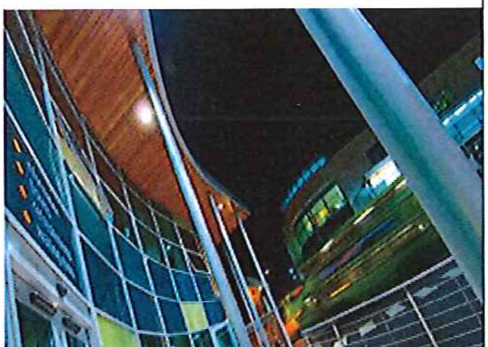
Forth Road Bridge
Truss End Link Assessment
Supplementary Report

March 2014



FAIRHURST

FAIRHURST

CONTROL SHEET

CLIENT: Forth Estuary Transport Authority

PROJECT TITLE: Forth Road Bridge

REPORT TITLE: Truss End Link Assessment Supplementary Report

PROJECT REFERENCE: 79866C

Issue and Approval Schedule:

ISSUE 1	Name	Signature	Date
Prepared by			27/03/14
Reviewed by	C Clark		27/03/14
Approved by	C Clark		27/03/14

Revision Record:

Issue	Date	Status	Description	By	Chk	App
2						
3						
4						
5						
6						

This report has been prepared in accordance with procedure OP/P02 of Fairhurst's Integrated Quality and Environmental Management System (QEMS)

1.0 Introduction

Fairhurst were appointed by the Forth Estuary Transport Authority to undertake a supplementary assessment of the truss end links on the Forth Road Bridge.

The purpose of the supplementary assessment was to undertake a more detailed examination of the proposed upgrades to identify the maximum stress in the end link elements due to the abnormal load effects of a 250 tonne SO vehicle.

The road decks on both the main and side spans had been previously assessed as part of an earlier review completed by Fairhurst (see Suspended Structure Assessment Report dated February 2011). The assessment of these elements has been reviewed and where appropriate updated to reflect changes in assessment requirements as part of the supplementary assessment.

This assessment has been undertaken in accordance with instructions from Barry Colford of Forth Estuary Transport Authorities Email Dated 10/02/2014.

2.0 COMPUTER MODELLING ANALYSIS

2.1 General

To undertake a structural assessment of the truss end links on the Forth Road Bridge, the stress in each link was determined through the use of computer analysis. The bridge was analysed with 3D finite element models using LUSAS computer analysis software. The whole bridge was modelled to simulate the full behaviour of the structure.

2.2 Loadings

The end links have been assessed for combinations of the following loads.

A. Dead Loads. The dead loading comprises two types of permanent loading present on the bridge structure;

   i. Dead loads representing the weight of the steel and concrete structural members forming the bridge.

   ii. Superimposed dead loads representing the weight of all other materials permanently present on the bridge. Typically these are surfacing on the carriageways and footways and the weight of services.

B. Live loads which represent vehicular or pedestrian traffic on the bridge. The assessment has been undertaken for an abnormal 250 tonne SOV and operational live loads.

   i. **250 tonnes SO Vehicle**

   SOV loading was based on BD86/01 clause 3.10.5 SV-train, in which the loading for each axle was proportionally increased in magnitude to equal an equivalent 250 tonne vehicle.

   ii. **Operational Loadings**

   Load combinations which comprise live loading (vehicular and pedestrian traffic) and are representative of the potential live loading which may be developed by the actual traffic crossing the bridge. Vehicular traffic loading is represented by the Bridge Specific Assessment Live Loading (BSALL). Pedestrian traffic loading is represented by the Bridge Specific Footway Live Loading (BSFLL). BSALL was taken from the Fairhurst's report "2010 Bridge Specific Assessment Live Loading" dated February 2011 whilst BSFLL was taken from "Bridge Specific Footway Live Loading Report" dated June 2006.

No wind loads have been considered as a combination with live loads due the Forth Estuary Transport Authorities (FETA) procedures for dealing with high winds on the bridge. In these situations, restrictions are imposed on traffic permitted to cross the bridge in particular an equivalent SOV 250 tonne vehicle.

Combinations of loading and the load factors for each combination have been applied in accordance with BD 86/01 "The Assessment of Highway Bridges and Structures for the Effects of Special Types General Order (STGO) and Special Order (SO) Vehicles". Where SOV and BSALL have been combined, BSALL has been applied to the opposite carriageway only and not on the same carriageway as the SOV. This takes into account

FETA procedures for high good vehicles, where normal traffic is stopped to allow an abnormal vehicle to cross the bridge.

Based on the above loadings and the FETA procedures that are in place, three load combination were considered for this supplementary assessment:

1. Dead + SOV 250
2. Dead + SOV 250T + BSALL
3. Dead + SOV 250T + BSALL + BSFLL

3.0 RESULTS AND CONCLUSIONS

The analyses concluded that the maximum load in the truss end link was when the SOV was positioned closest to the links, this applied for all end links across the total span (see Figure 1 for nominal results representing the SOV moving from the north tower along the main span and refer to Appendix 1 for panel location along deck span).

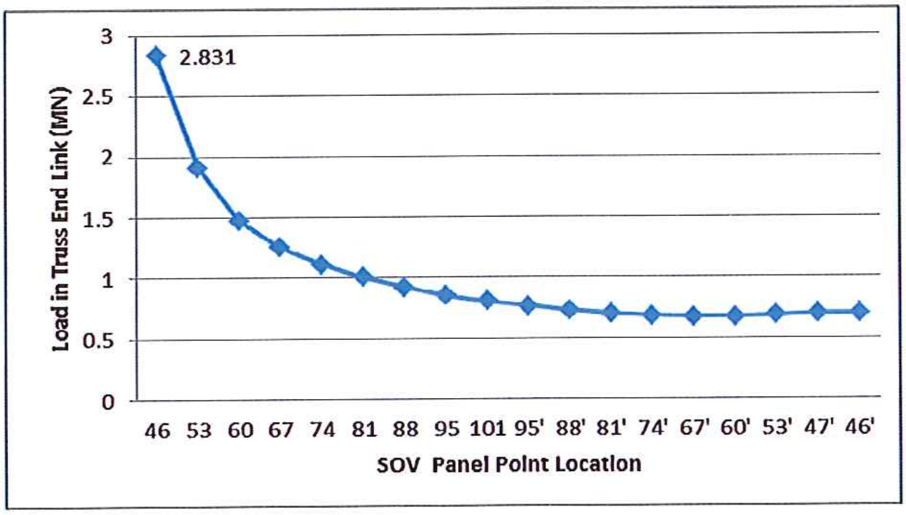


Figure 1: Load in North Main Span Truss End Link due to SOV

Taking the critical loading condition for the SOV and applying with a combination of BSALL it was found that when BSALL was applied at a distance greater than 50m from the end links then a twisting effect on the bridge deck occurred. This twisting of the deck caused uplift on the opposite side from the BSALL where the SOV was applied which resulted in a reduced load in the end link (see Figure 2). For this reason, BSALL loading was restricted to a distance of 50m either side of the tower, given an overall loaded length of 100m along a carriageway at 21.11kN/m^2

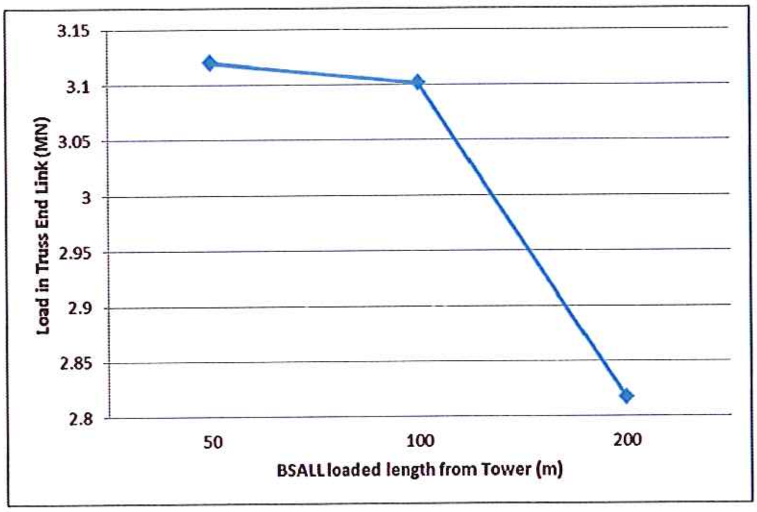


Figure 2: Truss End Link load due to varying length of BSALL

The maximum load from the combination of SOV and BSALL was found on the north truss end link supporting the main span of the bridge. This load was assessed further by applying with a BSFLL over an 18m loaded length from the tower on both side of the deck. From this analysis it was observed that load in the truss end link increased further.

Previous assessments completed by Fairhurst calculated the capacity of the end link arrangement (see Suspended Structure Assessment Report dated February 2011) with new proposed strengthening works detailed on Fairhurst Drawings 79866/013 to /016. Based on this information, Tables 1 to 6 below summarise the overstress indices for each element of the end link after strengthening has been completed. Results have been provided for the critical loading location for the main and side span arrangements.

3.1 Overstress Indices Main Span Link Arrangement – Critical Load Case

The location of Sections and Welds in the link brackets where overstress indices (OI) are reported are shown in Figure 3.

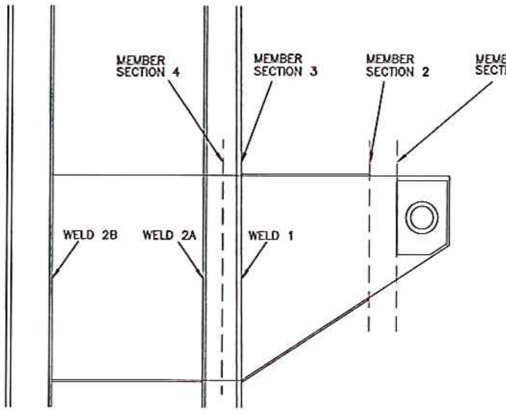


Figure 3: *Crticial Locations in Link Bracket*

Load Case	OI (Section 1)	OI (Section 2)	OI (Section 3)	OI (Section 4)	OI Max
Dead + SOV 250T (SLS)	0.75	0.84	0.74	0.77	0.84
Dead + SOV 250T	0.97	1.05	0.84	0.87	1.05
Dead + SOV 250T + BSALL	1.23	1.32	0.95	0.98	1.32
Dead + SOV 250T + BSALL + BSFLL	1.36	1.45	1.00	1.04	1.45

Table 1: ***Main Span End Link Bracket Overstress Indices under Critical Factored Loading***

Load Case	OI (Weld 1)	OI (Weld 2A)	OI (Weld 2B)	OI Max
Dead + SOV 250T (SLS)	0.77	0	0.90	0.90
Dead + SOV 250T	0.87	0	1.01	1.01
Dead + SOV 250T + BSALL	0.99	0	1.19	1.19
Dead + SOV 250T + BSALL + BSFLL	1.04	0	1.21	1.21

Table 2: Main Span End Link Bracket Weld Overstress Indices under Critical Factored Loading

Load Case	Link Members	Link Member Welds	Link Member Pins	OI Max
Dead + SOV 250T (SLS)	0.55	0.70	0.60	0.70
Dead + SOV 250T	0.62	0.79	0.67	0.79
Dead + SOV 250T + BSALL	0.70	0.89	0.76	0.89
Dead + SOV 250T + BSALL + BSFLL	0.74	0.94	0.80	0.94

Table 3: Main Span End Link Member Overstress Indices under Critical Factored Loading

3.1.1 Overstress Indices Side Span Link Arrangement – Critical Load Case

The location of Sections and Welds in the link brackets where overstress indices (OI) are reported are shown in Figure 4.

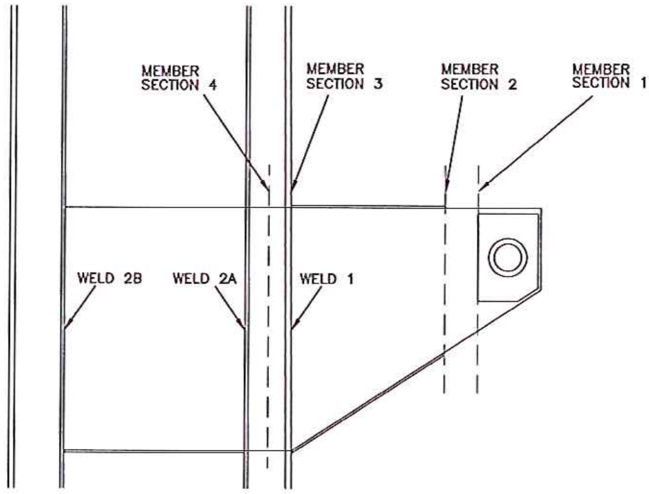


Figure 4: *Crticial Locations in Link Bracket*

Load Case	OI (Section 1)	OI (Section 2)	OI (Section 3)	OI (Section 4)	OI Max
Dead + SOV 250T	0.65	0.71	0.59	0.62	0.71
Dead + SOV 250T + BSALL	0.87	0.88	0.66	0.70	0.88
Dead + SOV 250T + BSALL + BSFLL	0.98	0.98	0.70	0.74	0.98

Table 4: ***Side Span End Link Bracket Overstress Indices under Critical Factored Loading***

Load Case	OI (Weld 1)	OI (Weld 2A)	OI (Weld 2B)	OI Max
Dead + SOV 250T	0.68	0	0.63	0.88
Dead + SOV 250T + BSALL	0.77	0	0.71	0.77
Dead + SOV 250T + BSALL + BSFLL	0.82	0	0.75	0.82

Table 5: Side Span End Link Bracket Weld Overstress Indices under Critical Factored Loading

Load Case	Link Members	Link Member Welds	Link Member Pins	OI Max
Dead + SOV 250T	0.59	0.76	0.64	0.76
Dead + SOV 250T + BSALL	0.67	0.86	0.74	0.86
Dead + SOV 250T + BSALL + BSFLL	0.71	0.91	0.78	0.91

Table 6: Side Span End Link Member Overstress Indices under Critical Factored Loading

3.2 Main Tower Link Arrangements Findings

3.2.1 Brackets Loadings

Under the critical load case, the bracket plates on the main span side of the main tower were found to have overstress indices greater than 1.00 as was reported previously in Fairhurst's assessment. The maximum assessed overstress index was 1.45 based on a load combination of Dead, 250T SOV, BSALL and BSFLL. The assessment found that the critical section of the bracket was Section 2 which is where the flanges terminate. At this section the bracket web has insufficient bending moment capacity. The proposed strengthening to section 4 of the bracket would result in an overstress index of 1.04

It was found that that if the Dead and SOV was applied only then section 2 would be overstressed at the fully factored ULS with an overstress index of 1.05 with all other section passing. This overstress index reduced to 0.84 when loading was considered at serviceable limit state (SLS).

The bracket plates on the side span of the main tower were not found to be overstressed under the critical load combination. The side span bracket has a shorter cantilever length than the main span. The maximum overstress index calculated for the side span bracket plates was 0.98.

3.2.2 Bracket Welds

The welds that connect the bracket plate to the main tower were found to have overstress indices greater than 1.00 when assessing the proposed new welds. The critical weld was found to be weld 2B between the bracket plate and internal stiffener of the main tower inner cell. However both load carrying welds were assessed as being overstressed on the main span. On the main span side the calculated overstress index was 1.21 for Weld 2B and 1.04 for Weld 1.

It was found that that if the Dead and SOV was applied only then welds 2B would be overstressed at the fully factored ULS with an overstress index of 1.01 and weld 1 passing with an overstress index of 0.87. Welds 2B overstress index reduced further to 0.90 when loading was considered at SLS.

The welds on the side span of the main tower were not found to be overstressed under the critical load combination.

3.2.3 Links Operational Loadings

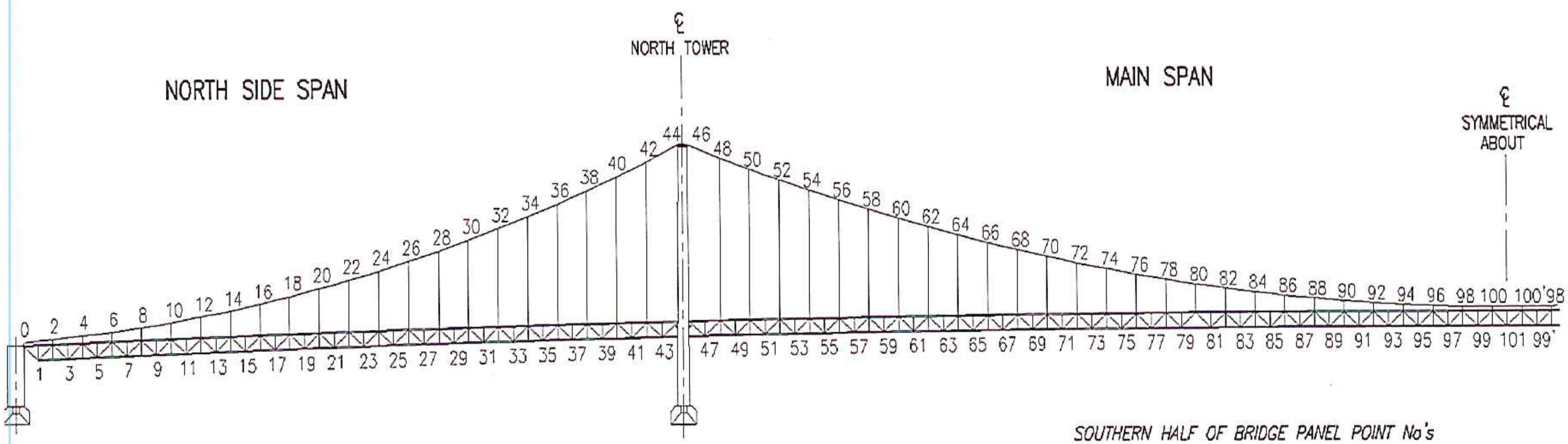
The critical element of the end link member was found to be the welds that connect the fork coupling to the main link member. However under no parts of the end link members were found to be over stressed on either the main or side span.

3.3 Conclusion

It can be concluded from the analysis that after strengthening works have been completed then the end link arrangement would be overstressed when a 250T SOV, road and footway traffic were present. It would be recommended for a 250T vehicle to cross the Forth then the bridge should be closed to all traffic on both carriageway directions. The SOV loading resulted in marginal overstress in Section 2 of the plate and weld 2b at fully factored ultimate limit state. At SLS however the overstress indices drop below 1.0.

Appendix 1

Panel Reference Point along Deck Span



4.0 REFERENCES

Fairhurst Report:

- Suspended Structure Assessment Report, February 2011
- 2010 Bridge Specific Assessment Live Loading, February 2011
- 2005 Bridge Specific Footway Live Loading, June 2006

www.fairhurst.co.uk

Aberdeen
Bristol
Birmingham
Dundee
Edinburgh
Elgin
Glasgow

Inverness
Leeds
London
Manchester
Newcastle upon Tyne
Sheffield
Watford

CIVIL ENGINEERING • STRUCTURAL ENGINEERING • TRANSPORTATION • ROADS & BRIDGES
PORTS & HARBOURS • GEOTECHNICAL & ENVIRONMENTAL ENGINEERING • PLANNING & DEVELOPMENT • WATER SERVICES • CDM COORDINATOR SERVICES

FAIRHURST