WAKA KOTAHI
NZ TRANSPORT AGENCY

ASM

AHB STRINGER HALF JOINT MANAGEMENT

Auckland System Management

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DOCUMENT CONTROL

Report

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Revision Control

Revision	Name	Date	Description
Draft	s 9(2)(a) [redacted]	July 2021	Draft for review
1.0		August 2022	Reviewed and issued

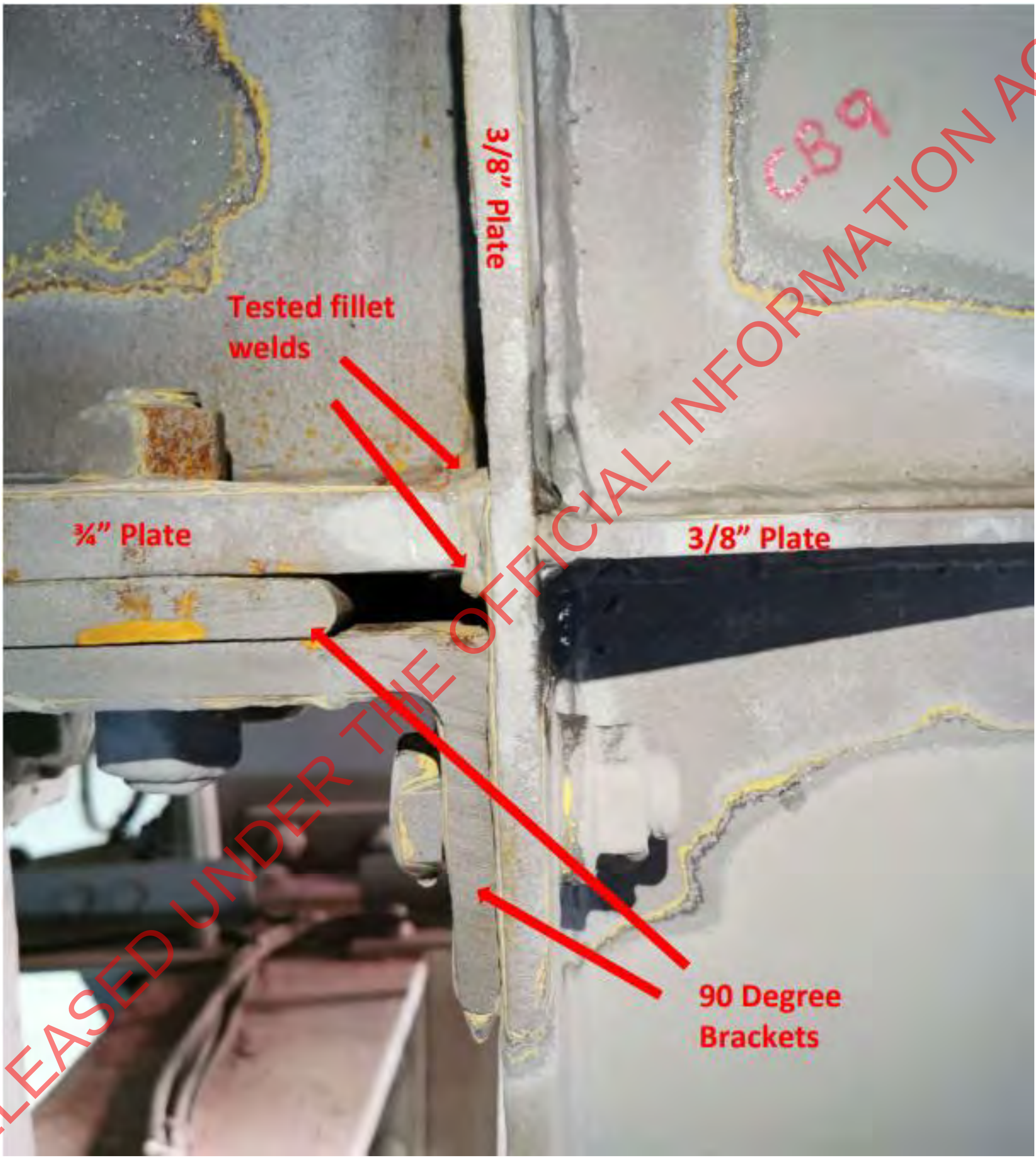
Contents

PURPOSE

To consider and recommend options for managing the risk of unforecast fatigue cracking in the Auckland Harbour Bridge deck stringer half joint welds requiring emergency or short notice lane closures or temporary load restrictions until repairs can be undertaken.

SCOPE

This report considers stringer half joint connections on the AHB main truss bridge, northern steel viaduct and southern steel viaduct (refer Appendix A for layout drawings).



BACKGROUND

The fillet welds of the AHB stringer half joints (joining the half depth stringer end pieces to the full depth stringers) are susceptible to fatigue. In 2015, estimates of remaining fatigue lives for the truss bridge west outer stringer joints (stringer 'F') were nil in spans 1,3,4,5 with normal design assumptions.

Weld cracks require lane closures to repair, and temporary closures or load restrictions may be required to prevent failure of the stringer end connection.

Fatigue cracks are expected to originate at the root of the weld and propagate towards the surface, therefore visual inspections may not detect fatigue cracking until the crack has propagated right through the weld throat. However, some of the recent cracks in the approach viaduct stringers have started at the weld toe and propagated horizontally toward the root. Observations of poor weld shape and undersized welds may have led to this unexpected crack orientation in the weld.

Previous Assessment & Investigations

Truss Bridge Fatigue Life Assessments (2015)

Remaining fatigue life estimates were done in 2015. Span 2 was not assessed because the half joint support detail at the double depth cross girders in different (inverted) and the fillet welded cruciform joints are in compression. Overall, the outcome of the assessment was that all assessed welds have very short remaining fatigue life.

All outer stringers on the western side may have short remaining fatigue lives, with Span 4 having the shortest remaining lives for typical stringers. Span 4-7 and the viaduct stringers have narrower plate widths compared to the model for spans 1&3 and consequently the risk level appears to be similar over the length of bridge.

In respect of life safety risks, the potential for immediate sudden failure is avoided by interconnections with the adjacent stringer via the deck slab and secondary bracing components at the stringer ends. At the TN6 expansion joint, a catch frame is in place (for risk of unseating in an extreme seismic event), and this provides temporary redundancy. At the typical truss bridge end connections the bolted angle cleats may offer limited additional support but significant deformations could occur, requiring closure of a lane to all traffic.

The result for the eastern stringers (A) in spans 1&3 indicates generally longer lives for all spans but still inadequate in the longer term. However, the analysis of fatigue loading for lane 3S was approximate and derived using a fixed proportion of the lane 3N which should be updated to allow for changes in southbound lane use.

The fatigue loading on the inner stringers (B-E) is much lower than the outer stringers because wheel loads for individual vehicles are shared by two stringers (remaining lives greater than 50 years).

An update is needed to the previous assessment findings based on measured weld sizes and findings from the 2021 NDT (this work is programmed to be done in 22/23 as a special project). The assessments summarised above were based on specified weld sizes but if the sizes measured in the north steel viaduct are repeated through the truss bridge spans, the estimated remaining lives could drop to nil.

Phased Array Investigations (2020)

SGS were engaged to inspect a sample of 26 joints at truss bridge stringer F via PAUT/TfM (Total focussing method using full-matrix capture of the array probe scans).

Five locations of probable sub-surface fatigue cracking were identified, along with several weld quality issues.

The five locations of probable fatigue cracking were reinspected approximately 12 months later, with no obvious signs of progression.

Risk factors

Overweight Vehicle Crossings

Weld fatigue lives are significantly reduced by overweight vehicle crossings, particularly those travelling at high speed. In 2021 permits were revoked for the heaviest permitted overweight vehicles, which were found not to be obeying their permit speed restrictions. This reduces the maximum load demands that can lead to sudden fracture of the remaining portion of partially cracked welds.

Over long periods the cumulative damage contribution from overweight freight vehicles exceeding the general access mass limits (44-46 tonnes) is more significant than that for overweight permit vehicles, but the majority of total fatigue damage is caused by vehicles at or below legal mass limits due to their much larger total counts.

Wheel Tracks and Heavily loaded lanes

The outer stringers (A and F) have shorter theoretical fatigue lives as they are directly beneath wheel tracks, whereas wheel loads are shared by the inner stringers (B – E).

Panel Length & Joint size

Weld fatigue lives vary with panel length and joint size (e.g., plate thicknesses and weld sizes).

Weld Quality

Investigations to date have observed variable weld quality which will have a significant impact on fatigue performance.

Defect types identified include heat affected zone (HAZ cracking), inclusions, gas pores, lack of fusion, undercut/poor terminations (undressed) and even missing gusset welds (TN11 A).

Undersized welds have been identified (where throat thickness is less than designed), and inconsistent leg lengths.

Joint geometry – misalignment of gusset and stringer flange

Figure 2: Half Joint at Cross Girder 3/11 (outside) exhibiting porosity

Figure 3: Cross Girder 3/11 (inside) inconsistent leg length and weld size

Figure 4: Poor alignment of gusset to 3/4 inch plate at Cross Girder 3/8

Figure 5: Poor weld terminations at Cross Girder 3/10

RISK MANAGEMENT STRATEGY

Current Approach

Special visual inspections of the half joints are undertaken regularly (quarterly for approach viaduct stringers, 6 monthly for truss bridge stringers A & F, annually for all other stringers).

Difficulty detecting cracks beneath thick layers of paint and where angle brackets obscure the underside weld in the truss bridge half joint connections.

Phased Array Ultrasound scanning (Total Focussing Method) has been undertaken on a sample of joints to investigate sub-surface weld cracking, however there is currently no programme to continue these investigations.

Options

The risk of unforecast fatigue cracking requiring emergency or short notice lane closures or temporary load restrictions can be managed in four ways:

- by improving crack detection,
- improving forecast accuracy of fatigue cracking,
- improving the response time for undertaking repairs, and
- reducing the likelihood of fatigue cracks occurring.

The options below have been categorised into these four categories.

Crack Detection

1. Continue visual inspections
   The current visual inspections have the limitations of only detecting cracks once the break the surface, and even surface breaking cracks may be hidden beneath thick layers of paint. The underside weld of the truss bridge joints is also obscured by an angle bracket making full visual inspection of this weld unachievable.

2. Continue visual inspections and use borescope to inspect underside weld at truss bridge joints
   A borescope can be used to inspect the underside weld at the truss bridge half joints, where and angle bracket obscures view for visual inspection. This will add some time/cost to the inspections.

3. Conduct MPI
   This method is only capable of detecting cracks at or very near the surface, and therefore would not detect sub-surface fatigue cracking such as typical fatigue cracking which has originated at the root of the weld and propagates towards the surface. Paint removal is required, adding significant cost. MPI will confirm the presence and extent of surface cracks which can be difficult to see.

4. Phased Array Ultrasonic Inspection (Total Focussing Method)
   This method has been used to inspect a sample of joints to date. It provides approximate measurement of throat thickness and length of cracking and will determine orientation of cracks. PAUT will also identify sub-surface quality defects. This method requires paint removal and engaging a specialist technician.

5. Acoustic Emission Monitoring
   Acoustic Emission Monitoring (AEM) has previously been considered for screening a large sample of half joints, however specialist equipment is required from overseas, and this method would not be capable of identifying the exact location, size, or orientation of cracks.

Improving weld failure predictions

6. Remove paint & visual inspection of weld quality
   Removal of protective coatings from the half joint welds will allow visual inspection of the weld quality and identification of weld defects such as undercut and porosity which may affect fatigue lives.

7. Measure weld sizes (leg lengths, throat thickness)
   Measuring weld sizes and identifying where sizes vary from the design sizes used in fatigue life assessment will better inform the risk of failure.

8. Complete fatigue life assessment
   Fatigue life assessments have not yet been undertaken for all connections. Existing fatigue life assessments could be refined by using measured weld sizes (if available) and using finite element modelling.
   Completing fatigue life assessments for all half joints will enable production of a hierarchy of connections at theoretical highest risk of failure, to target investigations and/or pre-emptive retrofit.

9. Crack growth assessment (fracture mechanics)
   A crack growth assessment may provide more information on the rate of crack propagation and the effect of other weld defects on the fatigue life, to enable better forecasting of failures and prioritisation of investigations and/or weld retrofit.

Improving response/repair timeframe

10. Complete repair design & specification for truss bridge joints
    Temporary support frame design is yet to be completed for some truss bridge locations. A site survey will be required to accommodate any obstructions that may require alteration to the existing concepts. Having the design completed for all connections will enable prompt repair of any joints where cracking is detected and reduce the likelihood or duration of lane closures.

11. Fabricate support frame
    Fabrication of temporary support frames for remaining joint types would also enable prompt repair of any joints where cracking is detected and reduce the likelihood or duration of lane closures.

Reduce likelihood of cracking

12. Preventative weld retrofit

    Pre-emptive retrofit of welds prior to cracks occurring will eliminate the risk of the stringer end connection being compromised due to fatigue cracking and requiring unscheduled lane closures.

13. Load Management

    Improving heavy vehicle compliance or reducing/limiting heavy vehicle use of the truss bridge will extend the remaining life of the welds.

OPTIONS SUMMARY

	Option	Cost (per joint)	Cost (all joints)	Notes/assumptions
Crack detection	1. Continue visual inspections	s 9(2)(i) [redacted]	[redacted]	
	2. Continue visual inspections inc. borescope to inspect truss connection underside weld	[redacted]	[redacted]	
	3. MPI	[redacted]	[redacted]	Including paint removal [redacted] s 9(2)(i) Non-qualified NDT technician
	4. PAUT/TfM	[redacted]	[redacted]	Including paint removal. Approx. 10 joints per day
	5. AEM	[redacted]	[redacted]	
Failure prediction	6. Inspect weld quality & measure weld sizes	[redacted]	[redacted]	Including paint removal.
	7. Fatigue life assessment	[redacted]	[redacted]	Item 2 of the recommendation on the following page.
	8. Crack Growth assessment	[redacted]	[redacted]	
Response	9. Complete Design	[redacted]	[redacted]	
	10. Support frame fabrication	[redacted]	[redacted]	
Failure Likelihood	11. Pre-emptive Weld Retrofit	[redacted]	[redacted]	
	12. Load Management	[redacted]	[redacted]	

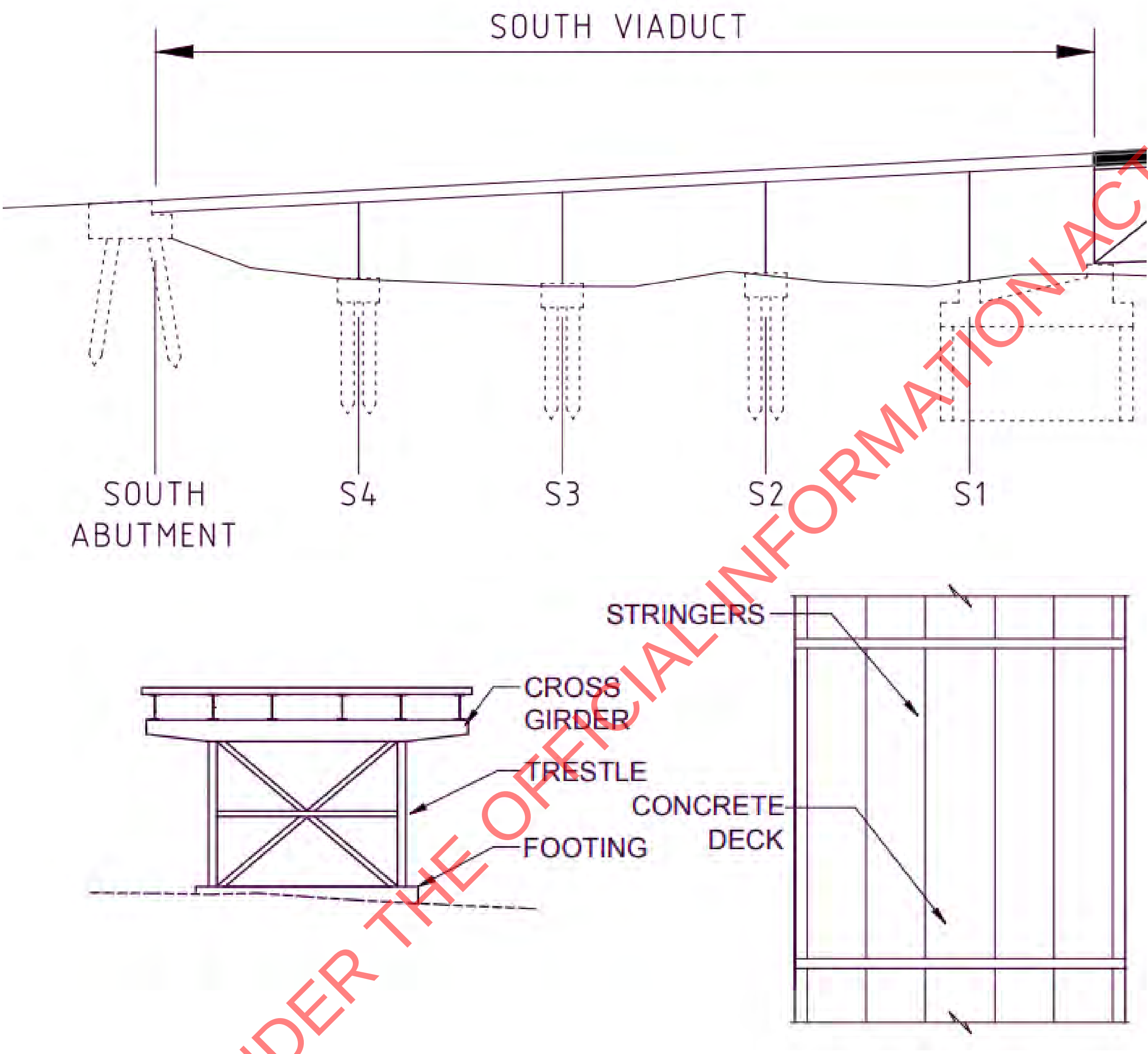
DISCUSSION

- Weld size and quality may be having significant impact on failures as well as the loading, therefore investing in crack detection and weld quality/size investigations should be undertaken in addition to theoretical assessments.
- Preventative retrofit needs to be evaluated to determine priorities and a programme for repairs.
- Without undertaking complete retrofit of all joints there will however always be a risk of unforecast failures. For this reason, it is recommended regular visual inspections continue, and
- Design and fabrication of support frames should be undertaken for all connections to minimise the risk of disruption to the motorway network if failures for occur.

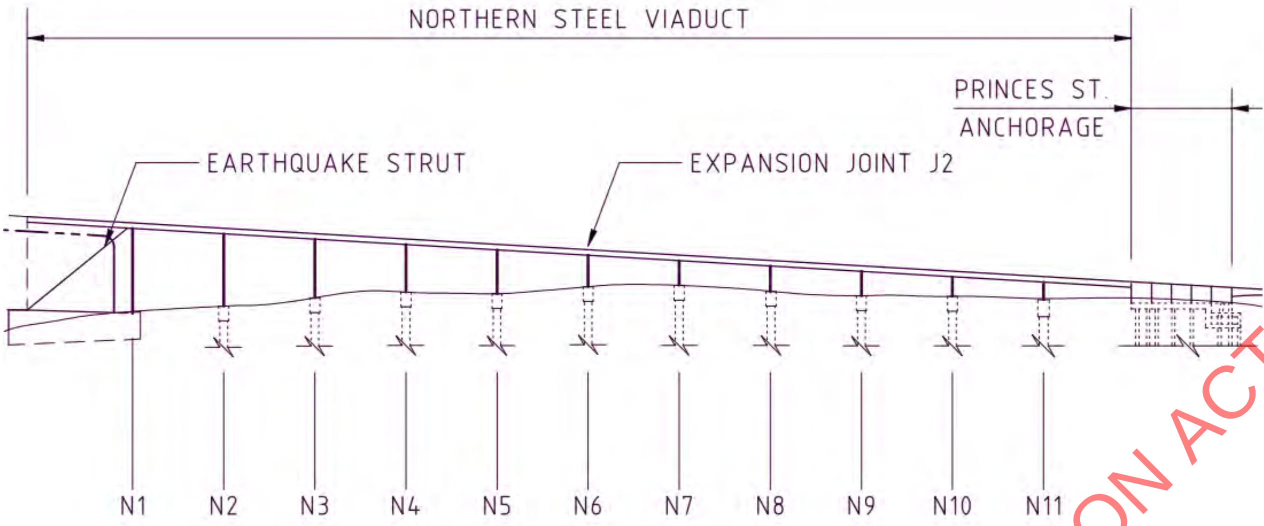
RECOMMENDATIONS

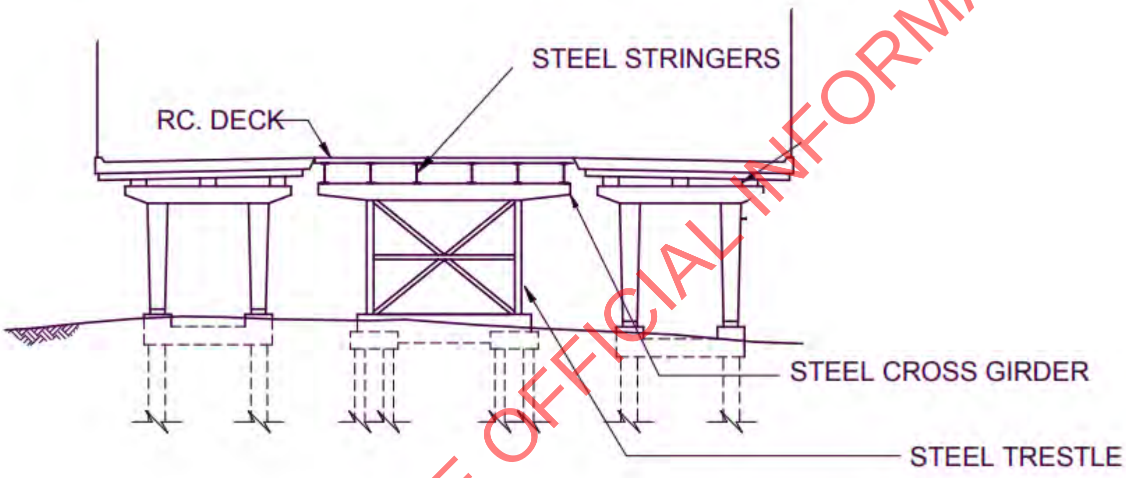
- Complete design of temporary support frames and retrofit detailing s 9(2)(i) [redacted] Design partially completed in 21/22, remaining work to be completed in 22/23.
- Undertake fatigue assessment and residual capacity assessment of weld connections to establish a priority list of connections to be targeted for further investigation and/or pre-emptive retrofit (22/23, s 9(2)(i) [redacted]
- Fabricate support frame/s required to undertake repair (22/23, s 9(2)(i) [redacted])
- Continue visual inspections and introduce borescope inspection for the underside weld in all truss bridge locations (ongoing)
- Remove paint on all connections and record weld sizes and any visible weld defects. Connections should be primed following inspection for corrosion protection. Any signs of corrosion should be reported following regular special inspections and addressed (22/23, s 9(2)(i) [redacted]).
- Compare weld size/quality records against fatigue life assessment to identify highest risk connections for Phased Array Ultrasonic Inspection (22/23, s 9(2)(i) [redacted]).
- Monitor and programme retrofit of connections where sub-surface weld cracking is detected.
- An indicative programme will be developed during the 22/23 year once further investigations & studies have been completed.

APPENDIX A – LAYOUT DRAWINGS

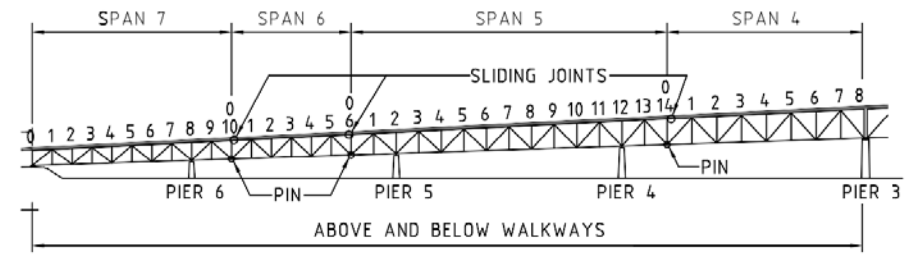


South Steel Viaduct (Total 24 half joints)

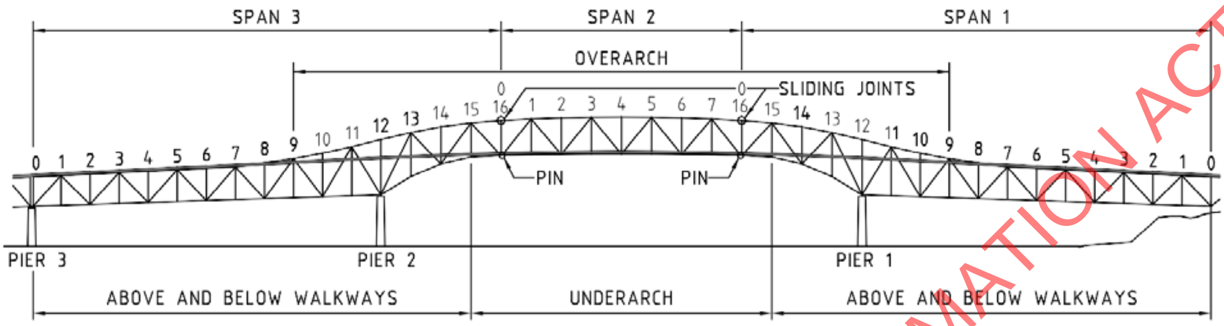




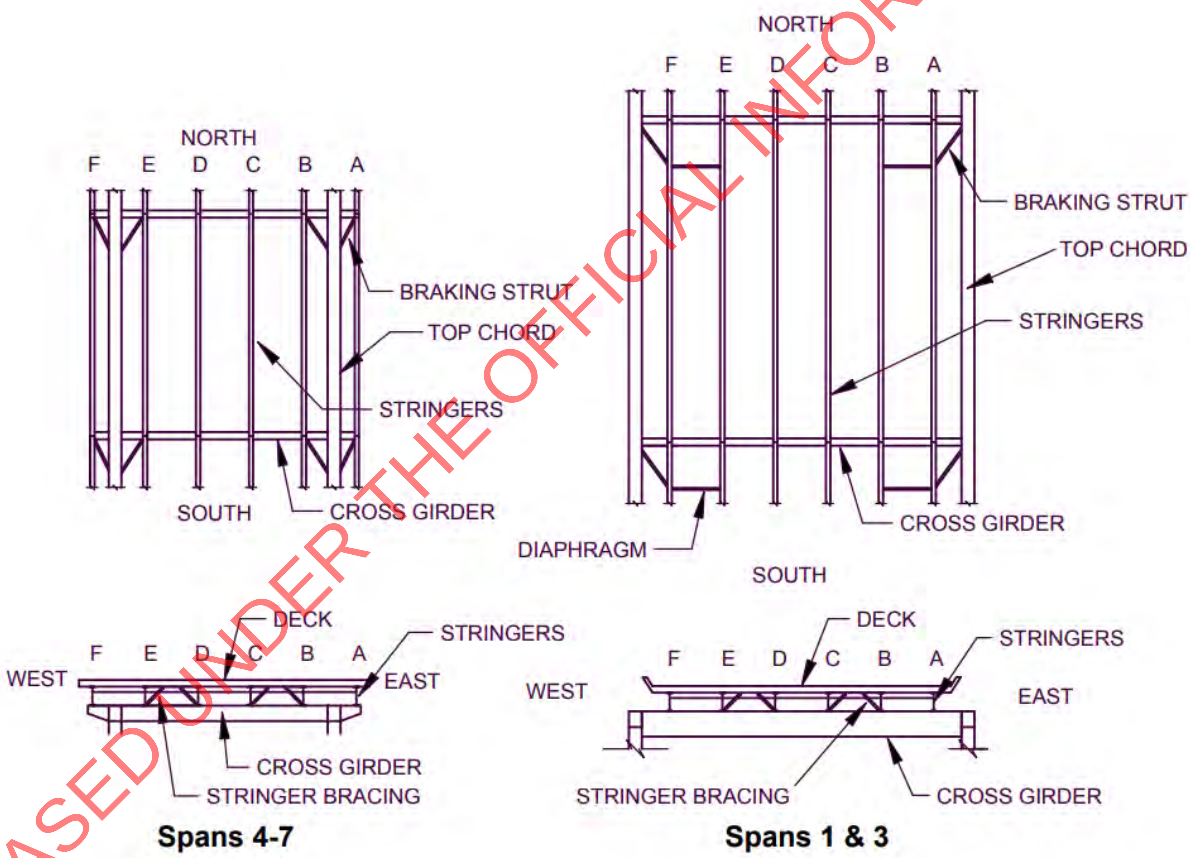
North Steel Viaduct (Total 66 half joints)



ELEVATION - TRUSS BRIDGE SPANS 4 - 7



ELEVATION - TRUSS BRIDGE SPANS 1 - 3



Truss Bridge (total 468 half joints)