Wolverhampton City Centre Extension
Railway Drive Arch Bridge
Structural Assessment
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Job No: 60274057  Reference: M001.023-W2-RP-001  Date Created: 14 February 2014

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Introduction

Railway Drive Arch Bridge carries the approach to Wolverhampton Railway station over the Birmingham Canal; see Figure 1 below. The Passenger Transport Authority Centro has developed a programme of extensions for the current Midland Metro Tramway system. The extensions will include a spur to the Wolverhampton Railway Station. It is proposed that this spur will be carried by Railway Drive Arch Bridge.

The structure consists of a single span masonry arch of approximately 13.5m span. The arch barrel consists of a six-ring brick arch, with approximately 0.5m of fill above the arch crown extrados. The abutments are part of the retaining walls in the area.

This report summarises the assessment of the arch for supporting the proposed Metro loading. As part of the assessment, a visual inspection of the structure was carried out. The computer software programme LimitState RING 3.0 was used to assess the arch.

Figure 1: Bridge Location
Structural description

The bridge consists of a single span masonry arch, with a clear span of approximately 13400mm springing off masonry abutments. The arch is comprised of a six-ring brick arch barrel, with approximately 0.5m of fill above the arch crown extrados. The arch crown rise is approximately 2326mm. The bridge was reportedly saddled circa 1985 to strengthen the arch but no records or details are available. The abutments, arch barrel, voussoirs, spandrel walls and parapets are constructed from blue engineering brick.

The abutments form part of the retaining wall structures in the area. To the immediate north of the structure, retaining walls adjoin both abutments. To the immediate south, the structure is abutted by another single span arch bridge that carries Wolverhampton Train Station car park over the Birmingham Canal. This abutting structure is a five-ring brick arch bridge that has not been assessed as part of the works.

The bridge carries a three-lane road with two lanes heading towards Wolverhampton Train Station, and one lane heading in the opposite direction, as well as adjacent footways. Edge protection consists of steel Manchester bollards that line the vehicular carriageways over the arch and metallic pedestrian parapet railing to the north side of the structure, with one masonry pilaster at the north east corner. To the south side of the structure, the joint with the abutting bridge is undefined at road level.

Foundation details are unknown and are not indicated in available documents. No intrusive works were conducted. Arch backing level and internal superstructure construction is unknown.

Network Rail have limited archives relating to this structure, referred to as RBS2 109. The structure details are taken from an extract of their archives and given in Appendix B. It is noted that the Network Rail archives for the structure are unclear and there is confusion as to the name and actual ownership of the asset.
Previous Assessment Summary

The 5Ws Wolverhampton Loop Structures Report by AECOM on June of 2009 recorded the following information:

5Ws Wolverhampton Loop Structures Report – AECOM

The study suggests that the bridge was reportedly saddled circa 1985, but no saddle details were available. There were differing reports on the capacities of the structure, varying from HA with 28HB to HA with 39HB. The ownership of the structure was also in question.

A live load dispersal exercise was carried out using Ring 2 software to compare existing and proposed Metro loadings. For the existing situation the lower HB capacity of 28 units was used, and an axle load for the Metro vehicle was derived from generic Metro vehicles.

The load dispersal analysis found that the Metro alignment reduces the load on the structure compared with 28 units of HB loading. For the purposes of the Outline Business Case costing it was recommended that no allowance for strengthening be included.

It was recommended that further investigation work be undertaken to determine the ownership and actual capacity of the bridge taking into account its previous strengthening works.
Inspection for Assessment Summary

A visual inspection was carried out on 8th January 2014. A copy of the report of the inspection is included in Appendix A. Two structures were inspected:

- W1 Bridge carrying Railway Drive over Wolverhampton Ring Road
- W2 Bridge carrying Railway Drive over Birmingham Canal

The visual inspection found the arch bridge to be in an overall fair condition; with seepage noted in several locations. No intrusive works were undertaken.
Assessment Method

The bridge was assessed using 2D arch analysis software LimitState RING version 3.0. RING requires the input of the geometrical and material properties of the structure and the applied load, from which it deduces a load ("adequacy") factor based upon a calculated collapse load divided by the applied load.

The geometric properties of the bridge were obtained from the June 2009 5Ws Wolverhampton Loop Structures Report. These properties are shown in Figure 2.

![Figure 2: Bridge Dimensions (in mm)](image)

In the absence of definitive information, the road surface was modelled as flat, and no backing was specified to the arch barrel. The unit weight of masonry was specified as 21 kN/m³.

In accordance with Midland Metro Phase 2 Design Criteria a load of 0.5RL was used as a representation for the proposed Metro.

The arch effective widths for the different load cases were determined by RING in accordance with BD 21/01.

The partial factors applied to loads were determined according to BD 21/01 and BD 37/01 appropriately as listed in Table 1 below.
Table 1: Load Factors

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>Masonry unit weight ( \gamma_{f,m} )</td>
<td>1.265</td>
</tr>
<tr>
<td>Fill unit weight ( \gamma_{f,f} )</td>
<td>1.32</td>
</tr>
<tr>
<td>Surface fill/ballast unit weight ( \gamma_{f,sf} )</td>
<td>1.32</td>
</tr>
<tr>
<td>Track load ( \gamma_{f,t} )</td>
<td>1.32</td>
</tr>
<tr>
<td>Axle load ( \gamma_{f,l} )</td>
<td>1.54</td>
</tr>
<tr>
<td>Dynamic ( \gamma_{f,dyn} )</td>
<td>1</td>
</tr>
</tbody>
</table>

The material factors \((\gamma_{m})\) to be applied to masonry strength, taken from Clause 2.4.3 of BS EN 1996-1-1, are dependent on a number of factors (such as level of construction supervision and whether the mortar specifications were designed or prescribed). This information is unknown for the Railway Drive Arch Bridge structure. Hence a sensitivity analysis for the material factor was conducted, testing values from 1.5 to 3.
Assessment Results

RING 3.0 outputs an adequacy factor, calculated by dividing the collapse load by the applied load. The results for the sensitivity analysis of material factor are as listed below in Table 2.

<table>
<thead>
<tr>
<th>Material Factor, $\gamma_m$</th>
<th>Adequacy Factor</th>
</tr>
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<tbody>
<tr>
<td>1.5</td>
<td>1.51</td>
</tr>
<tr>
<td>1.7</td>
<td>1.37</td>
</tr>
<tr>
<td>2</td>
<td>1.2</td>
</tr>
<tr>
<td>2.2</td>
<td>1.1</td>
</tr>
<tr>
<td>2.5</td>
<td>0.95</td>
</tr>
<tr>
<td>2.7</td>
<td>0.87</td>
</tr>
<tr>
<td>3</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Table 2: Sensitivity Capacity

As can be seen above, the structural capacity of the bridge is dependent on the value adopted for the Material Factor. With a Material Factor of 2.2 or lower, the bridge was assessed as able to support the proposed tram loading. However, use of Material Factors of 2.5 or higher resulted in bridge failure.

The partial material factors, $\gamma_m$, to be used in the ultimate limit state are stated in Clause 2.4.3 of BS EN 1996-1-1:2005+A1:2012. The relevant value depends on the level execution control (Class 1 to 5) and whether the masonry was constructed with specified mortar (designed or prescribed) or any mortar was used in the construction. All these factors are unknown or currently unavailable; hence the sensitivity analysis was undertaken.
Commentary

Due to the evident sensitivity of the analysis to the material factor, it would be prudent to perform investigations to confirm an appropriate material factor.

In addition to the material factor, further parameters are subject to variability and should also be considered in sensitivity analyses and investigations, such as masonry strength, angle of friction of fill and inter-ring friction coefficients.

It would also be worthwhile to confirm the strengthening/saddling work already undertaken, either by the provision of As-Built drawings for review or through site investigations. These works could have a significant impact on the capacity of the structure.

On the basis of our findings, it is recommended that an intrusive investigation of the structure be undertaken. If, however, further analysis identifies the need for strengthening, the following is a suggestion of methods by which this could be achieved.

- Addition of reinforced concrete saddle
- Provision of concrete backing to the arch
- Use sprayed concrete lining / cast in-situ concrete repair to arch barrel intrados
- Install relieving slab
- Deck reconstruction
Appendix A: Inspection Report
1.1 Executive Summary

AECOM have conducted visual inspections of two bridges that carry Railway Drive on the approach to Wolverhampton Train Station. Passenger Transport Authority Centro are proposing to extend the Midland Metro Tramway System over the bridges and have requested an investigation into required strengthening works.

The two structures under investigation are:

- W1 Bridge carrying Railway Drive over Wolverhampton Ring Road
- W2 Bridge carrying Railway Drive over Birmingham Canal

On 8th January 2014 visual inspections of the two structures were conducted. This Technical Note records the findings from the inspections.

W1 – Railway Drive over Wolverhampton Ring Road

W1 consists of two pre-cast concrete spans of approximately equal length. A central pier is located in the central reservation of the ring road. The abutments of the bridge form part of the retaining walls in the area. Access to the substructure of the west span of the bridge was not possible for the inspection due to restricted access by a high fence and lack of footway.

The visual inspection found the bridge to be in an overall fair condition, however the following defects were noted:

- At deck level, there are transverse cracks to the surface course of Railway Drive where the road crosses over the bearings – there are no joints in the road makeup to allow for bridge movement.
- At substructure level, there is seepage underneath the deck above the bearing shelf at the east abutment.

W2 – Railway Drive over Birmingham Canal

W2 is an existing brick arch bridge which carries Railway Drive over the Birmingham Canal on the approach to Wolverhampton Station. The structure comprises a six ring brick arch. To the immediate south of the structure is an abutting masonry arch bridge, with a five ring brick arch, that supports the train station car park.

The visual inspection found the bridge to be in an overall fair condition, with seepage noted in several locations.
1.2 Introduction

Centro are proposing to extend the existing Midland Metro Tramway System, with a spur to Wolverhampton Train Station. It is proposed to send the tramway over two existing bridges, W1 and W2, which currently carry Railway Drive to the train station. Initial visual inspections of the two structures were carried out by AECOM personnel Abdelmoneim Mahgoub, Lara Rueda Diaz-Portales and Rory Shanks on the morning of 9th January 2014.

The two structures under investigated are:
- W1 Bridge carrying Railway Drive over Wolverhampton Ring Road
- W2 Bridge carrying Railway Drive over Birmingham Canal

Figure 1 shows the location of W1 and W2.

1.3 Description of Structures

W1 – Railway Drive over Wolverhampton Ring Road

W1 is an existing bridge that currently carries Railway Drive over Wolverhampton Ring Road on the approach to Wolverhampton Rail Station. W1 is a two span simply supported structure. The first span is 19.364m and the second span is 21.651m. The structure consists of a reinforced concrete deck on pre-cast beams. The central pier is in the central reserve of Wolverhampton Ring Road, with the abutments being part of the Ring Road retaining walls.

Photo 1 shows a general view of W1.
Photo 1: General view of structure W1, Railway Drive over Wolverhampton Ring Road, looking at the south elevation.

**W2 – Railway Drive over Birmingham Canal**

W2 is an existing bridge that currently carries Railway Drive over the Birmingham Canal on the approach to Wolverhampton Rail Station. W2 is a single span (13.411m) masonry arch structure, with a six ring brick arch. There is approximately 0.5m of fill above the crown of the bridge. To the immediate south, W2 abuts another masonry arch bridge, a five ring brick arch that carries the train station car park over the Birmingham Canal.

Photo 2 shows a general view of structure W2.

Photo 2: General view of structure W2, Railway Drive over Birmingham Canal, looking at the north elevation.
1.4 Elements not inspected

The substructure of the west span of W1 was not inspected due to restricted access – a busy fenced off bus lane runs underneath the west span.

Foundations were not visible for either structure.

The visual inspections were performed from ground level and as such there was no close inspection of the bridge soffits or other areas at high level.

1.5 Defects

W1 – Railway Drive over Wolverhampton Ring Road

At deck level, there are transverse cracks to the surface course of Railway Drive where the road crosses over the bearings – there are no joints in the road makeup to allow for bridge movement. See photos 3, 4 and 5.

At substructure level, there is seepage underneath the deck above the bearing shelf at the east abutment. See photo 6.

W2 – Railway Drive over Birmingham Canal

There is seepage from the north elevation wing walls and west spandrel wall over the arch. See photos 7 and 8.

There is evidence of seepage from the barrel, especially where the arch meets the abutments on both east and west sides. See photos 9 and 10.

There is seepage at the joint between structure W2 and the abutting arch structure to the south side. See photo 11.
Photo 3: Cracking to the surface course of Railway Drive over the bearings of the east abutment of W1.

Photo 4: Cracking to the surface course of Railway Drive over the bearings of the central pier of W1.
Photo 5: Cracking to the surface course of Railway Drive over the bearings of the west abutment of W1.

Photo 6: Seepage underneath the deck, above the bearing shelf at the east abutment of W1.
Photo 7: Seepage from the west wing wall of the north elevation of W2.

Photo 8: Seepage from the spandrel wall over the west end of the arch, and seepage from the west wing wall of W2.
Photo 9: Seepage from the barrel where it meets the west abutment of W2.

Photo 10: Seepage from the barrel above the east abutment of W2.
Photo 11: Seepage from the joint to the south side of W2 where it abuts an adjoining arch structure.
Appendix B: Birmingham Canal Arch Bridge Details
M.O.T. Code B.E.4

Clear Span. = 44.0 ft, L
Arch Ring Rise at Crown. = 7.63 ft, r_c
Arch Ring Rise, 1/4 points. = 5.88 ft, r_q
Arch Ring Thickness at Crown. = 1.675 ft, d
Average Depth of Fill (1/4 pt transverse road profile) = 1.46 ft, h *
Total Thickness at Crown. = 3.335 ft, h + d
Provisional Axle (Nomogram 13).
Span/Rise Ratio L/r_c, \[ \frac{44.0}{7.63} = 5.77 \]
Span/Rise Factor (figure 7). = 0.772 FR
Profile Ratio r_q/r_c, \[ \frac{5.88}{7.63} = 0.771 \]
Profile Factor (figure 8). = 0.86 FP
Ring Factor (Table III). = 1.0 Fr *
Fill Factor (Table IV). = 0.9 Fl *
Material Factor
\[ \frac{(Fr \times d) + (Ff \times h)}{h + d} \left( \frac{10 \times 1.875}{(102 \times 1.46)} \right) = 0.956 FM \]
Width (Joint) Factor (Table V). = 0.9 Fw *
Depth (Joint) Factor (Table VI). = 1.0 Fd *
Mortar Factor (Table VII). = 1.0 Fm
Joint Factor = Fw x Fd x Fm, x x = 0.9 FJ
Condition Factor = 0.9 FC
Allowable Axle Load = PA x FR x FP x FM x FJ x FC
\[ = 27 \times 0.772 \times 0.95 \times 0.966 \times 0.9 \times 0.9 = 15 \text{ Tons} \]

Taking the capacity as an under estimate is very approximate.

25 TON AXLE: 25000 lb

This Allowable Axle Load is for an axle of a bogie - not single axle.