Forth Estuary Transport Authority

Forth Road Bridge
Feasibility Study of Overbridging Option

Revision No. A

January 2008

Notice

Document History

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CONTENTS

1 Summary

An overbridging option over the Demag joint at the tower on the suspension spans has been considered to minimise the disruption to traffic.

Plane frame models have been used to determine the local loads on the existing deck and cross beams. The loads considered are permanent loading, temporary load from the overbridge, BSALL and HB vehicles.

For the load comparison, HB vehicles and BSALL are considered on the existing deck, while only BSALL is considered for the overbridging option.

In this report, usage factors are used to report on the adequacy of the structure. A usage factor exceeding one indicates an overstress in the member, while a usage factor less than one indicates that the component has adequate capacity.

2 Introduction

2.1 Description of Structure

The Forth Road Bridge spans the Firth of Forth to link the towns of North and South Queensferry to the west of Edinburgh. Construction of the bridge was started in 1958 and work was completed with the official opening in 1964. The main structure is a three span suspension bridge with a central span of 1005 metres and side spans of 408 metres. On both approaches to the bridge there are multi-span viaducts, the north side having six spans and an overall length of 257 metres and the south side having 11 spans and an overall length of 438 metres.

The road over the bridge comprises a pair of two lane carriageways, both 7.3 metres wide. The carriageways are flanked by cycle paths 2.74 metres wide and footpaths 1.83 metres wide. The overall width of the structure is 33 metres.

The deck of the main bridge comprises a series of steel trusses spanning transversely, hung from the vertical hangers of the suspension cables. Over the trusses each carriageway and foot / cycle way are separate discrete constructions, which comprise, for the main span, longitudinal steel girders and steel deck plates. The side spans also have longitudinal steel girders, but with a reinforced concrete deck slab. The deck on the approach spans comprises a pair of longitudinal steel box girders supporting a series of transversely spanning steel girders. The transverse girders cantilever out from the box girders to support the parapets and verge construction. Over the transverse beams is a reinforced concrete deck slab.

Traffic usage in the first year of opening was over 4 million vehicles and this has grown steadily to over 24 million in 2006.

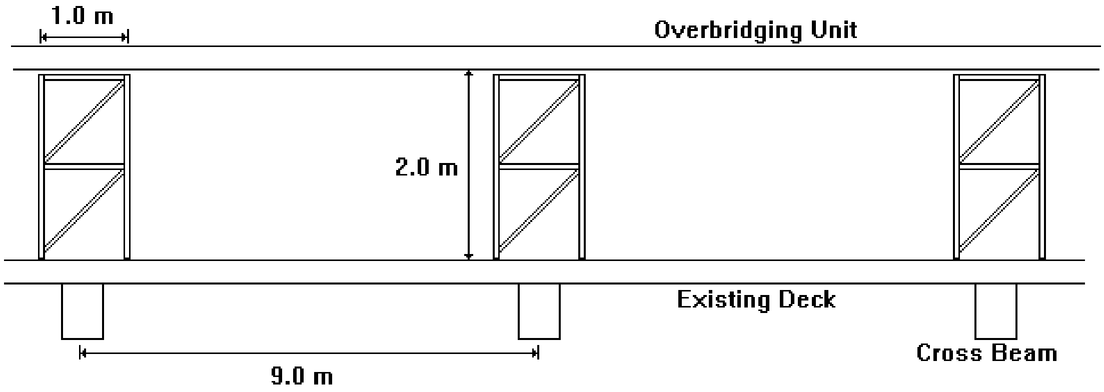
In 2001 the Bridge gained Category A listed structure status.

2.2 Overbridging Option

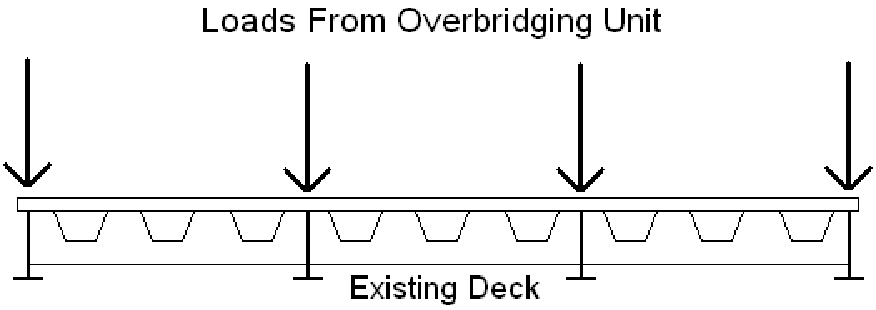
The replacement of the Demag joints at the main towers has been deemed necessary. The duration of each joint replacement is expected to be four weeks which will require the carriageway to be closed for the duration of the replacement. To reduce the road closure time, the option of constructing an overbridge on the existing deck to bridge spanning over the expansion joint is considered. This option would allow the carriageway to remain open for much of the replacement duration.

2.3 Assumed Layout of Overbridge Supports

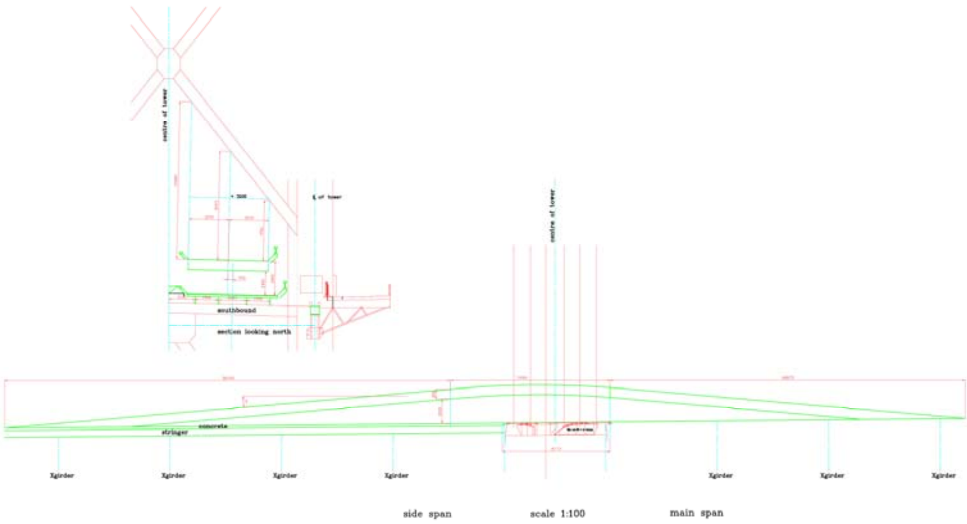
It has been assumed for the calculations in this report that the overbridging unit will be supported as shown in the following sketches. Each trestle has 8 legs, two resting above each of the four I-Beams in the deck. One of the trestles would support a fully fixed bearing.



Assumed position of overbridging unit trestles. (Typical dimensions)



Loads from over bridge assumed to act over longitudinal I-beams of the existing deck



Outline elevation for the overbridge

3 Assessment

3.1 Plane Frame Models

Plane frame models were set up to determine the additional loads on the existing deck structure. The total length of the overbridge structure was assumed to be 81.3m. The locations of the intermediate piers on the temporary bridge were chosen to correspond with the existing cross beam locations as this would minimise the effects on the existing deck. The plane frame models had rigid supports and did not therefore model the interaction between overbridge and deflections of the suspension bridge. This would need to be taken into account in the design of the new overbridge and also in deriving more accurate reactions.

An additional plane frame model was created to model the existing cross beams in order to determine the revised loading which would be acting on them due to the addition of the overbridge structure.

3.2 Loading

3.2.1 Permanent Loads

The weight of the permanent loads, including for steel, concrete and surfacing, was applied to the model as a uniformly distributed vertical load. Two cases were considered: the existing case without the overbridging unit and the additional loading due to the overbridging unit. The self weight of the ovrebridging unit was considered to equal 1.2 times the selfweight of the steel deck on the main span side of the towers.

3.2.2 Live Loading

3.2.2.1 Bridge Specific Live Loading (BSALL)

The bridge specific loading states that the combined effect of HA and HB loading do not need to be considered together. It provides a new UDL against Loaded Length chart and gives new lane factors compared with the loading given in BD 37/01. The HB loading is not modified.

The BSALL loading was applied to the plane frame model over a 30m loaded length as this had the greatest intensity and therefore would cause the largest local loads. The BSALL loading was considered on the structure with and without the overbridging unit.

3.2.2.2 HB Loading

The HB only loadcase was applied to the structure only for the case without the overbridging unit.

3.2.2.3 Longitudinal Loading

The effect of braking along the length of the overbridging unit would all act on the single fixed bearing. giving a moment at the base of the trestle. For this calculation the trestle leg was assumed to be 2 m tall. This effect has been included in the local web checks.

3.2.3 Wind Loading

Wind loading was also considered acting on the deck with and additional 2m high hoarding. These loads were applied to the structure to determine the overturning moments due to the wind.

3.3 Loading Comparison

A load comparison between the current loading and the loading occurring due to the overbridging unit was made. For the comparison HB loading was considered for the existing situation only. Three main comparisons were made:

1. The total load over the 80m span

	γ_{fl}	Maximum Total Load (kN) (no overbridge unit)	Maximum Total Load (kN) (incl. overbridge unit)
Self Weight of Overbridge	1.05		1324
Surfacing on Overbridge	1.75		539
BSALL	1.5	2160	2160
Existing Steel Selfweight	1.05	770	770
Existing Surfacing	1.75	539	539
Existing Concrete	1.15	1179	1179
Total ULS Load		6348kN	8682kN

From this it can be seen that the Total ULS load increases by 36.8% from the current condition to the condition with the overbridging unit. This means that a global check of the structure will be required before this option can be considered feasible. Total live loading for the global case has less influence than for the local cases on the cross beams and the deck checks.

2. The total loads acting on the cross beams

	γ_{fl}	Maximum Total Load (kN) (no overbridge unit)	Maximum Total Load (kN) (incl. overbridge unit)
Self Weight of Overbridge	1.05		149.8
Surfacing on Overbridge	1.75		61
BSALL	1.5		767.3
HB vehicle	1.3	1227.8	
Existing Steel Selfweight	1.05	51	51
Existing Surfacing	1.75	61	61
Existing Concrete	1.15	317	317
Total ULS Load		2121kN	1940kN

These results indicate that the total ULS load on the cross beams decreases slightly for the overbridging option. This occurs due to the high local loads caused by 45 units HB on the structure compared with the lower BSALL loads on the overbridging unit. For these short 10m spans the self weight of the overbridging unit is comparatively small.

3. The hogging moment on the existing deck, above the crossbeams. The trestle legs assumed to be 0.5 m from the centre line of the crossbeam on each side.

	γ_{fl}	Maximum Moment (kNm) (no overbridge unit)	Maximum Moment (kNm) (incl. overbridge unit)
Self Weight of Overbridge	1.05		37.45
Surfacing on Overbridge	1.75		15.25

BSALL	1.5		383.65
HB vehicle	1.3	1306.2	
Existing Steel Selfweight	1.05	43.1	43.1
Existing Surfacing	1.75	46.8	46.8
Existing Concrete	1.15	256.4	256.4
Total ULS Load		2120 kNm	1064 kNm

Similar to the loads on the cross beams, the total moment on the deck decreases when comparing the current condition with the overbridge condition. Again this is due to the small moments due to self weight of the overbridge unit compared with the high moments due to the 45 units of HB vehicle.

3.4 Material Properties

The material properties for the steelwork used were:

$E = 205$ GPa, $G = 80$ GPa, $f_y = 355/275$ MPa, Specific Weight = 77kN/m^3

3.5 Section Checks

The load effects calculated were applied to the cross beam and the existing deck and the section capacities checked. The section capacities for these sections were found to be adequate for the overbridging option loads. This is expected as the local loads due to the overbridge are smaller than the current maximum loads these elements currently experience; this is mainly due to the removal of the HB vehicle from the overbridging option.

3.6 Local Web Checks

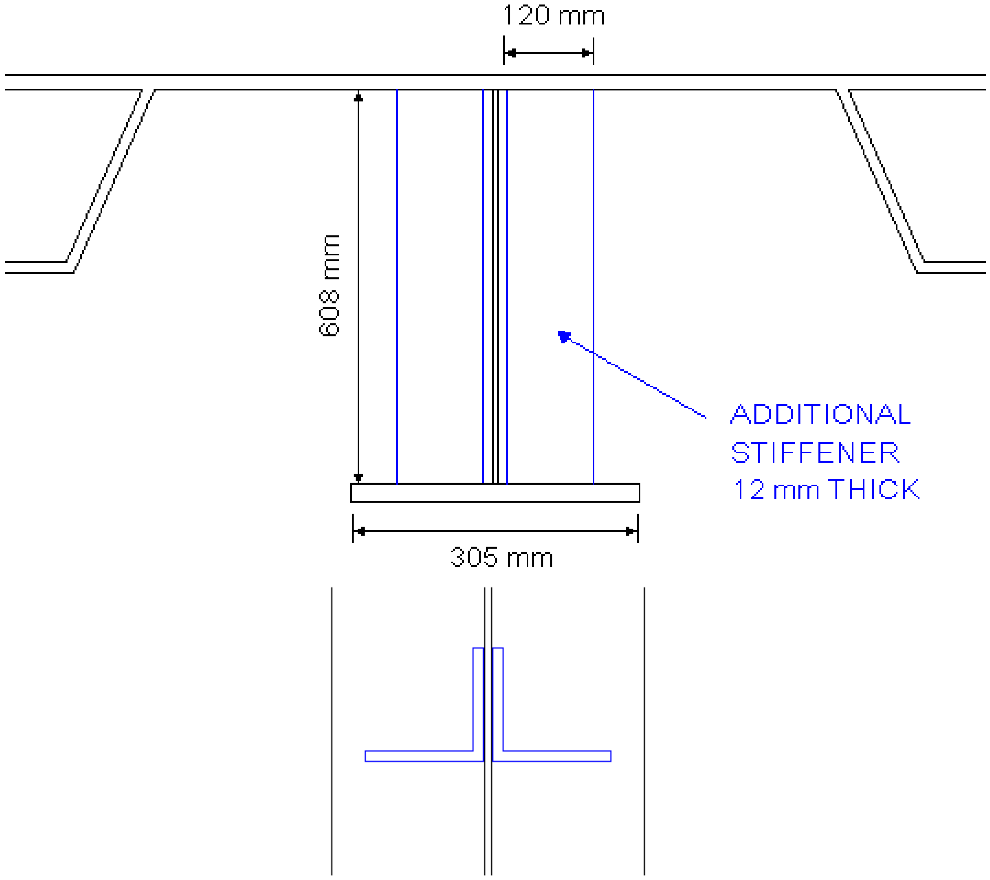
The legs of the support trestle will place a concentrated load on the existing deck. It was assumed that the trestle legs would be located directly above the four steel beams in the main span deck. The adequacy of the webs to resist these patch loads was checked.

The full overbridge and live loads were assumed to act on one side of the cross beam as the relative longitudinal movement between the overbridge and existing deck could require a roller bearing between the overbridge deck and trestle. This would make an even longitudinal distribution of load unlikely. The distribution of loads between the four trestle legs was determined with statics, the central beams are most heavily loaded. If sliding pot bearings were provided between the trestle and overbridge deck a more even distribution could be ensured reducing the maximum load.

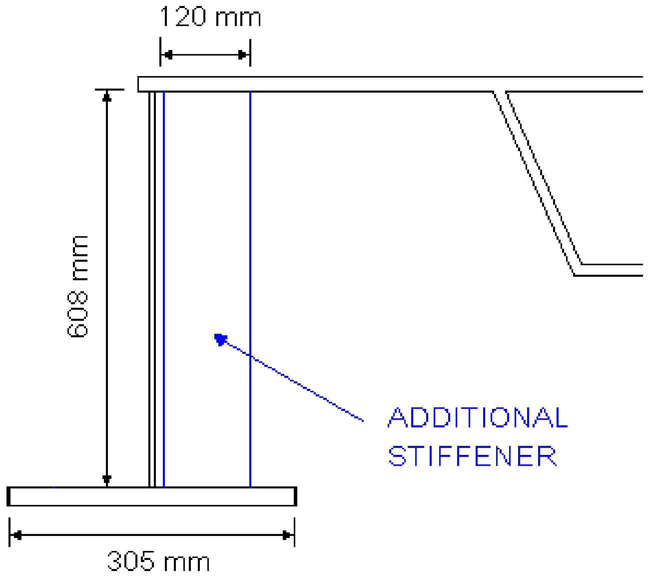
With vertical BSALL loading applied initial calculations show the webs would probably need no local strengthening, providing the load is spread over a 50 mm length for Combination 1 loading. However the effects of eccentricity of load from centreline of web have not been considered. Strengthening in the form of transverse stiffeners (see below) could be added if this was found to be a problem.

The maximum force in a trestle leg due to the longitudinal braking force, in Combination 4, is greater than that due to the vertical load. The web would need to be strengthened to take this load at fixed bearing positions.

If the overbridge were to take a 45HB vehicle additional stiffeners would need to be added to the webs under the trestle legs. The size of stiffener required was considered, for the central beams a 120 mm x 12 mm stiffener either side of the web would be adequate for the loads calculated here. For the outside beams a one sided stiffener could be fitted, the loads on this web would be lower, and a larger stiffener could be used. These are shown in the following diagrams.



Possible web strengthening on central deck beams.



Possible web strengthening on outside deck beam.

4 Other considerations

This report only considers the structural adequacy of the overbridge option concept:, but there are other problems to consider, including:

1. Parapet failure. Failure of the parapet would likely result in either a collision with the towers, which have been shown to fail under impact loading, or the colliding vehicle landing in the adjacent carriageway causing vehicle collision.

2. Parapet continuity between the overbridging structure and the existing parapets.

3. Construction time of the overbridging unit. The unit must be assembled/disassembled in a small enough timeframe to minimise the effect

5 Conclusions and Recommendations

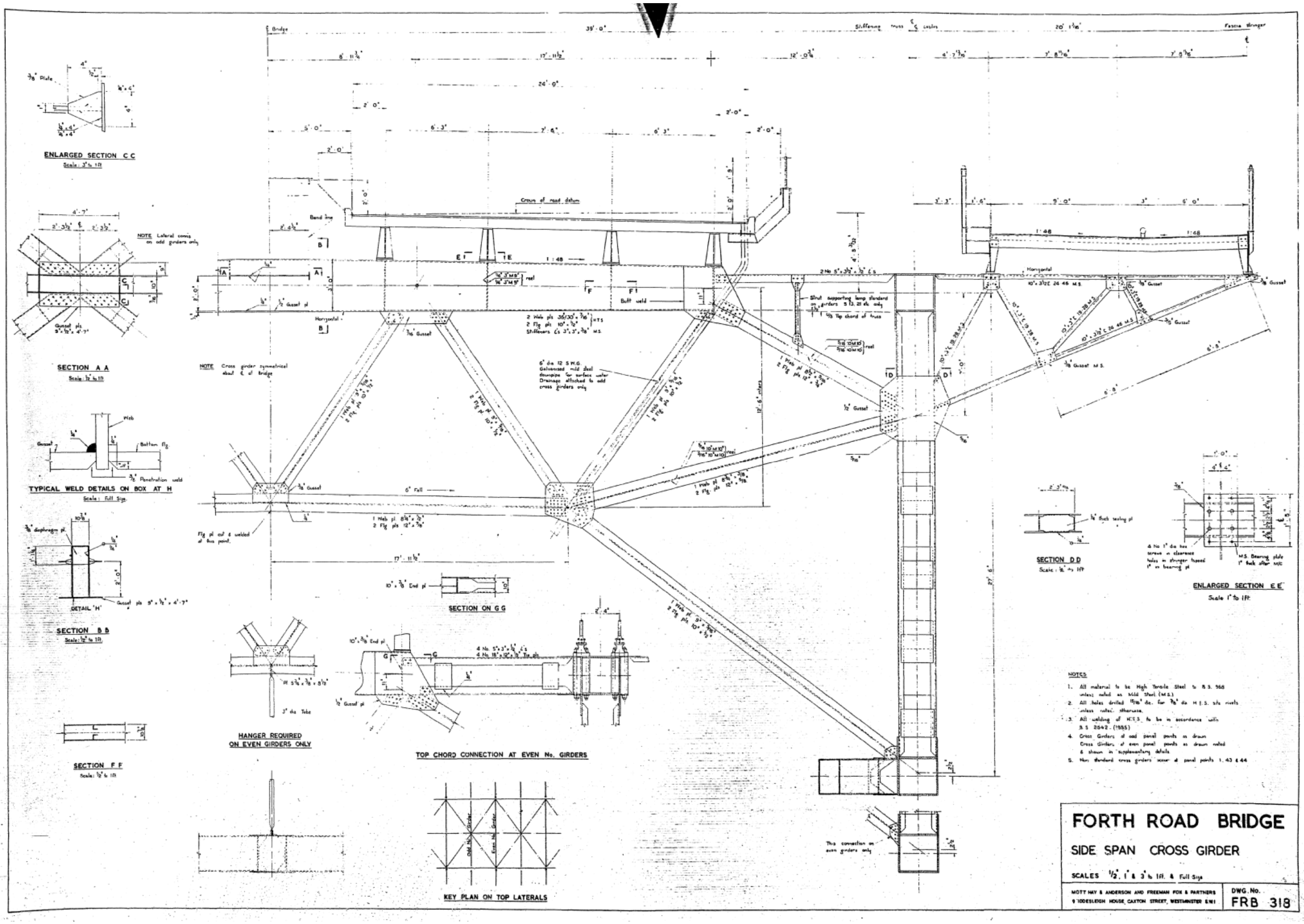
An overbridging option over the Demag joint at the tower on the suspension spans has been considered to minimise the disruption to traffic.

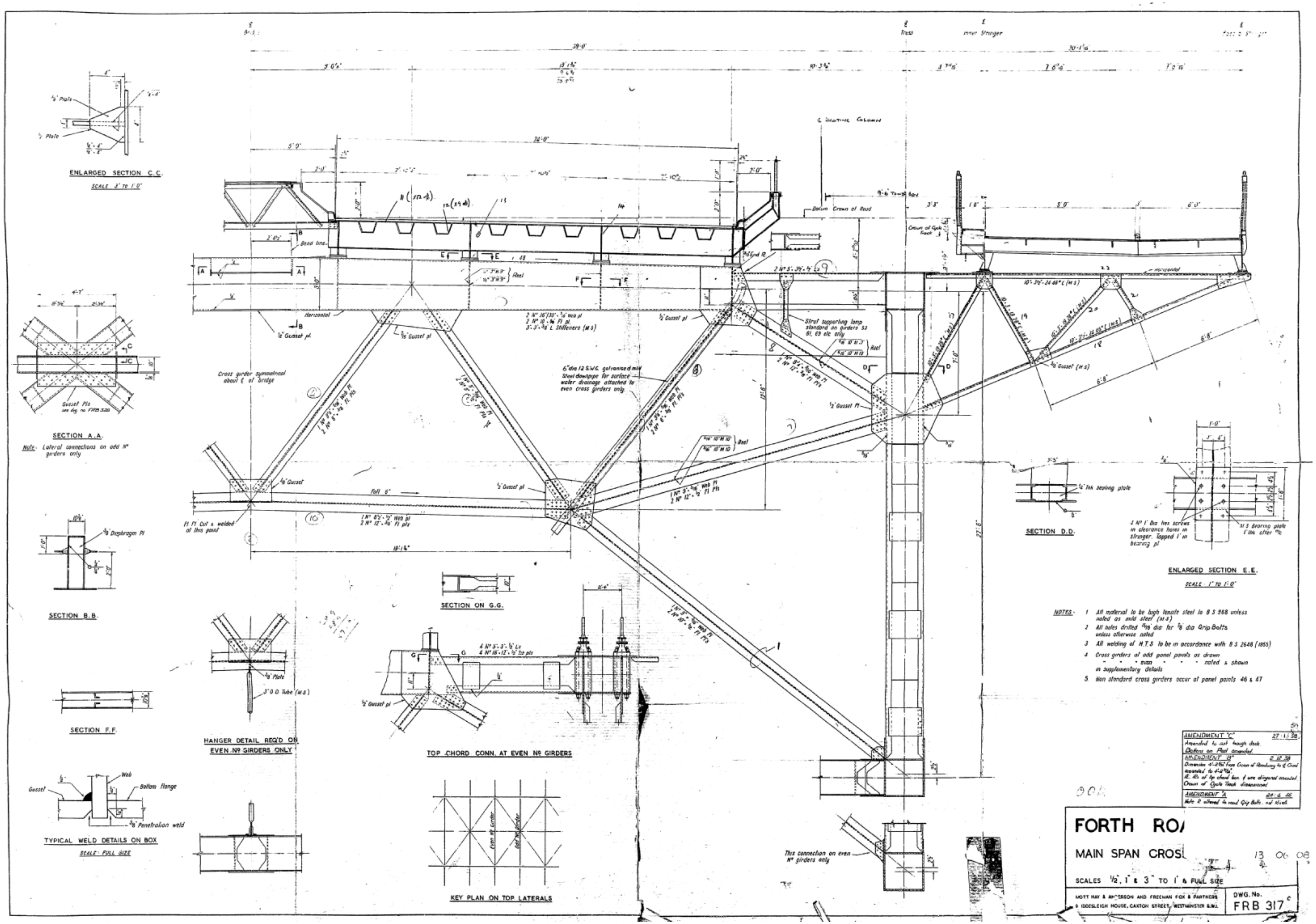
An analysis has been done to determine the effects of the overbridging unit on the existing structure. This found that the local effects on the deck and cross beams will reduce as this is dominated by the larger live loads (HB vehicles) permitted on the structure compared with the reducing the live loading (by removing the 45 unit HB vehicle) on the overbridging unit.

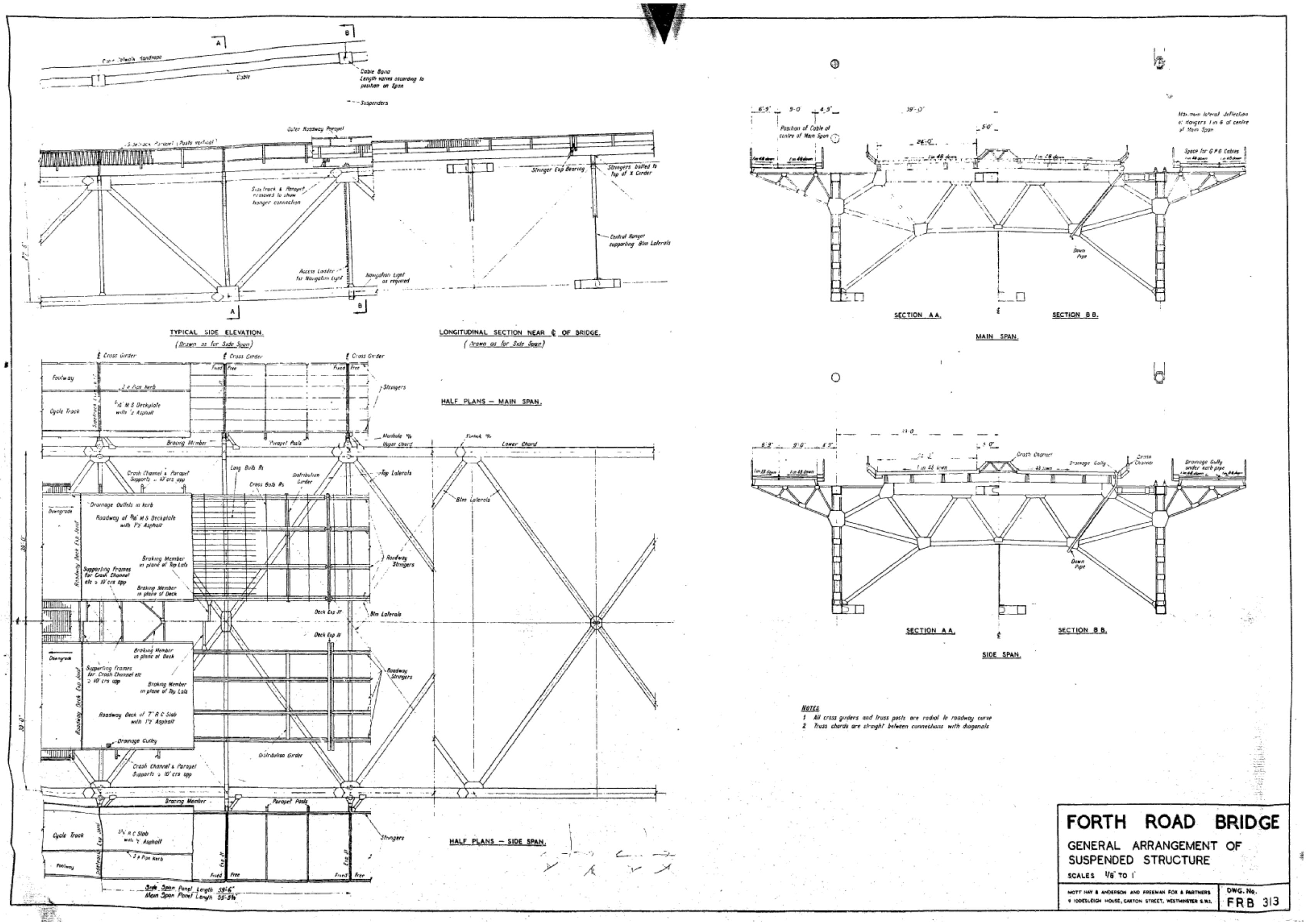
The effect of the local loading on the existing deck webs was checked and it was found extra strengthening in the form of transverse stiffeners may be required, particularly at fixed bearings, based on these initial calculations. This should be relatively straightforward to provide.

The global effects were found to increase by 36.8% over the 81.3m considered for the overbridging unit. As this report only looks at the local effects on the structure, further analysis will be required to determine the global effects on the structure.

Appendix A: *GENERAL ARRANGEMENT DRAWINGS OF DECK*


ENLARGED SECTION C C
SECTION A A
TYPICAL WELD DETAILS ON BOX AT H
SECTION B B
SECTION F F
SECTION ON G G
HANGER REQUIRED ON EVEN GIRDERS ONLY
TOP CHORD CONNECTION AT EVEN No. GIRDERS
KEY PLAN ON TOP LATERALS
SECTION D D
ENLARGED SECTION E E
NOTES
FORTH ROAD BRIDGE
SIDE SPAN CROSS GIRDER
MOTT HAY & ANDERSON AND FREEMAN FOX & PARTNERS
DWG. No.
FRB 318


ENLARGED SECTION C.C.
SECTION A.A.
SECTION B.B.
SECTION F.F.
TYPICAL WELD DETAILS ON BOX
HANGER DETAIL REQ'D ON EVEN Nº GIRDERS ONLY
SECTION ON G.G.
TOP CHORD CONN. AT EVEN Nº GIRDERS
KEY PLAN ON TOP LATERALS
SECTION D.D.
ENLARGED SECTION E.E.
This connection on even Nº girders only
NOTES.
5. Non standard cross girders occur at panel points 46 & 47
AMENDMENT "C"
AMENDMENT "B"
AMENDMENT "A"
FORTH ROA
MAIN SPAN CROS
SCALES ½", 1" & 3" TO 1' & FULL SIZE
MOTT HAY & ANDERSON AND FREEMAN FOX & PARTNERS
9 IDDESLEIGH HOUSE, CAXTON STREET, WESTMINSTER S.W.1.
DWG. No.
FRB 317 C


TYPICAL SIDE ELEVATION.
(Drawn as for Side Span)
LONGITUDINAL SECTION NEAR ℄ OF BRIDGE.
(Drawn as for Side Span)
HALF PLANS – MAIN SPAN.
HALF PLANS – SIDE SPAN.
SECTION A A.
SECTION B B.
MAIN SPAN.
SIDE SPAN.
NOTES
1 All cross girders and truss posts are radial to roadway curve
2 Truss chords are straight between connections with diagonals
FORTH ROAD BRIDGE
GENERAL ARRANGEMENT OF
SUSPENDED STRUCTURE
SCALES 1/8" TO 1'
MOTT HAY & ANDERSON AND FREEMAN FOX & PARTNERS
9 IDDESLEIGH HOUSE, CAXTON STREET, WESTMINSTER S.W.1.
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