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WOOD ENVIRONMENTAL & INFRASTRUCTURE SOLUTIONS AND BRITISH COLUMBIA MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

LIONS GATE BRIDGE NORTH VIADUCT 2021 ORTHOTROPIC STEEL PLATE DECK INSPECTION REPORT

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Executive Summary

COWI North America Ltd. (COWI) was engaged as a subcontractor to Wood Environment & Infrastructure Solutions (Wood) to carry out an inspection of the orthotropic steel plate deck (OSPD) of the North Approach Viaduct of the Lions Gate Bridge in West Vancouver, BC. The purpose of the inspection was to evaluate whether fatigue cracks had formed in the OSPD, specifically in the welds between the troughs and plate of the OPSD or floorbeams, and to identify other potential concerns that would need to be addressed prior to the repaving work currently slated for the summer of 2022.

Inspection was carried out between October 19 and 22, 2021 by Eileen McEwen, P.Eng., and Jessica Ng, EIT. Visual inspection was conducted from the sidewalk on top of the deck, the catwalks beneath the deck, and via a boom lift situated on the ground below the viaduct. Additionally, thermographic images of the underside of the deck were collected via drones operated by UAViation to look for possible water inside the sealed troughs.

The following summarizes the inspection findings:

- The wearing surface was identified by Wood as having extensive, low severity longitudinal wheelpath cracks [1].
- In general, the OSPD, including the welds, were found to be in good condition.
- A few OSPD deck welds were found to be in fair condition.
- Cracking and some local spalling was observed to be typical in the Polyester Polymer Concrete (PPC) wearing surface, which was installed in 2014 when the deck breather joints were replaced with link plates.
- The bolted OSPD splices, generally located in the middle of each approach span, typically showed signs of water ingress and corrosion particularly in areas where the bolt spacing was larger, with rust jacking noted at several locations.
- The underside of the OSPD in the vicinity of the link plates that were installed to replace the original breather joints were observed to be in poor condition, with moisture, paint coating failure, and evidence of corrosion noted.
- No signs of water inside the OSPD troughs were identified by the thermography.

Based on the observed conditions of the wearing surfaces and expansion joints, no actions are recommended for these elements at this time. COWI recommends that magnetic particle inspection (MPI) be performed at five OSPD weld locations to confirm that no cracks are present. For the OSPD bolted splices, COWI recommends the Ministry locally remove asphalt and observe their condition from the top of deck and consider sealing them from the top (possibly by adding a seal weld) to limit future water ingress. If welding is chosen, care will be required to avoid adding a potential fatigue stress riser.

Based on the condition of the underside of the deck at the link plate locations, COWI is concerned that the link plate detailing represents a long-term risk to the structure. Furthermore, inspection of the interface between the link plate and the OSPD is only possible by completely removing the link plate and the paving, which is not practical. Therefore, the extent of the corrosion is not something that can be monitored. COWI recommends the Ministry initiate a study to determine if any modifications to the link plates can be made to mitigate as much of this risk as possible before the paving is replaced during the 2022 repaving program.

CONTENTS

1 Introduction

The Lions Gate Bridge spans the Burrard Inlet at the First Narrows between Vancouver on the south side and the North Shore on the north side. The Bridge is owned by the British Columbia Ministry of Transportation and Infrastructure (MoTI). COWI North America Ltd. (COWI) was engaged as a subcontractor to Wood Environment & Infrastructure Solutions (Wood) to carry out an inspection of the orthotropic steel plate deck (OSPD) of the North Approach Viaduct. The purpose of the inspection was to determine if any serious issues exist with the OSPD that may need to be addressed in advance of the repaving work planned for the summer of 2022, as well as to inform the development of general guidelines for the repair of possible cracks in the OSPD that may be found in the deck plate during the wear surface renewal.

Section 2 of this report summarizes the results of the visual inspection as well as the implications of the findings. Recommendations are provided in Section 3.

1.1 Objectives

The primary objectives for the 2021 OSPD inspection included:

- Conduct a visual inspection of the underside of the OSPD deck and documenting the current condition.
- Identify if any cracking of the OSPD is visible from the underside of the deck.
- Produce a report detailing the inspection observations and the resulting recommendations for MoTI.
- Generate guidelines for repair of cracks that are found during the visual inspection, or that may be found during the wear surface renewal.

1.2 Description of Structure

The Lions Gate Bridge opened to traffic in 1938 and carries three lanes of traffic over the Burrard Inlet between Vancouver and the North Shore, as shown in Figure 1.

Figure 1: Aerial View of Lions Gate Bridge, with North Viaduct Indicated by Red Circle (Google Earth 2021)

The north approach viaduct is 2196'-6" (669.5 m) long, with 25 spans varying in length from 42' (12.8 m) to 123' (137.5 m). The superstructure cross-section consists of two girders that were installed in 1938. In 1975, the original concrete deck was replaced with the current OSPD that consists of transverse floorbeams, spaced at 13'-6 3/16" (4.17 m), roadway deck plate, and longitudinal deck troughs (U-shaped longitudinal stiffeners). The portion of the OSPD under the traffic lanes is composed of a 15/32" (11.9 mm) steel deck plate and 5/16" (9.5 mm) deck troughs spaced at 2' (0.61 m) centre to centre, while the portion under the sidewalks consists of 5/16" (7.9 mm) deck plate supported by 3/8" (9.5 mm) vertical stiffeners. The OSPD was installed in segments, generally with two segments per span on the longer spans and one segment per span on the shorter spans. The OSPD was made composite with the plate girders through the installation of shear plates above the girders.

A typical cross-section is shown in Figure 2. Each OSPD segment was fabricated in five sections that were connected by four longitudinal weld splices in the deck plate and bolted splices in the floorbeams. When the deck segments were installed in the bridge, adjacent segments in a given span were connected via bolted transverse splices located directly under the deck plate, as shown in Figure 3. Deck expansion joints are located at Bents 5, 9, 13, and 19. The remainder of the bents had intermediate breather joints that, in 2014, were cut out, bolted over with link plates (shown in Figure 4) and the paving was repaired with polyester polymer concrete (PPC). It is COWI's understanding that the 2014 work was related to changes to the girder articulations resulting from bearing replacements and a desire to remove the existing breather joints due to noise and maintenance concerns.

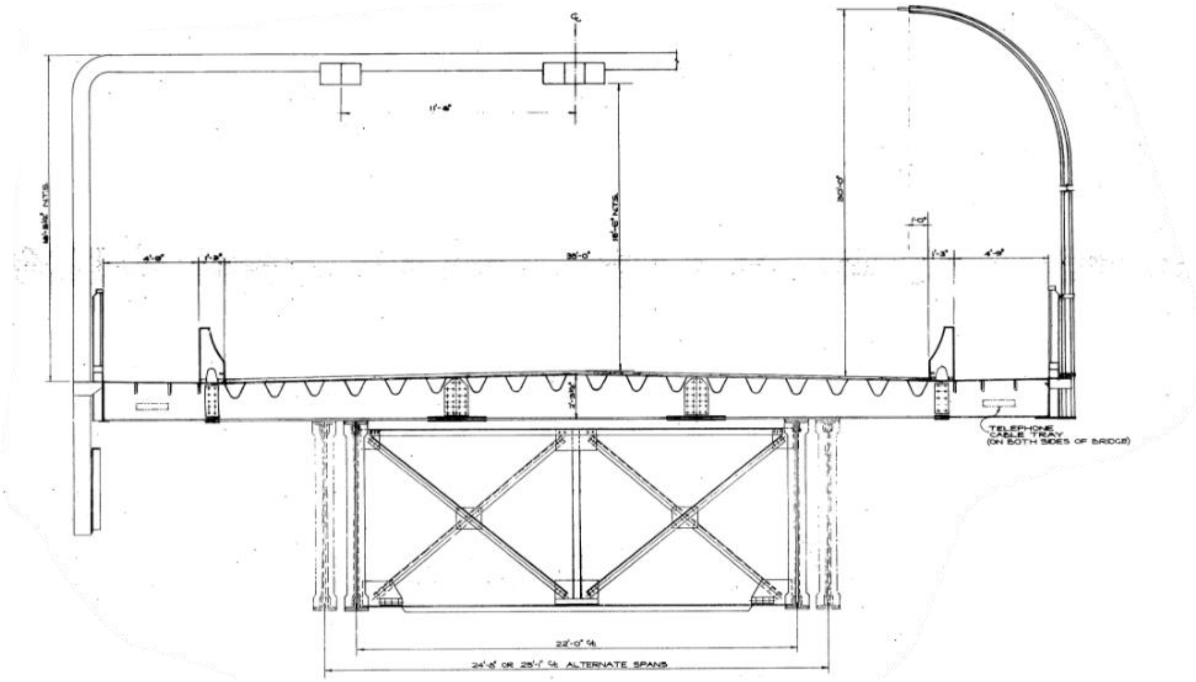

Figure 2: Typical Cross-Section of Lions Gate Bridge North Approach Viaduct

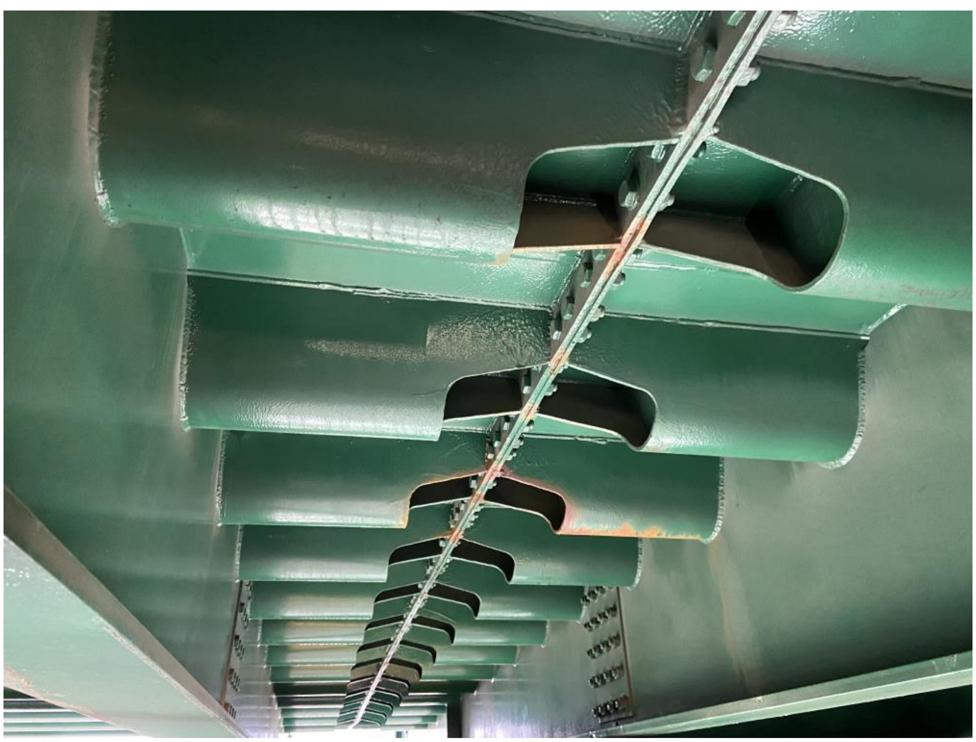

Figure 3: Typical OSPD Bolted Transverse Splice

Figure 4: Link Plate Installed at Breather Joints in 2014 (BC MoTI)

1.3 Inspection Scope and Access

For this inspection, the COWI team consisting of Eileen McEwen, P.Eng., and Jessica Ng, EIT, observed the underside of the OSPD and OSPD joints looking for evidence of deterioration including but not limited to, cracking of welds, corrosion, and water leakage. Inspection was conducted visually in the existing service condition of the bridge (i.e., with no paint or wearing surface removal).

For the portions of deck between the girders, inspection was conducted from the catwalks present along the inside face of each girder web from the North Cable Bent to approximately the midpoint of the span between Bent 24 and the North Abutment. Trough welds, transverse splices, and link plates within those extents were visually inspected.

For the portions of deck cantilevered outside the girders, inspection was conducted from a 125' articulating boom lift. Due to space constraints below the bridge, only select locations on the cantilevers were inspected; the OSPD was inspected in the vicinity of the floorbeams above Bents 7 through 21 on the west cantilever, and in the vicinity of the floorbeams above Bents 13 through 21 on the east cantilever.

The wearing surface was examined from the sidewalks on the bridge deck, specifically looking for indications of possible unexpected movements of the deck plate (the inspection of the wearing surface itself was not a part of COWI's scope). Wood performed a more detailed inspection of the wearing surface; the findings from that inspection can be found in the Surface Condition Assessment Report [1].

Thermal imagery of the underside of the OPSD was gathered via drone by UAViation, specifically looking for any indications of water inside the deck troughs.

1.4 Bridge Reference System

For the purposes of this inspection and report, floorbeams are identified in relation to the bents they are located near, and troughs are numbered sequentially from west to east. Bents are numbered in ascending order, beginning with 0 at the North Cable Bent, and 25 at the North Abutment. See Appendix A for an elevation view of with bent numbering.

2 Observations

The wearing surface, OSPD welds, splices, and joints were inspected and generally found to be in fair to good condition. Observations specific to these components are provided in this section.

2.1 Typical Wearing Surface

The typical wearing surface (not at the link plates) was observed from the sidewalk and no signs of unexpected movement of the deck plate were noted. For further detail on the condition of the wearing surface, refer to the Surface Condition Assessment Report [1].

The typical condition is shown in Figure 5.

Figure 5: Typical Wearing Surface Typical Condition.

2.2 Wearing Surface at Link Plates (PPC)

Similar to the typical wearing surface, the PPC wearing surface above the link plates was observed from the sidewalks. In general, the PPC wearing surface was observed to be in fair condition, with cracking observed in the transverse direction of the deck, as shown in Figure 6. This cracking is occurring along the edge of the link plates shown in Figure 4 that were installed in 2014.

Figure 6: Typical Cracking in Wearing Surface at Link Plates.

At some link plates, localized areas of spalling were observed, exposing the link plate underneath, as shown in Figure 7.

Figure 7: Localized Spalling in Wearing Surface at Link Plates.

For further details on the condition of the PPC at the link plates, refer to the Surface Condition Assessment Report [1].

2.3 OSPD Trough Welds

The OSPD trough welds connecting the trough to the deck plate (longitudinal) and to the floorbeams (vertical) were observed from the catwalks and the boom lift; these were found to good condition. At most of the locations inspected, the welds the paint system was found to be intact and there was no indication of cracking occurring. The typical condition of the welds is shown in Figure 8 below. The bolts shown in Figure 8 are those associated with the installation of a link plate.

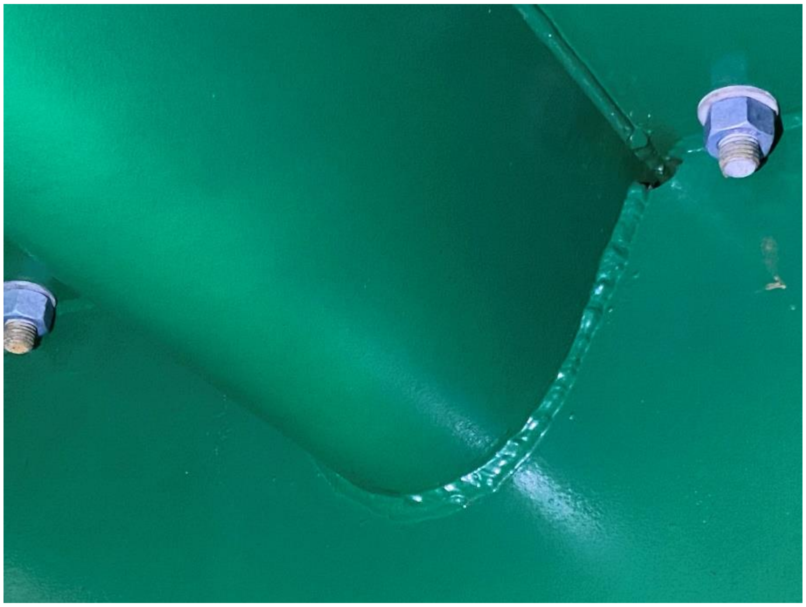

Figure 8: Typical Trough Weld Condition.

At the 5 locations listed in Table 1, some minor corrosion or deterioration of the paint coating was observed near the termination of the weld, although no signs of cracking were observed. These locations are shown in Figures 8 – 12.

Table 1: Locations Showing Indications of Corrosion or Paint Deterioration.

Span	Floorbeam	Trough	Observation
Between Bent 1 and 2	3rd from Bent 1	3rd on E side	Minor rusting along longitudinal weld. See Figure 9.
Between Bent 4 and 5	3rd from Bent 4	6th on W side	Local paint failure at termination of longitudinal weld. See Figure 10.
Between Bent 7 and 8	2nd from Bent 8	3rd on E side	Localized paint failure on longitudinal weld. See Figure 11.
Between Bent 9 and 10	4th from Bent 10	4th on W side	Cracked paint at termination of longitudinal weld. See Figure 12.
Between Bent 12 and 13	3rd from Bent 13	5th on W side	Minor rusting near termination of longitudinal weld. See Figure 13.

Figure 9: Minor Rusting on Longitudinal Weld on East Side of Trough 3 at 3rd Floorbeam from Bent 1 in the Direction of Bent 2.

Figure 10: Localized Paint Failure at Termination of Longitudinal Weld on West Side of Trough 6 at 3rd Floorbeam from Bent 4 in the Direction of Bent 5.

Figure 11: Localized Paint Failure on Longitudinal Weld on East Side of Trough 3 at 2nd Floorbeam from Bent 8 in the Direction of Bent 7.

Figure 12: Paint Deterioration at Termination of Longitudinal Weld on West Side of Trough 4 at 4th Floorbeam from Bent 10 in Direction of Bent 9.

Figure 13: Minor Rusting near Termination of Longitudinal Weld on West Side of Trough 5 at 3rd Floorbeam from Bent 13 in the Direction of Bent 12.

2.3.1 Thermal Imagery

To supplement the visual inspection, thermal imagery was also collected of the troughs using drones operated by UAViation. The intent was to take advantage of the thermal conductivity difference between steel and water to highlight regions of pooling water within the troughs, which may occur if the deck plates were cracked at the inside face of the trough welds. By collecting the images shortly after sundown on a sunny day, experience has shown that the camera will pick up temperature differential between the steel, which cools relatively quickly, and any water that may have collected.

For this inspection of the North Approach Viaduct, images were collected on October 19, 2021 between 5:00 pm and 7:30 pm using a Zenmuse H20T thermal camera mounted on a Matrice 300 RTK drone.

Following a detailed examination of the radiometric images, nothing was observed that suggested the collection of water in the troughs. It was noted in several locations that one of the panels was cooler than the ones on either side, as shown in Figure 14. However, this is unlikely to be due to fatigue cracking as a wide area showed consistently cooler temperatures within and between the troughs, and it would be highly unlikely for a fatigue crack to cross more than one trough. Instead, this temperature differential may be due to other factors such as thicker paving or moisture in the asphalt.

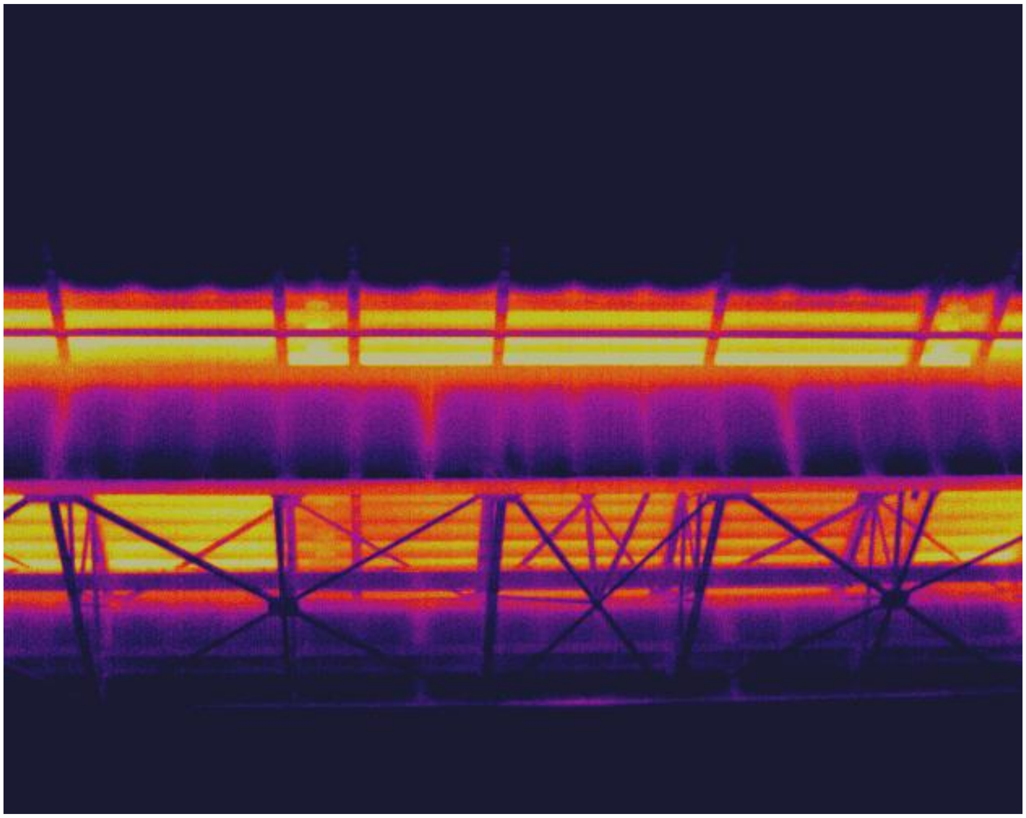

Figure 14: Typical Panel Showing Cooling Temperatures than Adjacent Panels. Span Between Bent 2 and 3 Shown.

Additionally, between the first and second floorbeams north of Bent 5, it was noted that the trough indicated in Figure 15 appeared to be warmer than the surrounding troughs. However, this was noted to be the location of a trough diaphragm (vertical plate extending from trough down to the girder below), and therefore not an area of concern.

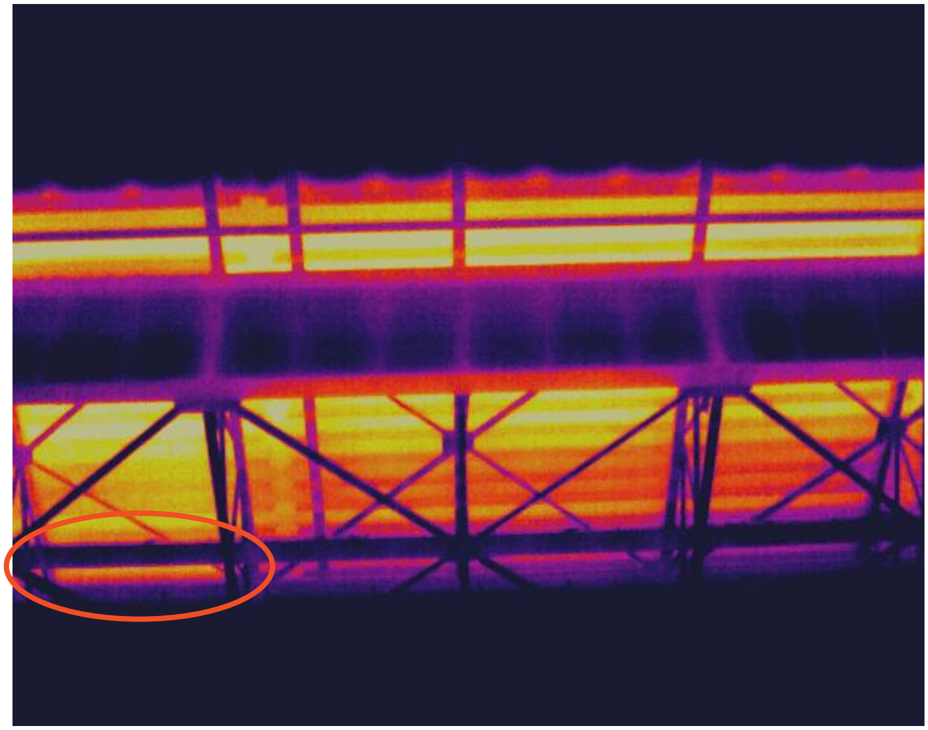

Figure 15: Slightly Brighter (Warmer) Trough Between First and Second Floorbeam North of Bent 5.

2.4 Sidewalk Panel Plate Welds

The welds connecting the sidewalk panel to the vertical plates, as shown in Figure 16, were found to be in good condition, with no indication of paint failure or indications of cracking noted.

Figure 16: Typical Condition of Sidewalk Panel Plate Welds.

2.5 OSPD Bolted Splices

The OSPD bolted splices were typically observed to be in fair condition. Localized areas of corrosion were noted along the length of most splices. As shown in Figure 17, these areas correspond to the locations where the trough walls are welded to the end flange of the OSPD segment. Therefore, it is likely that this corrosion is a result of the bolt spacing that is larger at these points than in the rest of the splice to accommodate the trough walls.

Figure 17: Typical OSPD Splice Condition (Splice 18A Shown).

While corrosion at most locations was found to be minor, more significant rust jacking was observed in the splice located between Bent 19 and 20, as shown in Figure 18.

Figure 18: Rust Jacking at Splice Between Bent 19 and 20.

Additionally, it appeared that more moisture than typical was seeping through the splice between Bent 4 and 5, where the steel deterioration was more widespread, as shown below in Figure 19.

Figure 19: Splice Between Bent 4 and 5 Showing More Moisture Than Typical.

The rust jacking and moisture observed suggest that the crevice corrosion will continue to advance and may begin to occur at locations that currently appear to be in good condition. If the prying of the plates extends up to the deck plate, the corrosion may be exacerbated as the jacking of the plates will allow more moisture in, leading to more corrosion.

2.6 Expansion Joints

The expansion joints were generally found to be in fair condition, with no deterioration observed in the paint, steel, or joint seal, as shown in Figure 20.

Figure 20: Typical Expansion Joint (Joint at Bent 19 Shown).

At Bent 9, the drainage trough appeared to have shifted since the last application of paint, as bare steel was visible at one the connections, shown below in Figure 21.

Figure 21: Evidence of Movement of Drainage Trough at Expansion Joint at Bent 9.

At the expansion joint at Bent 19, some cracking of the paint near the bolts was highlighted by a previous Inspector (Figure 22). As shown in Figure 23, closer inspection of the steel did not result in any cracking indications observed.

Figure 22: Cracked Paint at Expansion Joint at Bent 19 Identified Previous to this Inspection.

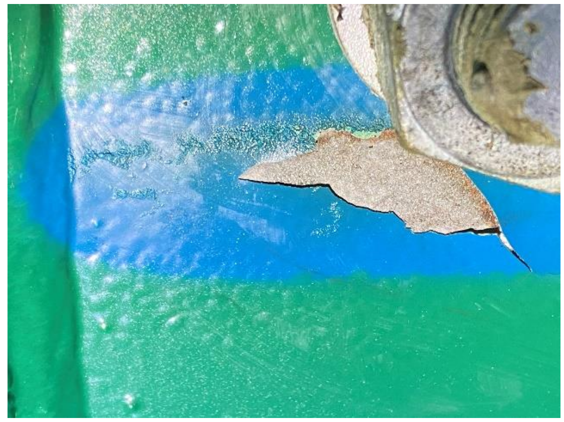

Figure 23: Close-Up of Plate Under Cracked Paint at Expansion Joint at Bent 19.

2.7 Link Plates

The link plates replaced the breather joints during joint articulation work that was performed in 2014. During this replacement, the breather seal was removed, the edge OSPD was flame-cut out, and a plate was bolted over the gap and paved with PPC.

In general, these link plates were observed to be in fair to poor condition. At all locations observed, it appeared that the cut edges of the OSPD plate were not ground smooth. As a result, the paint coating is failing and rust was noted to be forming on the exposed steel, as shown in Figure 24.

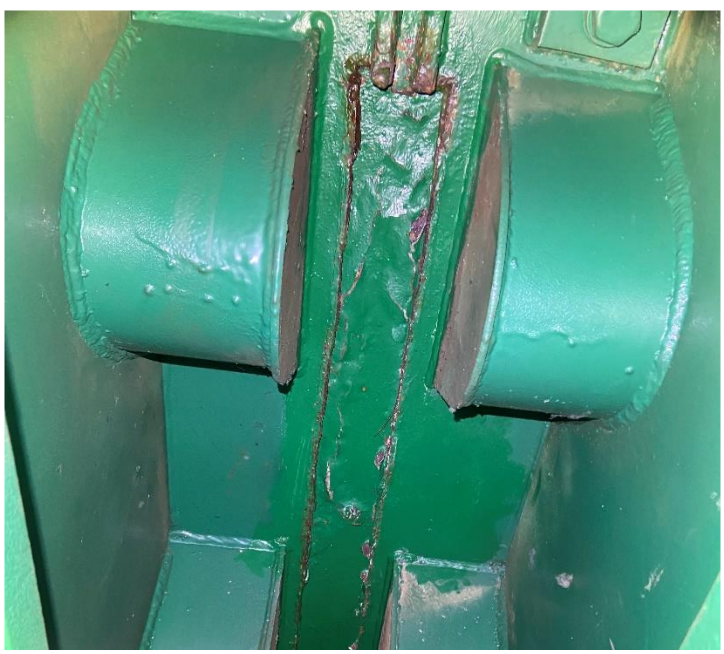

Figure 24: Typical Link Plate; Plate at West Side of Bent 20 Shown

At some locations, as shown in Figure 25, water was noted to be leaking from above, leading to more significant corrosion.

(a) (b)

Figure 25: Poor Condition Link Plates at (a) West Side of Bent 21 and (b) Bent 3

Based on COWI's observations of the underside of the link plates, significant corrosion exists after only seven years, and significant further paint failure and corrosion of the OSPD top plate is anticipated if the details are left as is. This deterioration is particularly of concern for the portions of OSPD top plate that are above the troughs, since even pinhole corrosion that occurs could lead to the ingress and collection of water in the troughs. These areas of the plate are very difficult to inspect since the sealed ends of the troughs prevent observation from below the deck, and inspection from above the deck would require removal of paving and the link plate.

3 Summary and Recommendations

The OSPD trough welds and expansion joints were found to be in fair or good condition. The condition of the typical wearing surface (as identified by Wood [1]), PPC paving above the link plates, the OSPD bolted splices, and the OSPD around the link plates are areas of concern. COWI's recommendations are summarized below.

3.1 Wearing Surface and Waterproofing

No structural concerns were observed in the typical wearing surface or waterproofing, and therefore no associated actions are recommended. While some longitudinal cracking has been previously noted, COWI understands this occurred shortly after installation and is expected to increase in severity over time.

Some locations of PPC were observed to be exhibiting spalls and cracks. COWI recommends that these locations be investigated to determine if measures should be implemented before the full paving replacement is completed, possibly in conjunction with the mediation measures associated with the link plates as outlined in Section 3.5 below.

Refer to the Surface Condition Assessment Report [1] for Wood's summary and recommendations for the wearing surface and waterproofing.

3.2 OSPD Trough Welds

The inspection did not note any significant defects or crack indications within the trough to top plate welds. However, as this is the susceptible region for fatigue cracking, particularly adjacent to floorbeams, COWI recommends that MPI testing be performed at the locations identified in Section 2.3 to confirm that no cracks are present in the welds. These locations were selected to represent the worst condition of the paint system observed to enable testing to capture the highest risk locations. COWI recommends that this be done prior to the paving program such that if cracks are found, they can be dealt with ahead of the paving closures where possible.

3.3 OSPD Bolted Splices

To appropriately plan mitigations to address the crevice corrosion observed at the OSPD bolted splices, COWI recommends that the pavement at the splices between Bents 4 and 5, and Bents 19 and 20 be removed and the condition of the splice be observed from above. If the corrosion extends up to the top of the plate, it is recommended that the corrosion be ground out and a weld seal applied (care must be taken in the details of the weld). If the corrosion does not appear to extend to the top of the plate, it is recommended that the bolts near the rust jacking be removed, the corrosion be ground out, the bolts replaced, and the paint coating reapplied.

COWI recommends that this work be performed well in advance of the paving closures, since the results of these two test locations may result in recommendations to do similar mitigation above all the OSPD bolted splices.

3.4 Expansion Joints

No deterioration was observed in the expansion joints and therefore no actions are recommended at this time. However, COWI recommends that the exposed steel at the drainage trough connection at Bent 9 be cleaned and repainted to reduce the risk of corrosion.

3.5 OSPD Near the Link Plates

The OSPD near the link plates was found to be in fair to poor condition after only seven years of service. The observed condition in conjunction with further investigation into the link plate details resulted in the following conclusions:

- Due to the presence of the closed deck troughs under portions of the link plate, it was not possible to install enough bolts to accomplish an effective seal between the link plates and the OSPD to prevent water ingress, and it is not possible to add more bolts to rectify this now.
- The original design of the link plates placed an epoxy sealant between the link plates and the OSPD. However, it is likely that the sealant was burnt during the welding of the deck plates and in combination with the movement of the deck under traffic loading, this sealant has been ineffective at eliminating water ingress as well, although it is not clear if the original design intended the epoxy to seal the plates or if it was simply to act as a leveling compound for the underside of the link plate.
- The stiff 25 mm link plates appear to cause high local stresses within the wearing surface as the system attempts to take all the global live load rotations at the ends of the link plates, focusing the rotations.
- The geometry of the 25 mm thick link plates results in a water dam on the deck surface, further placing the detail at risk of allowing moisture ingress and corrosion of the OSPD.
- The link plates were installed in pieces and then welded together, so inspection of the interface between the link plate and the OSPD is only possible by completely removing the link plate and the paving, which is not practical.

Due to the probable and significant negative impact on the lifespan of both the OSPD and the wearing surface if the observed deterioration continues, as well as the inspection challenges, COWI recommends that an alternate detail that ideally removes the link plates be explored. However, it is not immediately obvious if a solution can be developed for this as there are fatigue issues of the OSPD that must be avoided, and significant sophisticated analysis will be required to understand the global and local behaviour of the area. COWI further recommends that any retrofit in this area be performed prior to the repaving work, if possible.

4 References

[1] Wood Environment & Infrastructure Solutions, "Project No. 12268 - H99 Lions Gate Viaduct #01481V Wear Surface Replacement - Surface Condition Assessment Report," 18 November 2021.

Appendix A Bridge General Arrangement