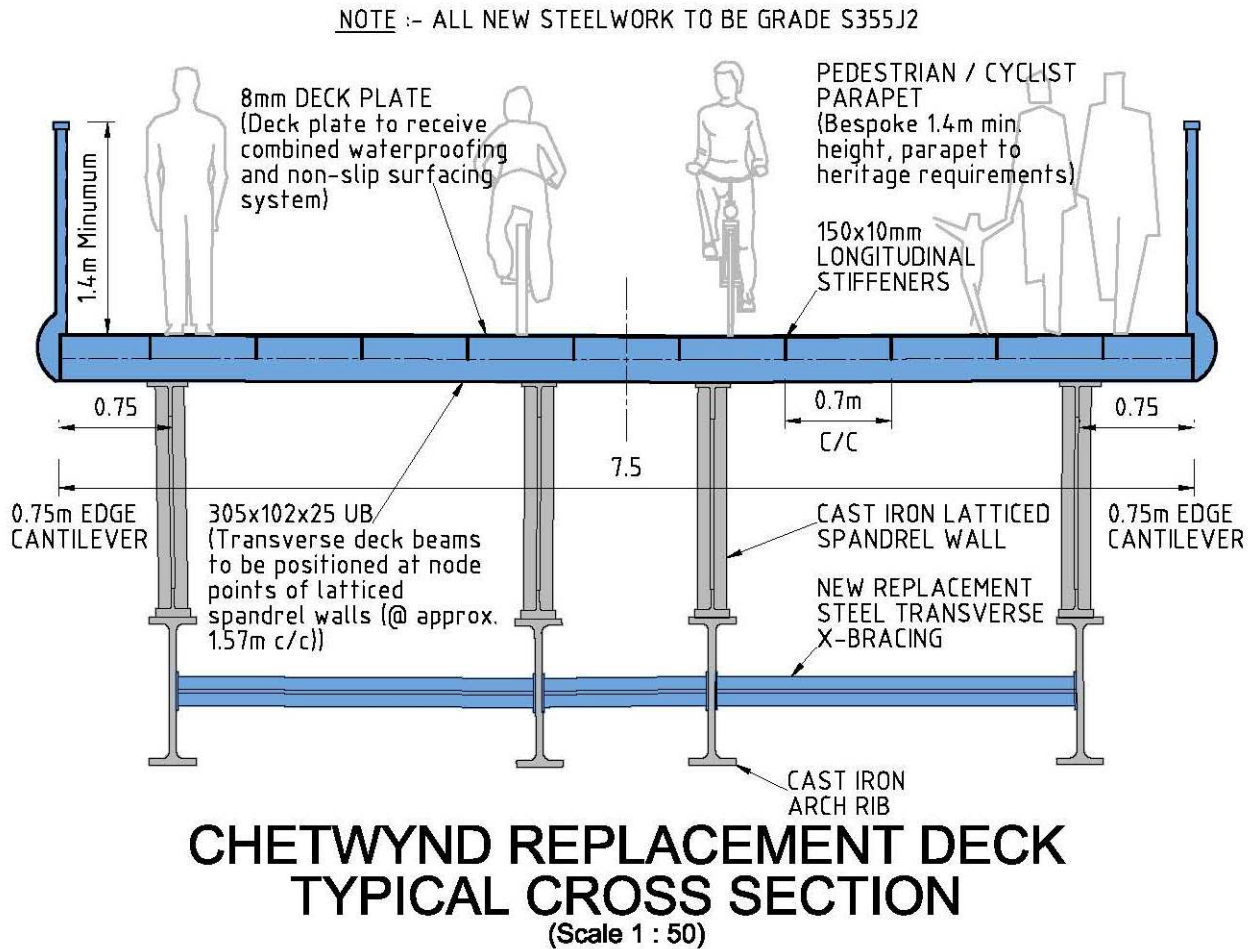


Figure 2.37: Preliminary structural form of deck replacement (existing cast iron shown in grey, new steelwork shown in blue)

Table 2.6: Preliminary rehabilitation cost estimate for Chetwynd Viaduct

Item	Description	Cost estimate (€)
1	Fabrication & installation of replacement steel transverse X-bracing (36T @ €3000/T)	108,000
2	Fabrication & installation of replacement steel transverse ties (3T @ €3000/T)	9,000
3	Fabrication & installation of transverse steel universal deck beams (28T @ €3000/T)	84,000
	Fabrication & installation of stiffened steel deck plate (122T @ €3000/T)	366,000
4	Bespoke pedestrian/cyclist parapet 1.40m minimum height (362m @ €400/m)	144,800
5	Protective paintwork to new structural steelwork (3167 m ² @ €50/m ²)	158,350
6	Combined waterproofing and non-slip surfacing to steel deck plate (1411m ² @ €55/m ²)	77,605
7	8 No. bollards to prevent vehicular access on bridge (8 bollards @ €240/bollard)	1,920
		949,675
8	Preliminaries (10% of construction costs)	97,968
Sub-total		1,047,643
9	Contingencies (20% of sub-total)	209,529
Total excluding VAT		1,257,172
10	VAT @ 13.5%	169,718
Total including VAT		1,426,890

Notes:

1. Price based on a complete deck replacement (entire deck width replaced with 0.75m edge cantilevers each side).
2. All new steelwork is priced as Grade S355J2.

The preliminary rehabilitation costing given in Table 2.6 above does not allow for repainting of the existing structure. Although the bridge has sufficient reserve capacity to tolerate some degree of sacrificial corrosion, repainting of the structure may require consideration. A preliminary total cost for this additional item is approximately €1,113,970 excluding VAT (€1,264,356 including VAT). The cost includes for a complete suspended enclosure system and an allowance for grit blasting to remove loose paintwork and achieve a suitable substrate. It is evident that painting the existing structure has a significant impact on the rehabilitation, with the cost effectively increasing by a factor of 1.9, thereby resulting in a total rehabilitation cost of €2,371,142 excluding VAT (€2,691,246 including VAT).

2.8 CONCLUSION AND RECOMMENDATIONS

Chetwynd Viaduct has sufficient capacity to carry the loadings imposed during its proposed re-use as a pedestrian/cycle bridge. It is recommended the following measures be taken in conjunction with the bridge rehabilitation:

- Complete deck replacement. Either steel or timber decking will be feasible, with the latter providing a more cost effective solution. Transverse deck beams should be placed at the node points of the latticed spandrel walls. Bolt holes are already present on the top of the spandrel members which facilitate ease of construction.
- Complete parapet replacement (1.4m minimum height with infill).
- Replacement of all missing lateral X-brace members.
- Replacement of lateral tie rods connected to latticed spandrel walls.
- Consultation with Heritage Officer throughout the rehabilitation.
- Detailed paint inspection. Although there is sufficient reserve capacity to tolerate some sacrificial corrosion, consideration should be given to repainting the structure.
- Scour protection measures to base of pier.
- Re-construct missing section of eastern embankment.
- Preclude vehicular access on the bridge with the provision of bollards at each abutment.

The preliminary cost estimate for the rehabilitation of Chetwynd Viaduct for its proposed reuse as a pedestrian/cycle bridge is approximately €1,257,172 excluding VAT (€1,426,890 including VAT). Should it be deemed necessary to repaint the existing structure, the preliminary cost will increase by approximately €1,113,970 excluding VAT (€1,264,356 including VAT), thereby resulting in a total rehabilitation cost of €2,371,142 excluding VAT (€2,691,246 including VAT).

3 HALFWAY VIADUCT

3.1 LOCATION

Halfway Viaduct located is on the abandoned Cork-Bandon and South Coast Railway. The viaduct is located immediately north of the village of Halfway. The rail line was officially closed on the 31st of March 1961. The bridge spans a river valley in an east to west direction. A tributary of the Owenboy River flows in a southern direction under the middle arch. The bridge location is shown in Appendix A.



Figure 3.1: Halfway Viaduct

3.2 DESCRIPTION

Halfway viaduct is a three-span masonry arch structure. Each arch is of equal geometry and forms a semi-circular profile. The total length of the structure, including abutments and wing walls, is approximately 88.4m.

A full structure inventory is given in Table 3.1. Dimensioned inspector's sketches are also provided in Appendix B.

Table 3.1: Halfway Viaduct Inventory

Inventory Item	Dimension/Remark
Number of spans	3
Minimum span length	16.95m (clear)
Maximum span length	16.95m (clear)
Overall length	88.4m
Width out-to-out	8.38m
Area	740.79m ²
Minimum parapet height	0.20m
Minimum parapet thickness	0.45m
Skew	0.00°
Bridge curved (Y/N)	N
Skew	0.00°
Span length: Span 1	16.95m (clear)
Span length: Span 2	16.95m (clear)
Span length: Span 3	16.95m (clear)
Standard design (Y/N)	Y
Design of cross-section	Masonry arch
Design of elevation	Arch, one or more spans
Material of primary members	Stone masonry
Rise of arch barrel at crown	8.12m
Rise of arch barrel at quarter points	6.87m
Thickness of arch barrel	0.87m
Average depth of fill	0.98m

3.3 PRINCIPAL INSPECTION

3.3.1 Inspection Methodology

The bridge inspection system used is the National Roads Authority (NRA) Irish Structure Management System (EIRSPAN).

A condition rating is assigned to the structure and each of its components based on the observed degree of distress or deterioration. The condition is registered by means of a rating from 0 to 5. A description of each of the condition ratings is given in Table 3.2. Based on the condition ratings of each of the individual components, the overall structure is also assigned a condition rating.

Table 3.2: Extract from NRA Eirspan Manual No.3 Principal Inspection (Revision C)

Condition Rating	Description
0	No or insignificant damage.
1	Minor damage but not in need of repair.
2	Some damage, repair needed when convenient. Component is still functioning as designed. Observe the condition development.
3	Significant damage, repair needed very soon, i.e. within the next financial year.
4	Damage is critical and it is necessary to execute repair works at once, or to carry out a detailed inspection to determine whether any rehabilitation works are required.
5	Ultimate damage. The component has failed or is in danger of total failure, possibly affecting the safety of traffic. It is necessary to implement emergency temporary repair works immediately or rehabilitation works without delay after the introduction of load limitation measures.

The Principal Inspection of Halfway Viaduct was carried out on 26th September 2013. Access to the underside and topside was on foot through difficult terrain and dense vegetation.

3.3.2 Bridge Surface

The carriageway is 7.37m wide between parapet faces with extensive vegetation present throughout. Dense vegetation growth restricted full access to the bridge deck. Moisture penetration was observed through the arch barrel. In conjunction with the bridge rehabilitation, it is recommended that all existing vegetation be removed from the bridge deck, and a minimum of 150mm deep layer of existing bridge surfacing/ballast be removed. A new concrete footway construction (similar to Figure 3.3) should extend to the full deck area. The new concrete pavement would prevent water seepage through the arch barrel.



Figure 3.2: Dense vegetation growth on the bridge deck

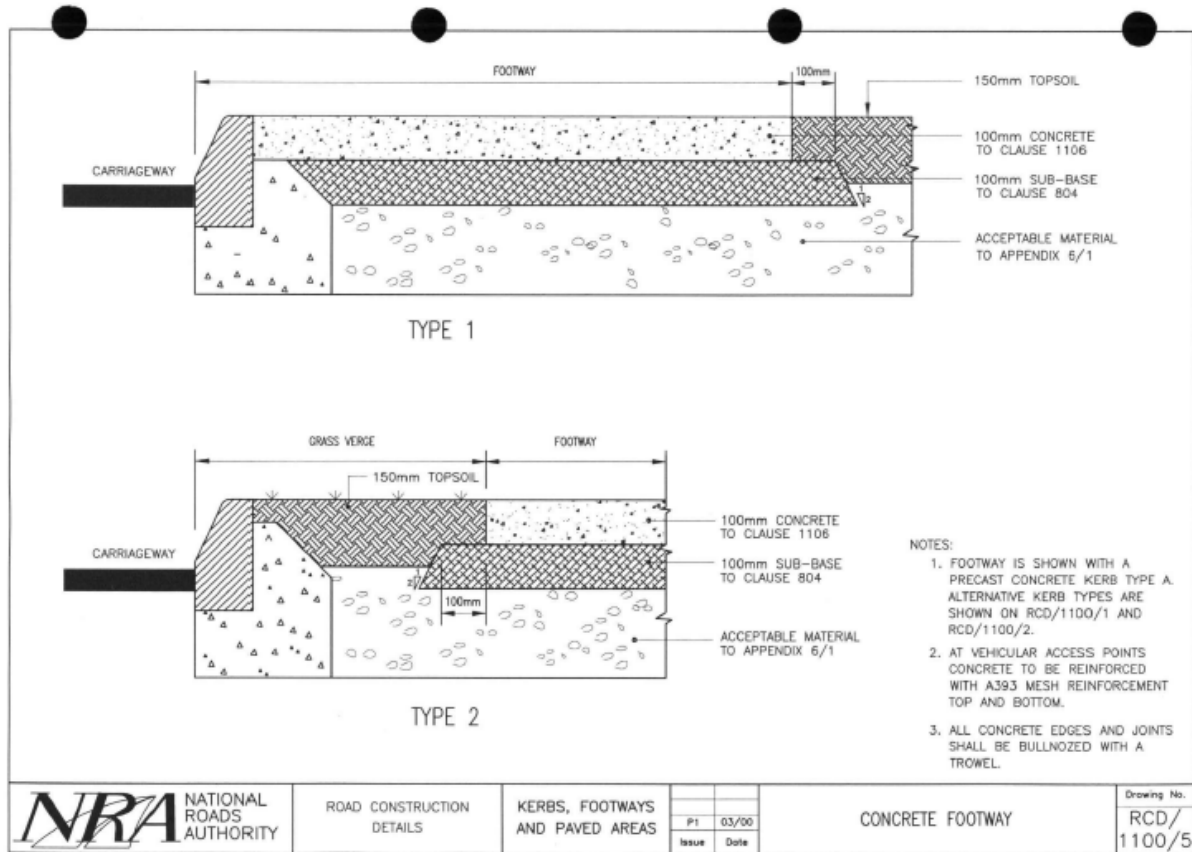


Figure 3.3: Recommended concrete pavement to bridge deck

3.3.3 Parapets

Low level parapets (0.20m minimum high at north side and 0.60m minimum high at south side) are present on the bridge deck. The parapets are extensively overgrown (Figure 3.4 & 3.5). The extensive vegetation growth prevented a full inspection of the masonry. When vegetation was cleared locally it was evident that the vegetation growth has caused damage to the masonry (Figure 3.6). In places the parapet capping/coping is missing. In order to accommodate cyclists, 1.4m minimum height parapets will be required. The parapet could be in the form of masonry (via extending the height of the existing parapets) or through the installation of guard rails similar to Figure 3.7. The design must be sympathetic to heritage requirements.



Figure 3.4: Northern masonry parapet wall



Figure 3.5: Southern masonry parapet wall



Figure 3.6: Evidence of damage to masonry caused by vegetation on southern parapet

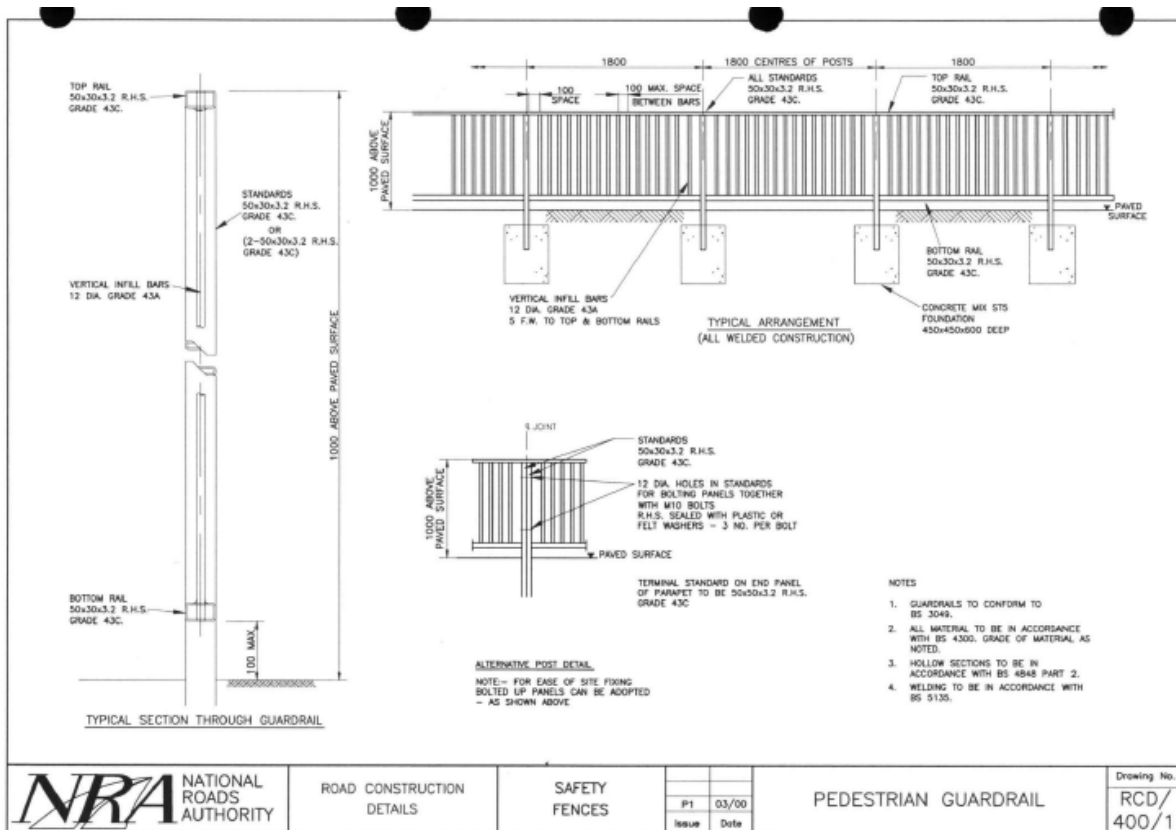


Figure 3.7: Bridge parapet details (note parapet to be a minimum of 1.4m high)

3.3.4 Spandrel Walls

The spandrel walls are constructed from coursed masonry. The walls are in good condition. Vegetation growth is more prominent on the northern elevation than the southern elevation (Figure 3.8 & 3.9). Sub surface drainage outlets are present over the piers (Figure 3.10). It was not possible to determine if the drainage outlet were functioning at the time of the inspection.



Figure 3.8: Northern elevation showing vegetation growth



Figure 3.9: Southern elevation



Figure 3.10: Sub surface drainage outlet in spandrel wall

3.3.5 Arch barrel

The arch voussoirs are made of cut stone and the deck barrel of coursed random rubble. Each arch has similar geometry, which includes a clear span of 16.95m and a rise from the springing point to the keystone of 8.12m. The springing point was measured at a height of 12.05m above ground level. The three arch profiles are in good condition with no signs of deformation/distortion.

There is evidence of water seepage from the extensive vegetation growth on the bridge surface resulting in localised loss of mortar and staining (Figure 3.11 and 3.12). The arches are generally in good condition, despite vegetation growth, which will require routine maintenance to remove.



Figure 3.11: Arch barrel soffit (note water penetration)

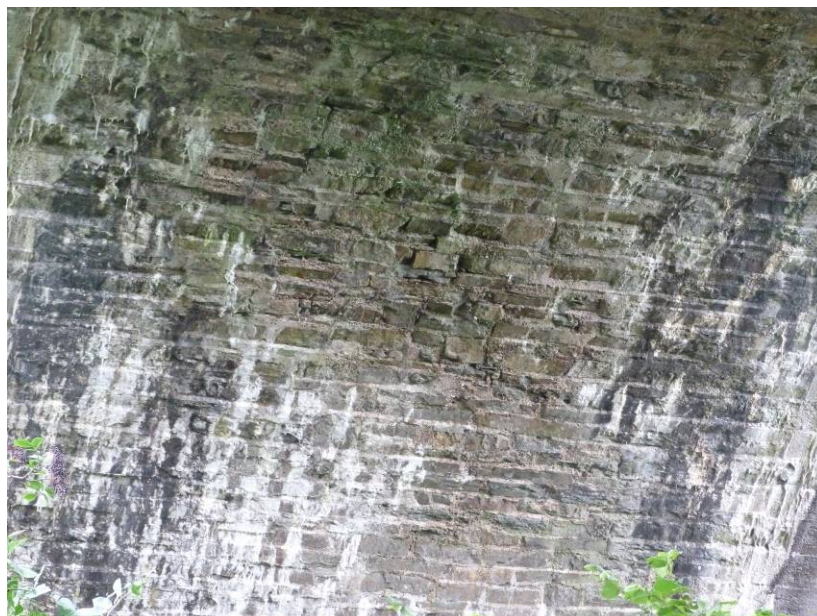


Figure 3.12: Water penetration and localised mortar loss on arch barrel

3.3.6 Abutments

The abutments are constructed from coursed masonry. Staining is present on the masonry. Despite vegetation growth, the abutments are generally in good condition requiring routine maintenance to remove vegetation.



Figure 3.13: Staining to eastern abutment



Figure 3.14: Vegetation growth on western abutment

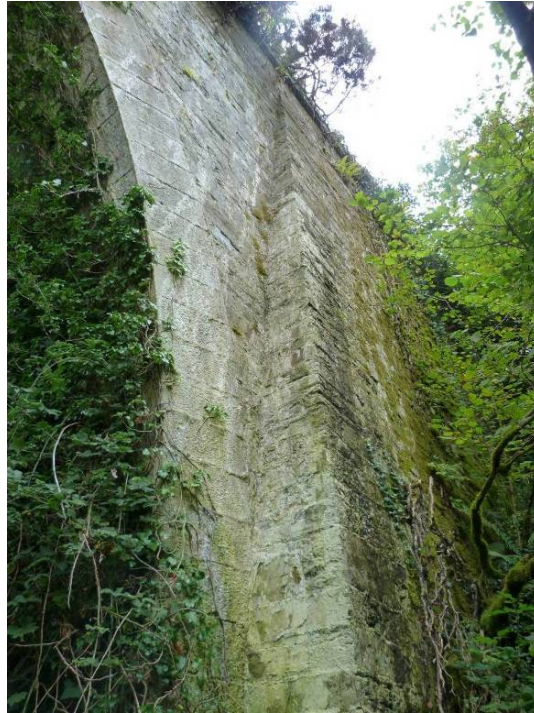


Figure 3.15: West abutment wing wall

3.3.7 Piers

The piers are constructed from coursed masonry. Staining is present on the masonry. Despite heavy vegetation growth, the piers are generally in good condition requiring routine maintenance to remove vegetation.



Figure 3.16: Vegetation growth on pier



Figure 3.17: Vegetation growth on pier footing

3.3.8 Riverbed

The river flows on a rock bed forming rock pools between the arches. There is no evidence of scour or undermining at the pier footings.



Figure 3.18: Riverbed

3.3.9 Lighting

There is up-lighting present to the bridge. It could not be determined at the time of the inspection if the up-lighting is functional.



Figure 3.19: Bridge up-lighting attached to pier

3.3.10 Summary and Condition Ratings

A summary of the primary defects observed during the Principal Inspection are as follows:

- Moisture penetration through arch barrel due to presence of dense overgrowth on the bridge deck;
- Loss of mortar to joints in arch barrel, parapets walls, spandrel walls, piers and abutments
- As would be expected for a structure that has been abandoned for over 50 years, there is extensive vegetation throughout.

The dense vegetation cover prevented a full inspection of the masonry.

Table 3.3 provides the condition rating for the bridge and each of its components.

Table 3.3: Condition ratings for Halfway Viaduct

Element	Condition Rating
Bridge Surface	5
Parapets	5
Spandrel Walls	2
Arch barrel	2
Abutments	2
Piers	2
Riverbed	2
Structure in General	3

3.4 ASSESSMENT

Measurements and an assessment of material properties were taken on site during the inspection to form the basis for the structural assessment.

3.4.1 Modified MEXE Method

The capacity of the bridge was assessed using the Modified MEXE Method in accordance with BA 16/97. The Modified MEXE Method of Assessment is adapted from the method set out in “Military Load Classification (of Civil Bridges) by the Reconnaissance and Correlation Methods”, MEXE May 1963. It is a relatively simple empirical technique for calculating the load capacity of masonry arches taking account of the condition of the arch barrel and its geometric properties. The method has been found to give safe results, but has the following limitations:

1. The method is intended to be applied primarily to single span arches.
2. It is intended to be used for spans not exceeding 18m.
3. For spans greater than 12m it becomes increasingly conservative compared to alternative methods.
4. The method should not be used where the arch is flat or appreciably deformed.

3.4.2 Assessment Results

A Modified MEXE assessment yielded a capacity permitting the passage of a 5 or 6 axle Heavy Goods Vehicle (HGV) with a Gross Vehicle Weight (GVW) of 44 tonnes. The maximum permissible vehicle axle loads are given in Table 3.4.

Table 3.4: Allowable axle loads for Halfway Viaduct

Allowable Axle Loads (tonnes) per axle	No. of Axles on the Bridge
28.5	Single axle
16.5	2 axle bogie
12.0	3 axle bogie at 2.6m spread

Accordingly, the bridge has sufficient capacity to comfortably carry the loadings imposed during its proposed re-use as a pedestrian/cycle bridge. The bridge also has sufficient capacity to support a maintenance vehicle, such as that given in Figure 5.2 of IS EN 1991-2, if required.

3.5 PRELIMINARY REHABILITATION COST ESTIMATE

A preliminary cost estimate for the rehabilitation of Halfway Viaduct for its proposed reuse as a pedestrian/cycle bridge is given in Table 3.5.

Table 3.5: Preliminary rehabilitation cost estimate for Halfway Viaduct

Item	Description	Cost estimate (€)
1	Site clearance, excavations, vegetation removal and masonry repointing	30,000
2	Installation of new concrete footway on entire bridge deck (652m ² @ €25/m ²)	16,300
3	Bespoke pedestrian/cyclist metal parapet 1.4m minimum overall height (177m @ €250/m)	44,250
		90,550
4	Preliminaries (10% of construction costs)	9,055
Sub-total		99,605
5	Contingencies (20% of sub-total)	19,921
Total excluding VAT		119,526
6	VAT @ 13.5%	16,136
Total including VAT		135,662

3.6 CONCLUSIONS AND RECOMMENDATIONS

Halfway Viaduct has sufficient capacity to comfortably carry the loadings imposed during its proposed re-use as a pedestrian/cycle bridge.

It is recommended that the extensive vegetation be removed throughout the structure. Due to the moisture penetration observed through the arch barrel it is recommended to install a concrete footway on the bridge deck. The following measures are also recommended:

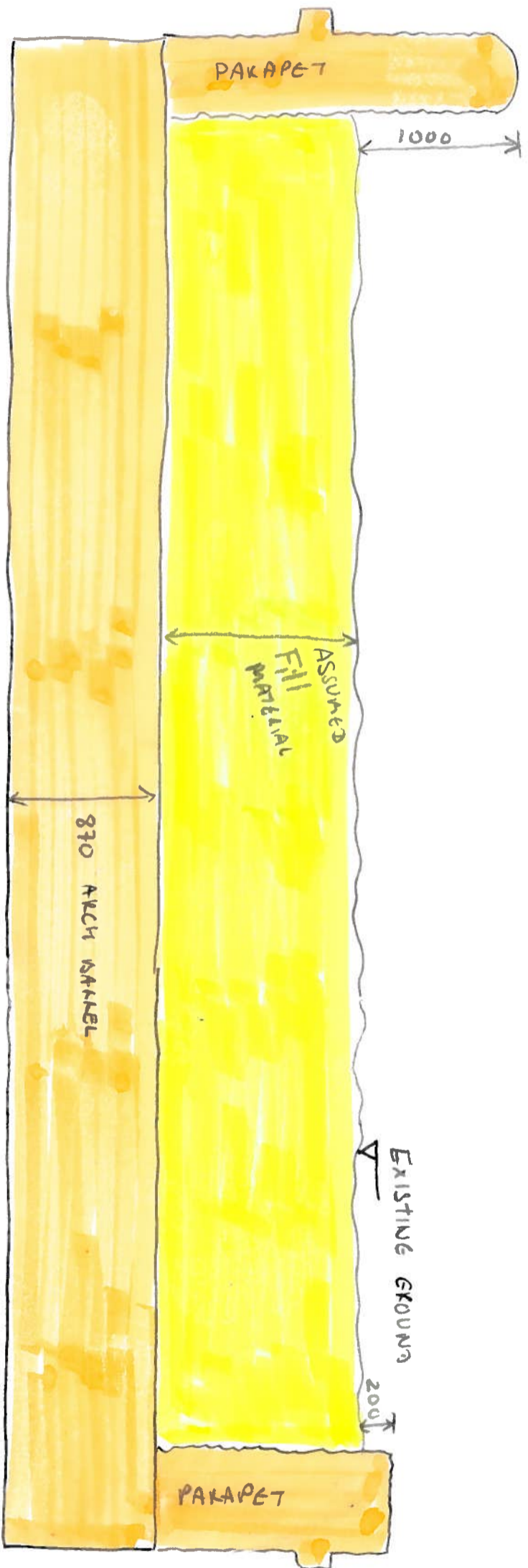
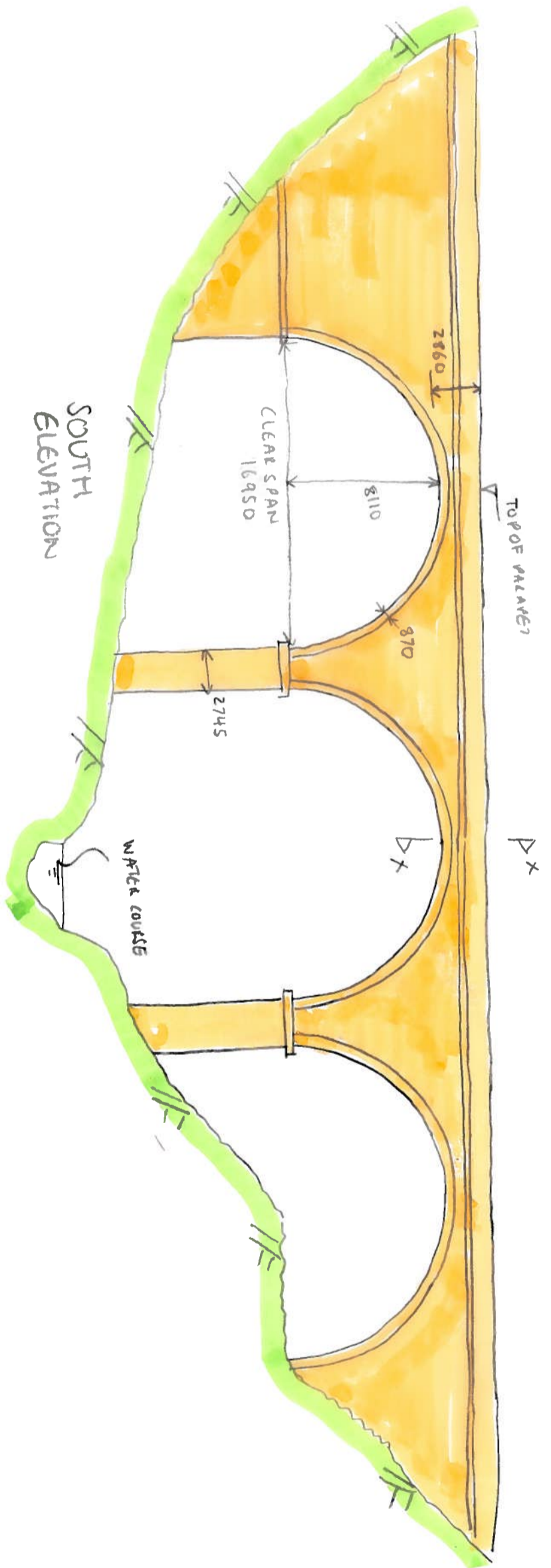
- Consultation with the Heritage officer in Cork County Council should be undertaken.

- Prior to works being carried out an ecological assessment should be carried out by an environmental scientist.
- Extensive vegetation growth and roots should be removed from all masonry.
- Following removal of the vegetation, an assessment of damage to the masonry should be carried out, and repointing with lime mortar be undertaken as necessary.
- All vegetation and roots on the bridge deck to be removed to at least 150mm below deck level. A new concrete bridge deck pavement should be installed to prevent future water ingress (and subsequent damage) to the arch barrel.
- New parapets should be installed on the bridge. Notwithstanding the heritage officer requirements, the parapets may take the form of masonry walls or metal rails. The parapets should be 1.4m above finished pavement level to cater for cyclists.

The preliminary cost estimate for the rehabilitation of Halfway Viaduct for its proposed reuse as a pedestrian/cycle bridge is approximately €119,526 excluding VAT (€135,662 including VAT).

APPENDIX A
LOCATION MAP

APPENDIX B
INSPECTOR'S SKETCHES



SECTION X-X

HALFWAY VIADUCT

APPENDIX C
MODIFIED MEXE ANALYSIS

Assessment of Masonry Arch Bridges by the Modified MEXE Method

Ref.: Part 4 BA 16/97

Bridge Name:	Halfway Viaduct
Bridge Location:	Halfway Co. Cork
Assessed By:	R. O'Donovan

Restrictions:

The method assess only the ARCH BARREL.
 The method may only be used for spans up to 18m.
 (Note: for spans > 12m, the method becomes increasingly conservative).

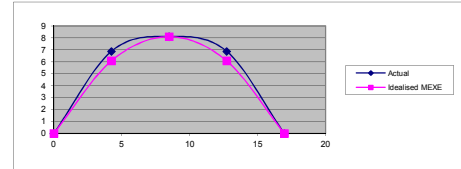
1. Survey Information

Span	L	16.95	m
Rise at crown	rc	8.11	m
Rise at quarter points	rq	6.87	m
Thickness of barrel adjacent keystone	d	0.87	m
Average depth of fill including road surface	h	0.99	m

2. Provisional Assessment

PAL*	64.616	t
PAL < 70t, ok		
PAL	64.616	t

Profile- actual and theoretical



3. Modifying Factors

3.11 Span/Rise Factor

Actual span / rise	-	2.090
Fsr	1.000	

Note: a span/rise of 4 or less is assumed to give optimum strength and has a factor of 1

3.12 Profile Factor

rq/rc	-	0.847
Fp	0.745	

Note: if rq/rc = 0.75, arch is parabolic

3.13 Material Factor

Tab. 3.1 Barrel factor

Enter '1' to indicate your choice

- Granite, whinstone, whether random or coursed and all built-in-course masonry except limestone all with large shapes voussoirs
- Ashlar quality siliceous sandstone
- Concrete or engineering brick and similar sized masonry (not limestone)
- Limestone (random or coursed), ashlar quality calcareous sandstone, good random masonry and building bricks, all in good condition
- Masonry of any kind in poor condition (many voussoirs flaking or badly spalling, shearing etc.).

Fb	1.000
----	-------

Tab. 3.2 Fill factor

- Concrete
- Grouted materials (other than those with a clay content)
- Well compacted materials
- Weak materials evidenced by tracking of the carriageway surface

Ff	0.500
----	-------

Fm	0.734
----	-------

3.16 Joint Factor

Tab. 3.3 Width factor

- Joints with widths up to 6mm
- Joints with widths between 6mm and 12.5mm
- Joints with widths over 12.5mm

Fw	0.800
----	-------

Tab. 3.4 Mortar factor

- Mortar in good condition
- Loose or friable mortar

Fmo	0.900
-----	-------

Tab. 3.5 Depth factor*

* instead of using this depth factor, it is preferable to reduce the barrel thickness by the amount of missing mortar.

- Pointed joints in good condition
- Unpointed joints, pointing in poor condition and joints with up to 12.5mm from the edge insufficiently filled
- Joints with from 12.5mm to one tenth of the thickness of the barrel insufficiently filled
- Joints insufficiently filled for more than one tenth the thickness of the barrel (this factor at the engineer's discretion)

Fd	0.800
----	-------

Fj	0.576
----	-------

3.21 Condition Factor

Fcm	0.800
-----	-------

Note: Refer to Cl. 3.20 for guidance on defects and condition factors

Comments on selection of condition factor:

4. Modified Axle Load

Combined modified factors	0.252	Fsr.Fp.Fm.Fj.Fcm
---------------------------	-------	------------------

Modified Axle Load	16.287	t
--------------------	--------	---

5. Axle Factors

Fig. 3/5a No axle lift-off

Enter single axle factor	1.750	----->	28.502	t	----->	
2 axle bogie	1.000	----->	16.287	t	----->	
Enter 3 axle bogie (2.6m spread)	0.750	----->	12.215	t	----->	

7. Weight Restriction

(Tab. 3/6)

N/A	t
N/A	t
N/A	t

Fig. 3/5b With axle lift-off*

Enter 2 axle bogie	0.000	----->	0.000	t	----->	N/A	t
--------------------	-------	--------	-------	---	--------	-----	---

*Situations where 'lift-off' case should be considered

1. A vertical road alignment with significant changes from positive to negative gradient over a short distance.
2. Arch located at the bottom of a hill or on a straight length of road where approach speeds are likely to be high.
3. Irregularities in road surface on the arch.