FORTH ESTUARY TRANSPORT AUTHORITY

FORTH ROAD BRIDGE

STIFFENING TRUSS ASSESSMENT REPORT

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REVISION SCHEDULE

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Issue 1	Draft Issue.			22 Dec. 04
Issue 2	Revised to incorporate FETA comments.		C.A. Clark	12 Aug. 05
Issue 3	Revised to incorporate FETA comments.		C.A. Clark	07 Nov. 05
Issue 4	Revised to incorporate new wind load data and updated dead load information.		C.A Clark	20 Sept 06
Issue 5	General revisions to results following additional analysis.			12 Mar 08

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1.0 INTRODUCTION

W.A. Fairhurst & Partners were appointed by the Forth Estuary Transport Authority to undertake a supplementary assessment of elements of the suspended structure of the Forth Road Bridge.

The purpose of the supplementary assessment was to undertake a more detailed examination of the elements previously identified as being overstressed. The findings of the supplementary assessment are detailed in this report.

2.0 STRUCTURE

2.1 Introduction

The deck structure of the Forth Road Bridge, which carries the carriageways and footways / cyclepaths, is suspended from the main cables by means of wire rope hangers. This suspended structure is formed from two modified warren trusses, referred to as the stiffening trusses, which are connected together by lateral bracing and cross girders. The cross girders span between the stiffening trusses and support the steel beams that carry the road decks.

2.2 Stiffening Truss and Cross Girders

The stiffening trusses are 27ft 6” (8.382m) deep and 78ft (23.774m) apart (refer to Figures 1 and 2). Fabricated box girders form the top and bottom chords of the trusses, which are connected by means of battened twin channel diagonal and vertical members. Site splices in the chord members are positioned at approximately 60 ft centres. The top and bottom lateral bracing members are formed from fabricated box girders. The sections forming the diagonals, verticals and lateral bracing are connected to gusset plates, which are attached to the top and bottom chords, by means of waisted high strength friction grip (HSFG) bolts.

Cross girders are located at 30 ft (9.144m) centres. The cross girders consist of a top chord formed of a fabricated box section supported by fabricated I sections to form a trussed system. The cross girder members are bolted together by means of gusset plate utilising waisted HSFG bolts.

Attached to the outer face of each stiffening truss at the cross girder positions are brackets supporting the footway / cyclepaths. The brackets are in the form of a triangulated truss and consist of rolled channel sections bolted to gusset plates with waisted HSFG bolts.

For the purposes of referring to locations on the suspended structure the bridge is divided into panel points. A panel point is located at each cross girder location. The panel points are numbered from the side towers to the midspan of the bridge with the even panel points coinciding with the hanger locations. A drawing showing the panel point locations is provided in Appendix A.

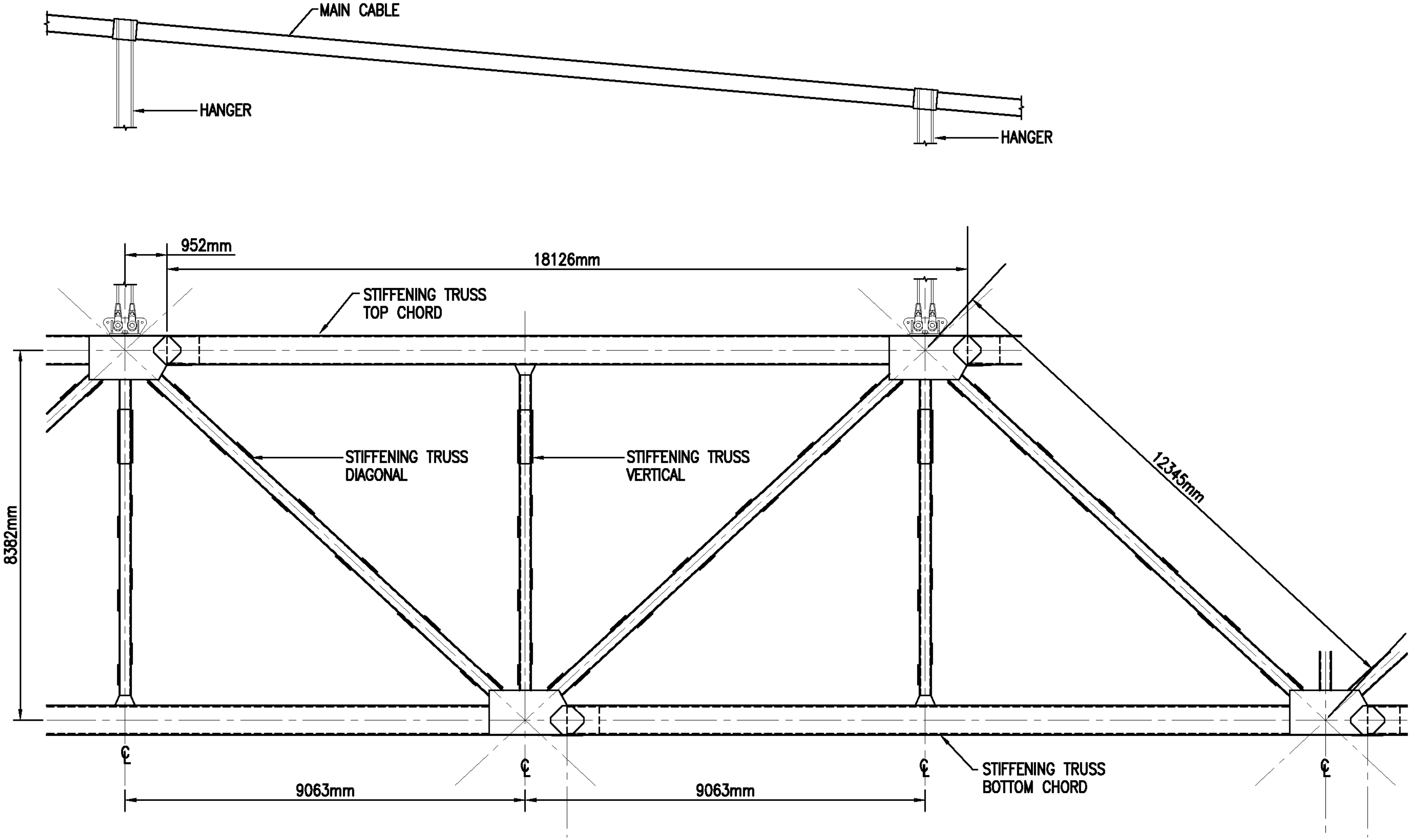

Figure 1 – Stiffening Truss Typical Layout

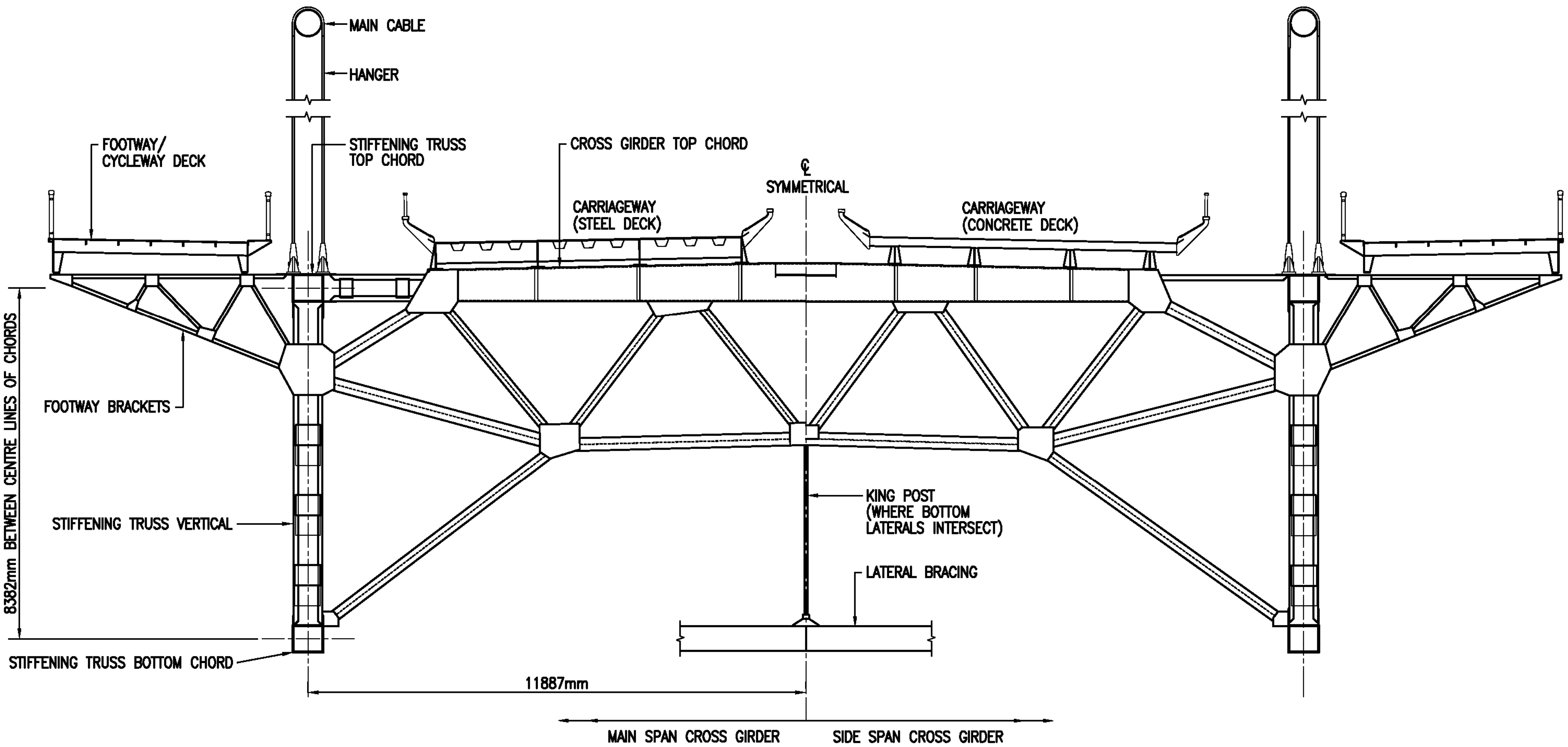

Figure 2 – Typical Cross Girder Layout

3.0 ANALYSIS

3.1 General

The analysis has been undertaken in accordance with the requirements of BD 56/96, Assessment of Steel Highway Bridges and Structures, of the Design Manual for Roads and Bridges.

The section properties calculated for the analysis have been based on gross properties in accordance with BD 56/96. Reference was made to the designers and fabricators drawings for the structure, which are held by the Forth Estuary Transport Authority, in the calculation of the section properties.

The structure was assessed for the effects of various combinations of loading. These include dead and superimposed dead loads in combination with live and wind loadings to establish the most onerous loading combination. Live loadings (in the form of HA and footway loading to BD 37/01 and the Bridge Specific Assessment Live Loading) were assessed to establish the critical loaded length and associated location for each element under consideration. Details of the critical load combinations established in the assessment including the arrangement of live and wind load are provided in Section 5.0 of the report. The basis of the footway loading applied in the assessment is summarised in section 3.2 of the report.

The following items have been obtained from previous work:

- The analysis undertaken for the supplementary assessment has been verified by comparison with the original assessment. Verification of the analysis undertaken for the original assessment was achieved by comparing the calculated movements with measurements taken at the bridge.
- Wind loading applied to the bridge as amended by wind tunnel testing undertaken by Glasgow University.
- Load factors (γ_{FL}) adopted for the analysis.
- The material properties of the elements of the suspended structure.
- Dead loading from the side span decks and the surfacing on the bridge.
- The Bridge Specific Assessment Live Loading (BSALL).
- The reduced wind loading when applied with BSALL representing the operational restrictions imposed by FETA.

Details of the above items can be found in the following reports :

- Report on Loading and Structural Integrity by W.A. Fairhurst & Partners. Published in ten volumes dated 1986.
- Report on Deck Structure by W.A. Fairhurst & Partners dated December 1994.

- Assessment of the Effects of a Painting Enclosure by W.A. Fairhurst & Partners dated August 2001.
- Bridge Specific Assessment Live Loading Report by W.A. Fairhurst & Partners dated June 2006.
- Wind Tunnel Testing of Deck Structure report by the University of Glasgow dated April 2006.

3.2 Footway Loading

The footway loading applied in the critical load combinations has been calculated in accordance with Clause 6.5.1 of BD 37/01 subject to the following.

- Critical BSALL load combinations. The nominal HA UDL described in Clause 6.5.1 (b) has been replaced with the nominal BSALL.
- Clause 6.5.1.2 Reductions in Intensity of Footway loading. Where two footways are loaded the loading on each footway has been reduced to 0.5 of the value calculated from Clause 6.5.1.1. Where only one footway is loaded then no reductions in intensity are applied.

The calculated nominal footway loadings for loaded lengths equivalent to the length of the side span, main span and the full bridge are tabulated below. For comparative purposes the loadings used in the original design and the previous assessment are also provided.

Loaded Length	Nominal Footway Loading (kN/m)			
	Original Design (refer to note 1)	1994 Assessment (refer to note 2.)	Assessment HA BD 37/01 (refer to note 3)	Assessment BSALL (refer to note 3)
408 m	1.66	5.91	6.79	4.87
1006 m	1.07	2.74	3.3	2.64
1822 m	1.07	1.58	1.91	1.33

Notes:
1. The original design loading has been calculated from the information provided in the ICE Proceedings November 1965.
2. The loading used in the 1994 Assessment is described in Report on the Deck Structure by W.A. Fairhurst & Partners, December 1994.
3. The nominal loadings for the Assessment HA and BSALL are then analysed in accordance with the relevant clauses of BD 37/01.

The footway loading used in the assessment reported in 1994 was the appraisal loading specified in the brief provided by the then Forth Road Bridge Joint Board. This loading was based on studies undertaken of the Severn Crossing.

4.0 ASSESSMENT

4.1 General

The assessment of the elements of the suspended structure was undertaken to the requirements of BD 56/96, Assessment of Steel Highway Bridges and Structures, of the Design Manual for Roads and Bridges except where otherwise noted. Clause 12 of BD 56/96 sets out the checks required at the ultimate and serviceability limit states for truss type structures. A summary of these checks is provided below.

Ultimate Limit State :

- Main plates or sections of the top chord, bottom chord, diagonals, verticals, lateral bracing and the cross girders.
- Bolted connections including the splice plates, gusset plates and the bolts. The waisted HSFG bolts have been assessed on the basis that they will act in bearing and shear at the ultimate limit state. Although not in accordance with BD 56/96 this approach is based on tests which were undertaken as part of the original assessment. Load tests of connections formed of waisted HSFG bolts demonstrated that the bolts have sufficient toughness and ductility to act in bearing and shear.

Serviceability Limit State :

- The main sections of the vertical and diagonal members for which the shape limitations set out in clause 12.2.3 of BD 56/96 were not met. Refer to Section 4.2 of the report.
- The HSFG bolts.

4.2 Stiffening Truss Diagonals and Verticals

The stiffening truss diagonal and vertical members were assessed in accordance with the requirements of BD 56/96. However it was found during the assessment that these members did not fully comply with the requirements of the standard in relation to the shape limitations and arrangement of the battens. Therefore the battens were checked against the recommendations given in Annex A of the advice note BA 56/96 of the Design Manual for Roads and Bridges. The highest stressed battened members were assessed and it was found that the battens were not overstressed allowing the members to be considered as a single element.

4.3 Bolted Splices in the Chords

The bolted splices in the top and bottom chords of the stiffening truss have been assessed in the following manner :

- At the ultimate limit state the bolts act in bearing and shear. Therefore slip of the bolts to achieve their assessed capacities is permitted. This results in rotation of the joint thus relieving the moments induced at the splice. Assessment of the splice is then based on the effects of axial loads alone.

  The effects of the release of moment in the stiffening truss were checked and it was found that it had no significant effect on the calculated stresses.

- At the serviceability limit state the bolts act in friction. Therefore the assessed capacity is based on preventing slip and hence rotation of the joint.

5.0 STIFFENING TRUSS ASSESSMENT

5.1 Introduction

The stiffening truss has been assessed in the manner set out in Section 4.0 of the report for the following loading scenarios:

- Load combinations of dead and superimposed dead load in conjunction with the full design HA (live) loading and/or the full design wind loading as appropriate. Live loading included footway loading.

- The highest stressed location in each of the elements which were found to be overstressed have been subject to a further assessment for the effects of reduced live and/or reduced wind loading where appropriate. The footway loading applied in conjunction with the reduced live loading is detailed in Section 3.2 of the report.

  The reduced live loading comprised the Bridge Specific Assessment Live Loading (BSALL).

  The reduced wind loading was based on a wind gust speed of 50mph and was applied only to critical load combinations that included both HA (live) and wind load. This scenario reflects the operational restrictions imposed by FETA during high winds.

In the results tables presented in Section 5.0 and Appendix B of the report the description "dead" in the loading is taken to refer to both dead and superimposed dead loading on the bridge.

For the purposes of the assessment the individual elements have been separated into the following components.

- The main plates and sections forming the particular element including those parts of the element that are holed at splice or gusset locations.

  Splices refer to joints formed between a pair of members e.g. the chord splices. Gusset plates connect two or more members of the suspended structure. Refer to Figure 3 for the locations and extent of gusset plates in the vicinity the panel points on the stiffening trusses.

  Comments on the stress in the chord gusset plates, excluding areas local to the attachments for other members, are made under cover of the chord results. The stresses in the gusset plates local to the attached vertical and diagonal members are covered by the vertical and diagonal member results.

- The cover plates for the bolted splices in the chords.

- The gusset plates connecting members of the cross girders, including the footway brackets and the gusset plates connecting the cross girders to the stiffening truss.

- The gusset plates in the chords of the stiffening truss local to the connection for the vertical, diagonal and lateral bracing and cross girders. The stresses in the gusset plates local to the attached members are covered by the appropriate section for that member.

- The lateral bracing gusset plate overstress indices cover the gusset plates connecting the bracing to the chords and cross girders. It also covers the connections between the lateral bracing members themselves. Similarly this applies to the lateral bracing gusset plate bolts.

- The bolts forming the connections.

Where a panel point or range of panel points are identified in the report this is deemed to include both panel points on the bridge i.e. panel point 22 and 22'.

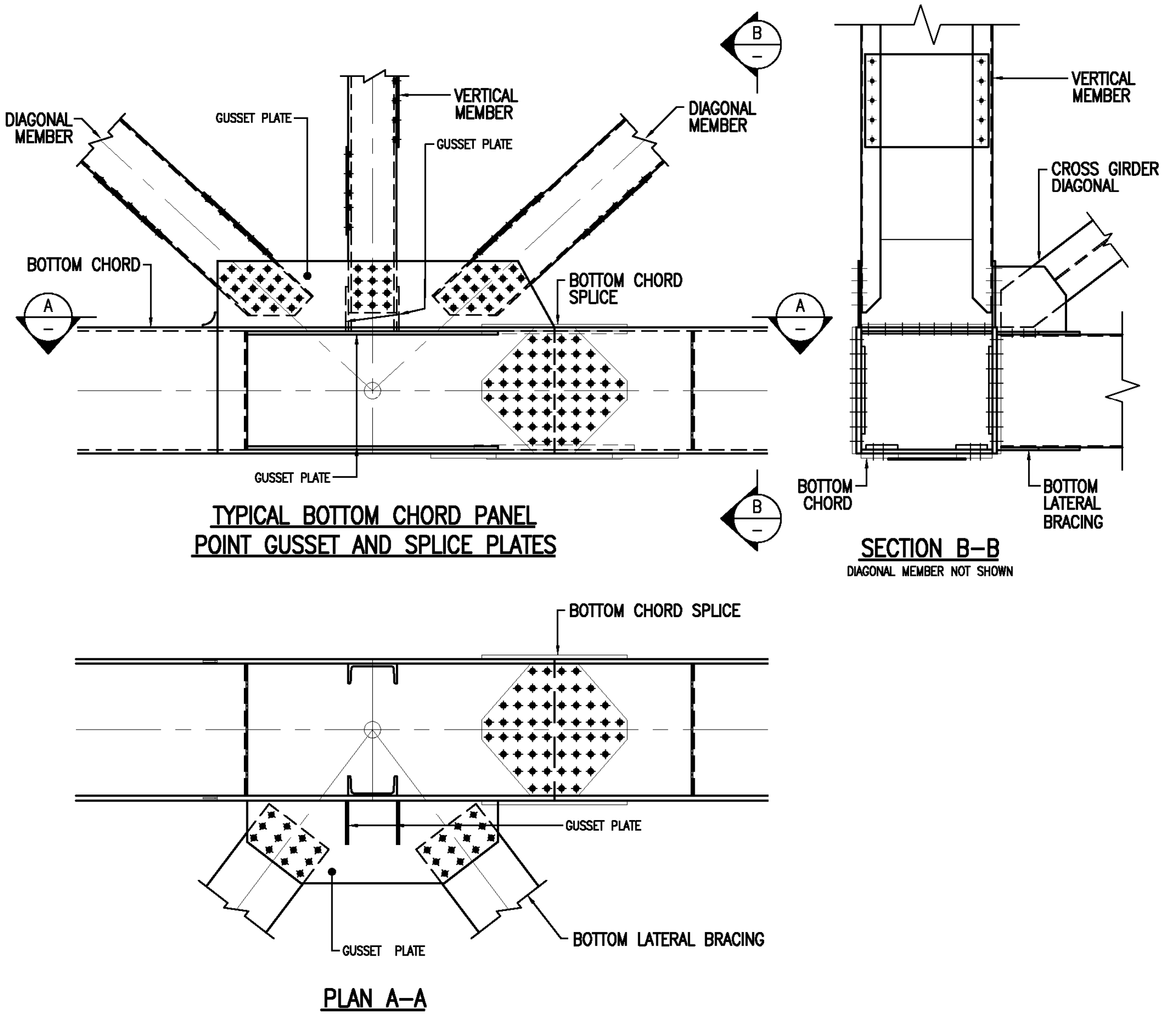

Figure 3 – Gusset and splice plate locations in the vicinity of the bottom chord.

5.2 Top and Bottom Chords

5.2.1 General

The overstress indices for the top and bottom chords are detailed in Appendix B. A summary of the critical overstress indices is provided in Tables 1 and 2. The overstress indices across the bridge are shown graphically in Figures 4 and 5.

The critical load combinations for the chords were:

- HA or BSALL applied to the main span over a loaded length varying from 130m to 200m. However the maximum overstress indices calculated in the side span occurs with a loaded length of 240m.

  HA and BSALL were applied to all the notional lanes forming the carriageway in the critical load combinations. However the highest loaded lane was located adjacent to the stiffening truss under consideration.

- Footway loading was applied to both footways coexistent with the HA or BSALL. Loaded lengths for the footway loading were the same as the coexistent HA or BSALL.

- The wind loading applied in the combination comprising dead, HA and wind consisted of the following.

  The wind load applied coexistent with HA was the maximum wind load for bridges with live load. This load allows for the increased wind resistance due to the presence of vehicles on the bridge.

  Where applicable maximum wind load calculated for bridges without live load was applied to the remaining portions of the span under consideration.

  The remaining spans of the bridge were loaded with wind load calculated for locations that have a relieving effect on the element under consideration.

- The wind loading applied in the combination comprising dead and wind consisted of the maximum wind load for bridges without live load applied to the span under consideration. The remaining spans were loaded with wind load calculated for locations that have a relieving effect on the element under consideration.

- The reduced wind loading based on a wind gust speed of 50mph has been analysed in combinations which included HA or BSALL live load.

- The chords were also examined for reversal of loading in members. The critical results are reported in Appendix B Tables B1 and B2 of the report.

Table 1 – Summary of Top Chord Overstress Indices.

Top Chord Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Plates	Dead + Wind	ULS	1.24	94	C
	Dead + HA +Wind	ULS	1.54	22	C
	Dead + BSALL + 50mph Wind	ULS	1.04	60	C
Splice Plates	Dead + Wind	ULS	1.75	78	T
	Dead + HA +Wind	ULS	1.62	20	C
	Dead + BSALL + 50mph Wind	ULS	1.04	20	C
Splice Bolts	Dead + Wind	SLS	1.43	22	–
	Dead + HA +Wind	ULS	0.59	22	–
		SLS	2.12	22	–
	Dead + BSALL + 50mph Wind	SLS	1.14	22	–

Notes: Load Effect Notation. ‘C’ indicates a compressive stress, ‘T’ indicates a tensile stress. The loadcase description “Dead” refers to both dead and superimposed dead loading.

Table 2 – Summary of Bottom Chord Overstress Indices.

Bottom Chord Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Plates	Dead + Wind	ULS	1.34	70	C
	Dead + HA +Wind	ULS	1.47	21	T
	Dead + BSALL + 50 mph Wind	ULS	0.91	21	T
Splice Plates	Dead + Wind	ULS	1.46	77	T
	Dead + HA +Wind	ULS	1.80	21	T
	Dead + BSALL + 50mph Wind	ULS	1.16	21	T
Splice Bolts	Dead + Wind	SLS	1.12	89	–
	Dead + HA +Wind	ULS	0.65	21	–
		SLS	1.55	21	–
	Dead + BSALL + 50mph Wind	SLS	0.95	21	–

Notes: Load Effect Notation. ‘C’ indicates a compressive stress, ‘T’ indicates a tensile stress. The loadcase description “Dead” refers to both dead and superimposed dead loading.

5.2.2 Main Plates

The maximum overstress indices in the top and bottom chords occur at panel point 22 on the side span due to a load combination incorporating HA and wind loading. A maximum overstress of 1.54 was calculated in the top chord, approximately 5% greater than the maximum overstress in the bottom chord. The chords were found to be overstressed over the majority of the length of the bridge. The critical load combinations generally included both HA and wind loading. The locations of the chord which were found to have overstress indices less than 1.00 were limited to areas in the vicinity of the main and side towers.

The effect of applying a reduced wind load based on a wind speed of 50mph in the critical load combination, which included dead and HA load, was assessed. The application of the reduced wind load reduced the maximum overstress in the top and bottom chords to 1.32 and 1.29 respectively. This amounted to a reduction in overstress of 14% in the top chord and 12% in the bottom chord.

Under BSALL the maximum overstress index of 1.54 reduced to 1.04 under the application of the BSALL and 50mph wind loading.

However it should be noted that the top and bottom chords are overstressed for the majority of the main span due to dead and wind loading. The bottom chord is also overstressed for a significant length of the side span due to dead and wind loading. The maximum overstress index due to the dead and wind load combination is 1.34 occurring at panel point 70 in the bottom chord.

Local to the panel points the chord web plates increase in depth to form the gusset plates for the diagonal and vertical connections (refer to figure 3). When the main chord elements were overstressed the gusset plates were also found to be overstressed local to the joint with the main web plate of the chord. However the overstress dissipates as the load disperses into the deeper plate. Therefore only limited portions of the gusset plates were overstressed.

5.2.3 Splice Cover Plates

The overstress in the splice cover plates generally occurs in the same panel points as the overstress in the chords. However the magnitude of overstress was found to increase due to a reduction in the effective section at the splice in comparison to that provided in the main section. Under HA and wind the reductions in effective section resulted in an increase in the extent of panel points with overstress indices greater than 1.00. The primary reasons for the reduction in effective section are detailed below:

- Manhole access through the bottom flange cover plates has been provided at all chord splices.

- A significant number of top chord splices have only single cover plates located on the outer faces of the webs and top flange.

- When assessing the splice cover plates for tensile loading the effective section is reduced further due to the presence of bolt holes. The maximum stress in the bottom chord is produced when the chord is in tension.

The extent of panel point splices with overstress indices less than 1.00 were.

- Top chord panel points 0 to 2 inclusive, 40, 42 and 44.
- Bottom chord panel points41, 43, and 47.

The tensile forces in the bottom chord were found to produce the greatest overstress indices with a maximum value of 1.80 calculated at panel point 21 in the side span under dead, HA and wind, approximately 11% greater than the maximum overstress index in the top chord.

Under BSALL and 50 mph wind the maximum overstress in the splice cover plates reduced to 1.04 for the top chord and 1.16 for the bottom chord. The splice plates at the following panel points remain overstressed.

- Top chord panel points 18 to 24 inclusive and 36.
- Bottom chord panel points 11 to 29 and 51 to 55 inclusive.

The application of dead and wind loading overstresses the top and bottom chord splice plates. The extent of overstress is greater than that for the BSALL and 50mph wind, although significantly reduced from that found due to HA and wind loading.

5.2.4 Bolts

The bolts were found to have no overstresses due to the effects of ultimate limit state loading.

At the serviceability limit state where the bolts are required to act in friction overstress indices greater than 1.00 were calculated. A maximum overstress of 2.12 was calculated in the top chord at panel point 22 on the side span due to a load combination including HA and wind. This overstress was approximately 37% greater than that calculated in the bottom chord. The extent of splice bolts with overstress indices less than 1.00 were.

- Top chord panel points 0, 2, 40 to 44 and 46.
- Bottom chord panel points 3 to 5, 37 to 43 and 47 to 51.

Under BSALL and 50 mph wind at the serviceability limit state there was a significant reduction in the extent of splices with bolts overstressed. The maximum overstress was found to reduce to 1.14. Panel points with overstresses in the splices exceeding 1.00 were confined to the top chord side span panel points 14 to 26.

The overstressing in the top chord was greater than the bottom chord due to the use of single sided cover plates. This results in a reduction in the number of shear interfaces and therefore a reduction in the friction capacity of the bolts.

The application of dead and wind loading overstresses the top and bottom chord splice bolts. The extent of overstress is greater than that for the BSALL and 50mph wind, although significantly reduced from that found due to HA and wind loading.

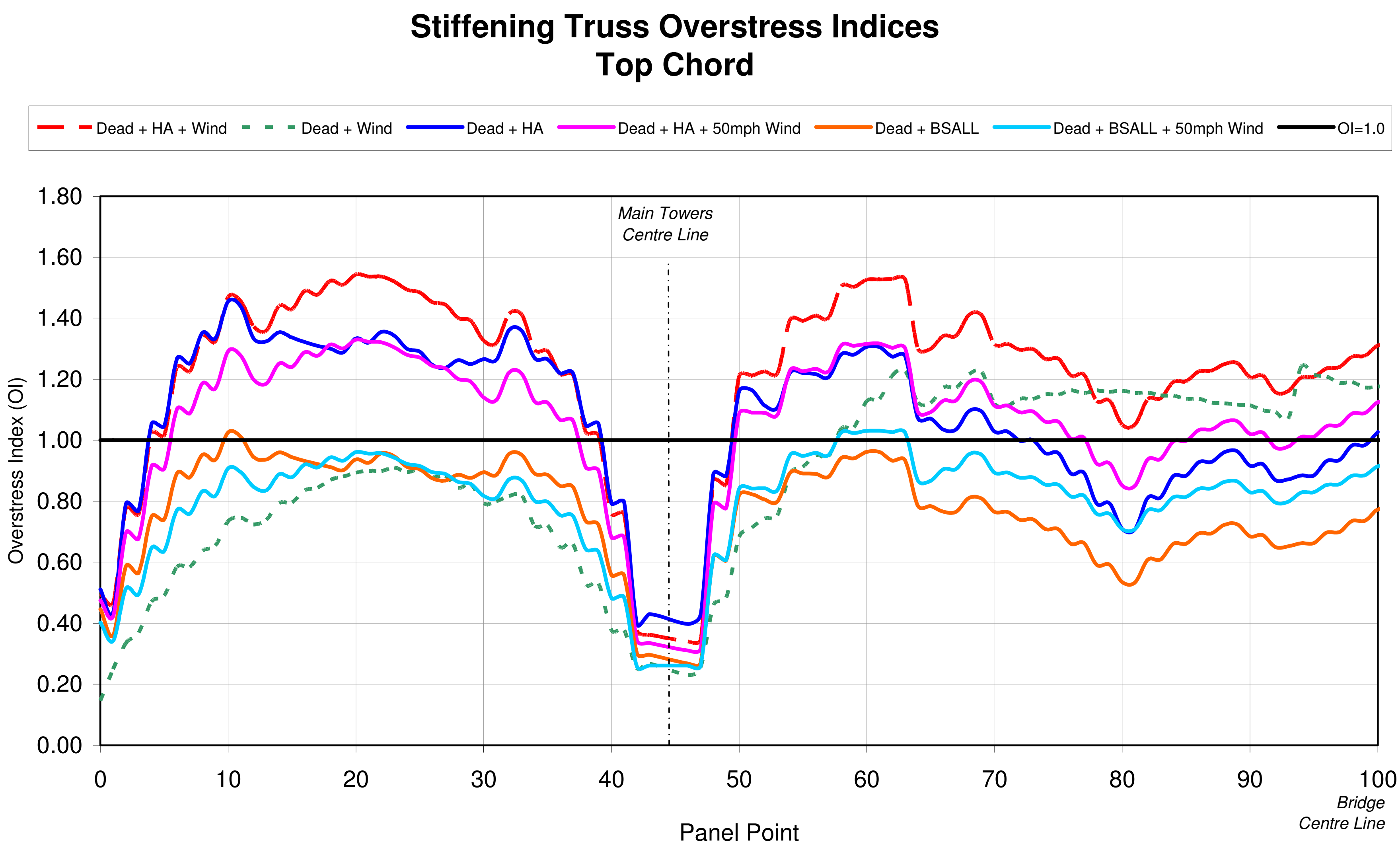

Figure 4 – Graph of Top Chord Overstress Indices.

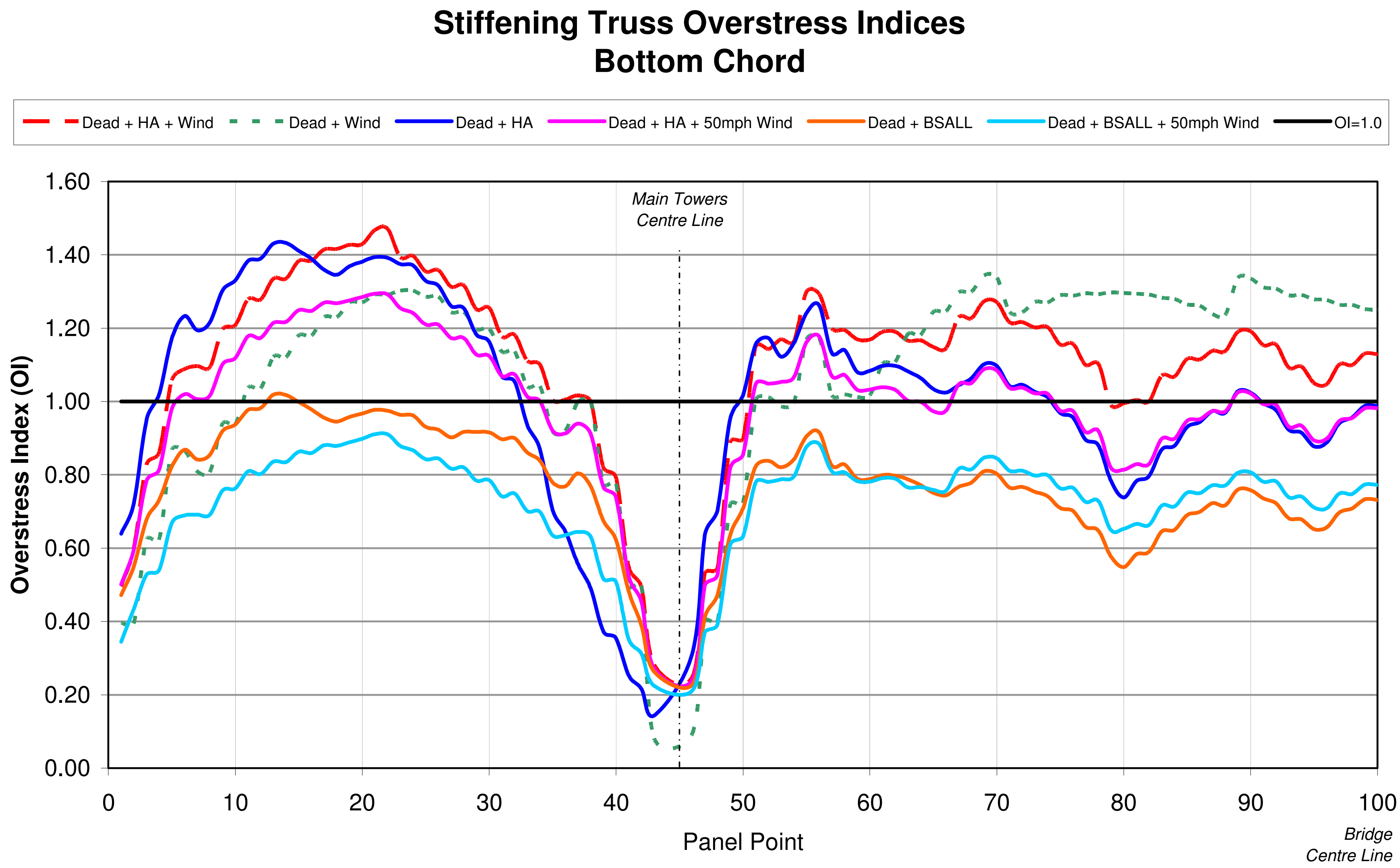

Figure 5 – Graph of Bottom Chord Overstress Indices.

5.3 Diagonals and Verticals

5.3.1 General

The overstress indices for the diagonal and vertical members are detailed in Appendix B. A summary of the critical overstress indices is provided in Tables 3 and 4. The overstress indices across the bridge are shown graphically in Figures 6 and 7.

The critical load combinations for the diagonal and vertical members were:

- The load combination that produced maximum shear effects on the stiffening trusses comprised dead and HA loading. The HA load was applied to all traffic lanes over a loaded length of 130m to 240m. The HA loading was positioned adjacent to the main or side towers as appropriate. BSALL loading was applied in the same manner as HA.

- The load combination that produced maximum torque effects on the suspended structure comprised dead and HA loading. The HA load was positioned on the main span such that a single carriageway was loaded for a portion of the span from one tower and the opposite carriageway loaded for the remainder of the loaded length from the opposite tower. The loaded lengths considered for the main span loading varied from 530m to 1000m. The HA load for torque effects on the side span consisted of a single carriageway loaded over a length varying from 380m to 400m. BSALL loading was applied in the same manner as HA.

- In combinations for maximum shear effects footway loading was applied to both footways coexistent with the HA or BSALL.

  However in load combinations for the torque effects the footway loading was applied in a similar manner to the HA or BSALL loading. Therefore a single footway adjacent to the loaded carriageway was loaded. This resulted in only a single footway being loaded at any section of the bridge.

  Loaded lengths for the footway loading were the same as the coexistent HA or BSALL.

- The diagonal members were overstressed only at one panel point under load combinations that included wind and HA loading.

- The vertical members were not overstressed under any load combinations.

Table 3 – Summary of Diagonals Overstress Indices.

Diagonal Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Members	Dead + Wind	ULS SLS	0.51 0.37	50 50	C C
	Dead + HA	ULS SLS	1.29 0.88	0 0	T T
	Dead + BSALL	ULS SLS	1.02 0.68	0 0	T T
Gusset Plates	Dead + Wind	ULS SLS	0.22 0.16	50 50	T T
	Dead + HA	ULS SLS	1.20 0.81	0 0	T T
	Dead + BSALL	ULS SLS	0.95 0.63	0 0	T T
Bolts	Dead + Wind	ULS SLS	0.12 0.29	50 50	– –
	Dead + HA	ULS SLS	0.55 1.20	0 0	– –
	Dead + BSALL	ULS SLS	0.44 0.93	0 0	– –

Notes: Load Effect Notation. 'C' indicates a compressive stress, 'T' indicates a tensile stress.
The loadcase description "Dead" refers to both dead and superimposed dead loading.
All loadcases are the critical cases that produce torsion of the suspended structure.

5.3.2 Diagonal Main Members

Diagonal members are overstressed at panel points 0, 46 and 48 due to the effects of the critical ultimate limit state load combination of dead and HA. These members are located at six panel points in the vicinity of the side and main towers of the bridge where the effects of shear and torsion are greatest. The maximum overstress was found to be adjacent to the side towers. However at the serviceability limit state the overstress at this location reduces to 0.88.

The main diagonal members were found to have overstress indices greater than 1.00 at the ultimate limit state due to the application of BSALL only at panel point 0. No overstress indices exceeding 1.00 were derived for the diagonals at the serviceability limit state.

Table 4 – Summary of Verticals Overstress Indices.

Vertical Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Members	Dead + Wind	ULS SLS	0.36 0.26	100 100	C C
	Dead + HA	ULS SLS	0.96 0.66	44 44	T T
	Dead + BSALL	ULS SLS	0.78 0.54	44 44	T T
Gusset Plates	Dead + Wind	ULS SLS	0.24 0.18	100 100	C C
	Dead + HA	ULS SLS	0.36 0.27	24 24	C C
	Dead + BSALL	ULS SLS	0.33 0.24	24 24	C C
Bolts	Dead + Wind	ULS SLS	0.26 0.62	100 100	– –
	Dead + HA	ULS SLS	0.33 0.82	24 24	– –
	Dead + BSALL	ULS SLS	0.30 0.75	24 24	– –

Notes: Load Effect Notation. 'C' indicates a compressive stress, 'T' indicates a tensile stress.
The loadcase description "Dead" refers to both dead and superimposed dead loading.
All loadcases are the critical cases that produce torsion of the suspended structure.

5.3.3 Vertical Main Members

Under all load combinations the vertical members were not overstressed at the ultimate or serviceability limit states. The greatest stresses occur in the vertical members adjacent to the main towers.

5.3.4 Chord Gusset Plates Local to the Connection with the Diagonals

The gusset plate local to the attachment of the diagonal members was overstressed at panel point zero. The calculated overstress index was 1.20. No overstress indices greater than 1.00 were calculated in the gusset plates local to the diagonals at the serviceability limit state. Under the application of BSALL the overstress index reduced to less than 1.00.

5.3.5 Chord Gusset Plates Local to the Connection with the Verticals

Under all load combinations the gusset plates local to the attachment of the vertical members were not overstressed at the ultimate or serviceability limit states.

5.3.6 Diagonals Gusset Plate Bolts

Under all load combinations the bolts in the diagonal members were not overstressed at the ultimate limit state.

At the serviceability limit state where the bolts are required to act in friction overstresses were found in the diagonal gusset bolts at panel point zero located immediately adjacent to the side towers.

Under the application of BSALL the gusset plate bolts for the diagonals were not overstressed at the serviceability limit state

5.3.7 Verticals Gusset Plate Bolts

Under all load combinations the bolts in vertical members were not overstressed at the ultimate or serviceability limit states.

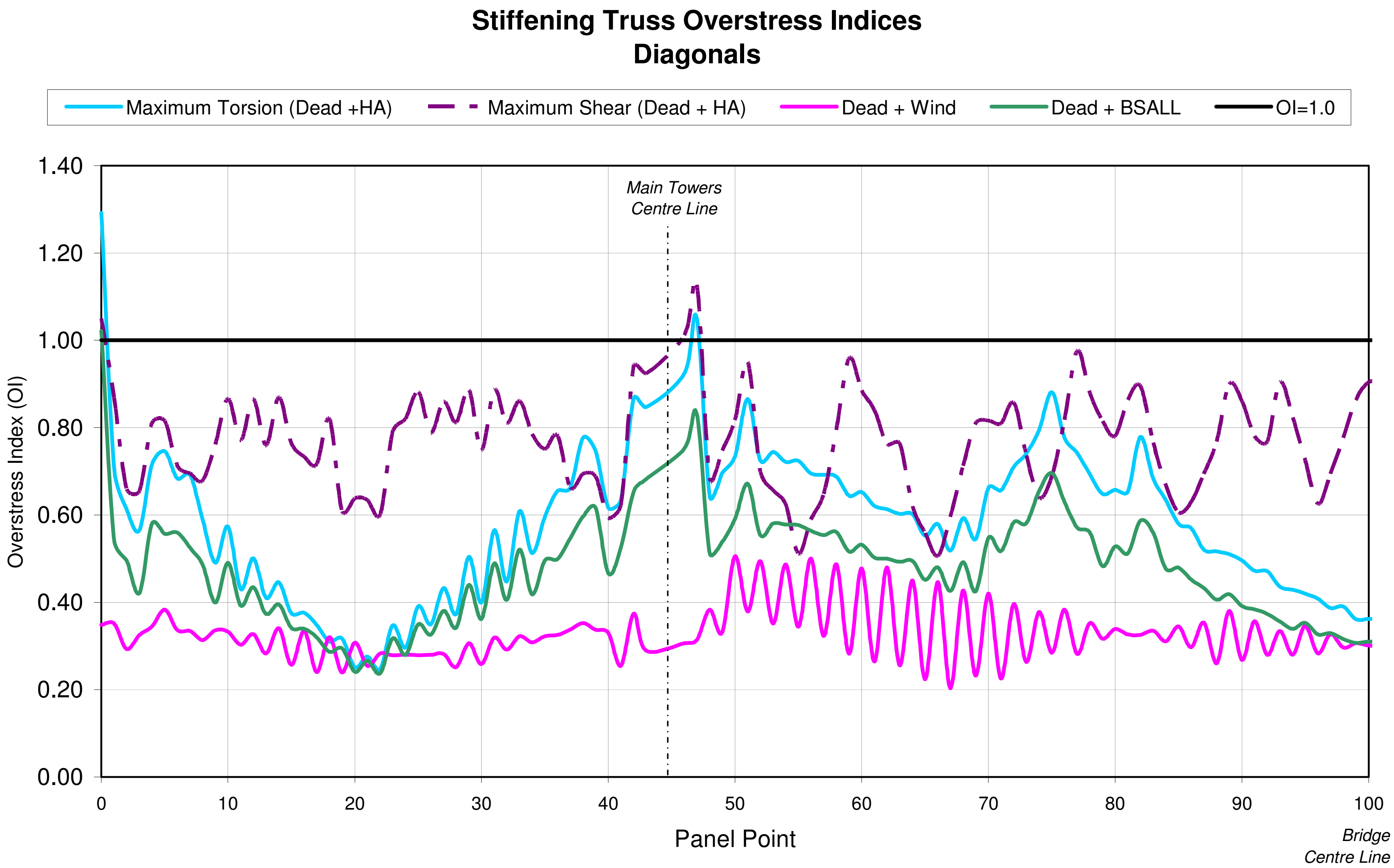

Figure 6 – Graph of Diagonals Overstress Indices

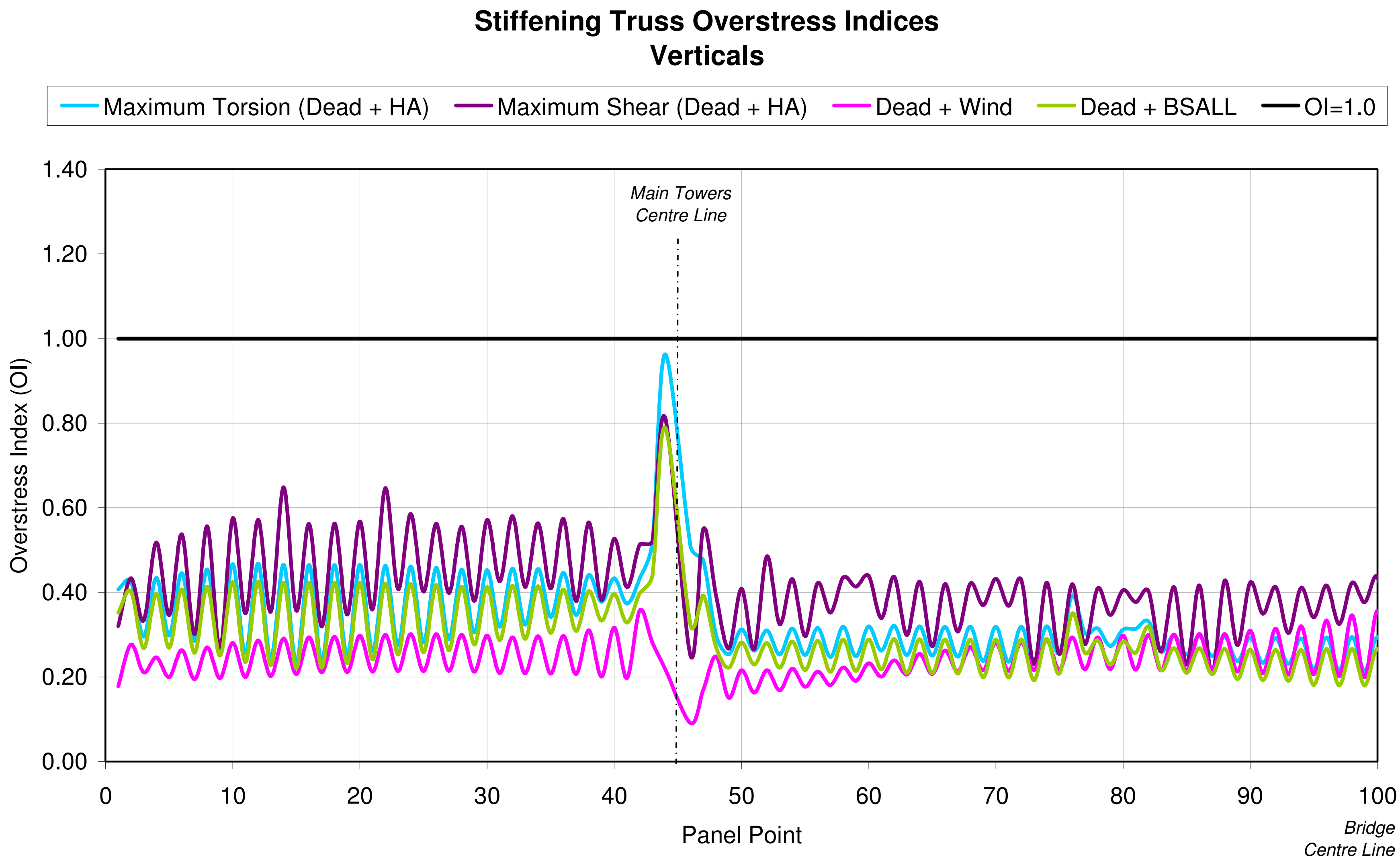

Figure 7 – Graph of Verticals Overstress Indices.

5.4 Lateral Bracing

5.4.1 General

The overstress indices for the top and bottom lateral bracing are detailed in Appendix B. A summary of the critical overstress indices is provided in tables 5 and 6 below. The overstress indices across the bridge are shown graphically in Figures 8, 9 and 10.

The critical load combinations for the top and bottom lateral bracing were:

- The wind loading applied in the combination comprising dead and wind consisted of the maximum wind load for bridges without live load applied to the span under consideration. The remaining spans were loaded with wind load calculated for locations that have a relieving effect on the element under consideration.

- The load combination that produced maximum torque effects on the suspended structure comprised dead and HA loading. The HA load was positioned on the main span such that a single carriageway was loaded for a length of 730m from one tower and the opposite carriageway loaded for the remainder of the span to the opposite tower. The total loaded length for the lateral bracing members was equal to the length of the main span.

  The arrangement of HA loading for maximum torque effect on the side span consisted of a single carriageway loaded for the full length of the span.

- A load combination comprising dead, HA and wind loading. The live load was applied in such way to produce maximum torque effects on the suspended structure. The wind load applied coexistent with HA was the maximum wind load for bridges with live load. This load allows for the increased wind resistance due to the presence of vehicles on the bridge. The remaining spans of the bridge were loaded with wind load calculated for locations that have a relieving effect on the element under consideration.

- Footway loading in combinations for the torque effects was applied in a similar manner to the HA or BSALL loading. Therefore a single footway adjacent to the loaded carriageway was loaded. This resulted in only a single footway being loaded at any section of the bridge. Loaded lengths for the footway loading were the same as the coexistent HA or BSALL.

- Load combinations that produced maximum shear or bending effects on the suspended structure were not critical.

Table 5 – Summary of Top Lateral Bracing Overstress Indices

Top Lateral Bracing Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Members	Dead + Wind	ULS	1.74	0	C
	Dead + Wind + HA	ULS	1.62	2	C
	Dead + BSALL + 50mph Wind	ULS	1.24	2	C
Gusset Plates	Dead + Wind	ULS	1.13	0	C
	Dead + Wind + HA	ULS	1.17	0	C
	Dead + BSALL + 50mph Wind	ULS	0.66	0	C
Bolts	Dead + Wind	ULS SLS	0.65 1.26	0 0	– –
	Dead + Wind + HA	ULS SLS	0.84 1.47	48 48	– –
	Dead + BSALL + 50mph Wind	ULS SLS	0.61 1.05	2 2	– –

Notes: Load Effect Notation. 'C' indicates a compressive stress, 'T' indicates a tensile stress.
The loadcase description "Dead" refers to both dead and superimposed dead loading.
All loadcases are the critical cases that produce torsion of the suspended structure.

5.4.2 Top Lateral Bracing Main Members

The top lateral bracing members have overstress indices greater than 1.00 over a significant length of the bridge due to the critical load combinations which were:

- Dead and wind,
- Dead and HA inducing torsion of the suspended structure,
- Dead, wind and HA inducing torsion of the suspended structure.

The highest stressed locations are generally located in the vicinity of the side and main towers and are induced by combinations including dead and wind and dead, wind and HA loads. A peak overstress index of 1.74 was calculated at panel point zero for loadcases included dead and wind loads.

It should be noted that the top lateral bracing members were found to have overstress indices greater than 1.00 due to load combination included both HA and wind loading. The maximum overstress index is 1.62 occurring at panel point zero.

When analysed using BSALL in place of HA loading and reduced wind loading based on 50mph wind speed, this reduced the overstress index to 1.24.

The panel points at which the top lateral bracing members have overstress indices less than 1.00 are summarised below:

- Side span: 11 to 31.
- Main span: 64 to 71 and 83 to 101.

Table 6 – Summary of Bottom Lateral Bracing Overstress Indices

Bottom Lateral Bracing Element	Loadcase	Limit State	Overstress Indices	Panel Point	Load Effect
Main Members	Dead + Wind	ULS	0.46	42	T
	Dead + HA	ULS	1.23	1	T
	Dead + BSALL	ULS	1.00	1	T
Gusset Plates	Dead + Wind	ULS	0.35	47	T
	Dead + HA	ULS	1.01	1	T
	Dead + BSALL	ULS	0.82	1	T
Bolts	Dead + Wind	ULS SLS	0.26 0.43	47 47	– –
	Dead + HA	ULS SLS	0.86 1.31	1 1	– –
	Dead + BSALL	ULS SLS	0.70 1.22	1 1	– –

Notes: Load Effect Notation. ‘C’ indicates a compressive stress, ‘T’ indicates a tensile stress.
The loadcase description “Dead” refers to both dead and superimposed dead loading.
All loadcases are the critical cases that produce torsion of the suspended structure.

5.4.3 Bottom Lateral Bracing Main Members

The bottom lateral bracing is overstressed at panel points 1 to 3, 41 to 43 and 51 to 54. The extent of overstresses in the bottom lateral bracing members is significantly less than for the top laterals and occurs due to the dead and HA case only. The panel points at which the bottom bracing is overstressed are largely confined to the vicinity of the side and main towers. The critical overstress index of 1.23 was calculated at panel point one.

Under the application of BSALL the bottom lateral bracing is not overstressed.

5.4.4 Lateral Bracing Gusset Plates

The assessment found six panel points, at which the top lateral bracing gusset plates have overstress indices greater than 1.00 under the application of dead, wind and HA. The element with the maximum overstress index of 1.17 is located at the side tower and connects the top lateral bracing at panel point zero.

Under the application of BSALL and reduced wind based on 50mph wind speed the overstress index in the top lateral bracing gusset plate at panel point zero reduces to 0.66.

However it should be noted that the top lateral bracing gusset plate is also overstressed in the side span due to dead and wind load. Overstress index of 1.13 is confined to panel point zero adjacent to side tower.

No overstress indices greater than 1.00 were calculated in the bottom lateral bracing gusset plates for the load combinations which included dead and wind loads.

At the highest stressed locations the top lateral bracing is in compression and the bottom lateral bracing in tension.

5.4.5 Lateral Bracing Gusset Plate Bolts

The calculated overstress in the lateral bracing bolts did not exceed 1.00 at the ultimate limit state under any load combination.

However the lateral bracing bolts were found to be overstressed at the serviceability limit state where the bolts are required to act in friction. The maximum overstress index of 1.47 was calculated at panel point 48 due to the application of dead, wind and HA. The extent of overstressed bolts for the lateral bracing is detailed below.

- Top Lateral Bracing: Panel points 0-6, 36-44 and 46-64.
- Bottom Lateral Bracing: Panel points 1-3, 41-43, 47-55 and 75-79.

The application of the BSALL and reduced wind based on 50mph wind speed reduced the extent of the overstress in the bolts at the serviceability limit state to panel points 2 and 48 with the values of 1.05 and 1.02 respectively.

The bolts in the top lateral bracing have overstress indices greater than 1.00 at the serviceability limit state under the application of load combinations included dead and wind loads. A maximum overstress index was 1.26 at panel point 0. The bolts in the bottom lateral bracing were not overstressed under the application of dead and wind loading.

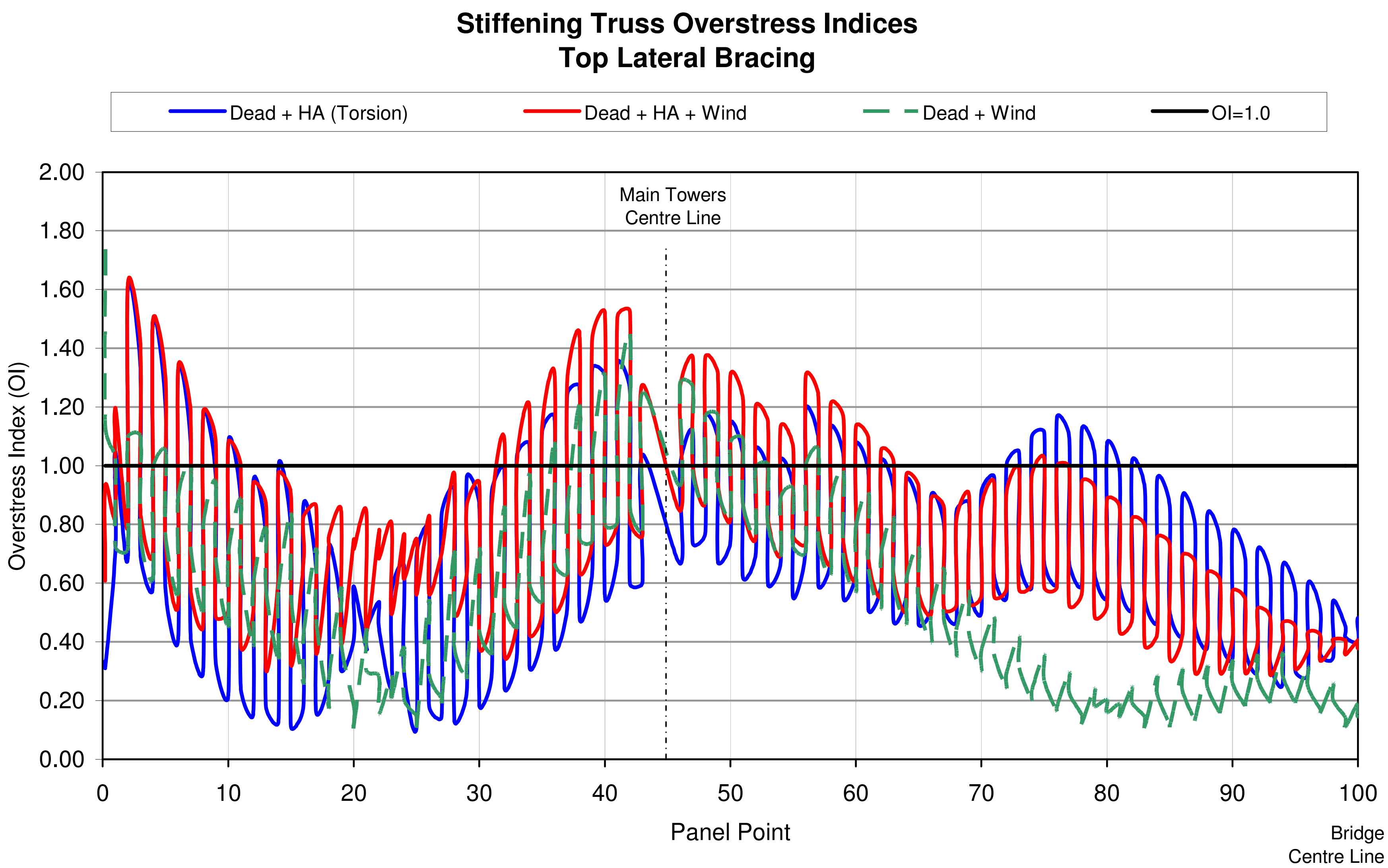

Figure 8 – Graph of Top Lateral Bracing Overstress Indices.

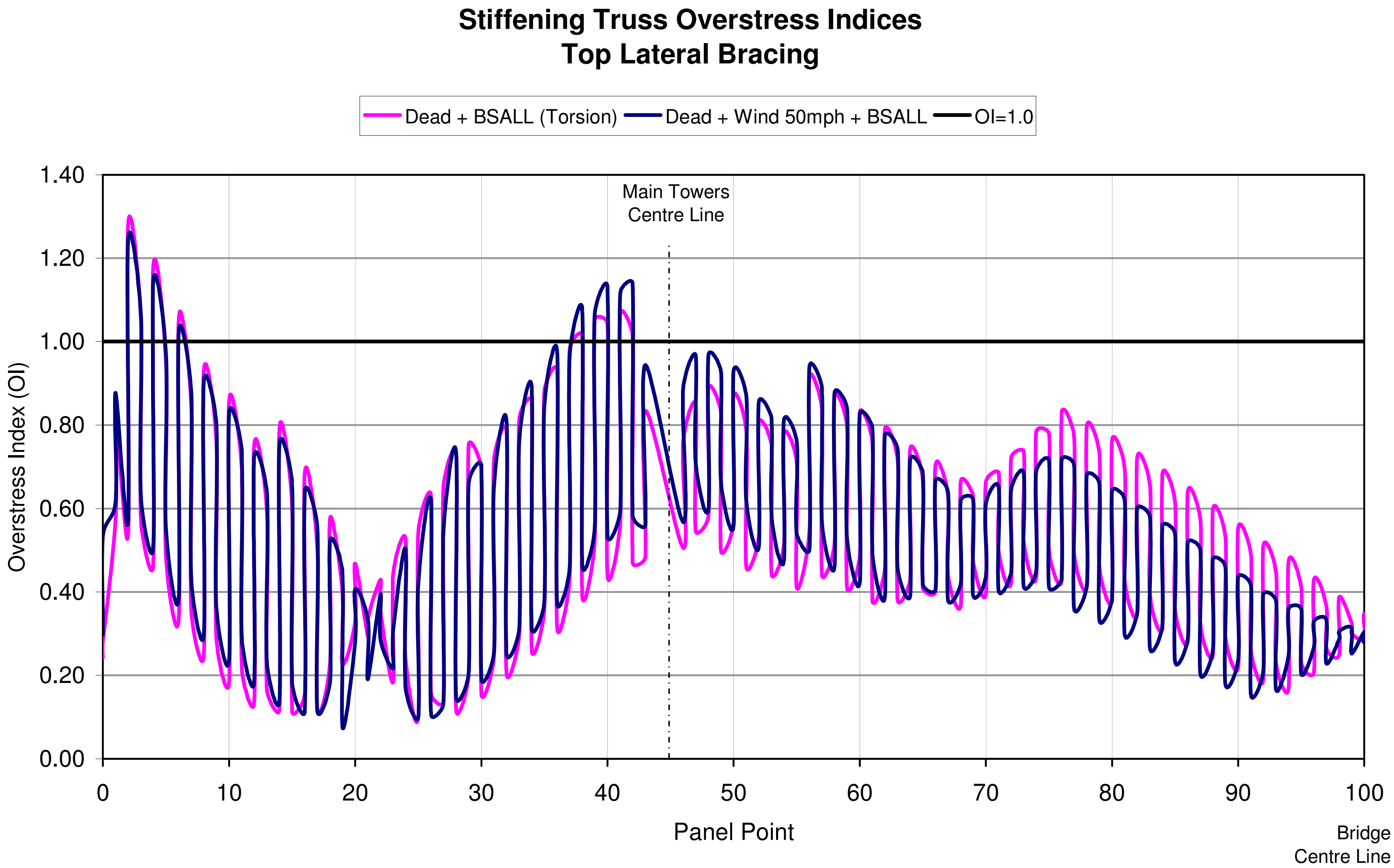

Figure 9 – Graph of Top Lateral Bracing Overstress Indices for Dead + BSALL.

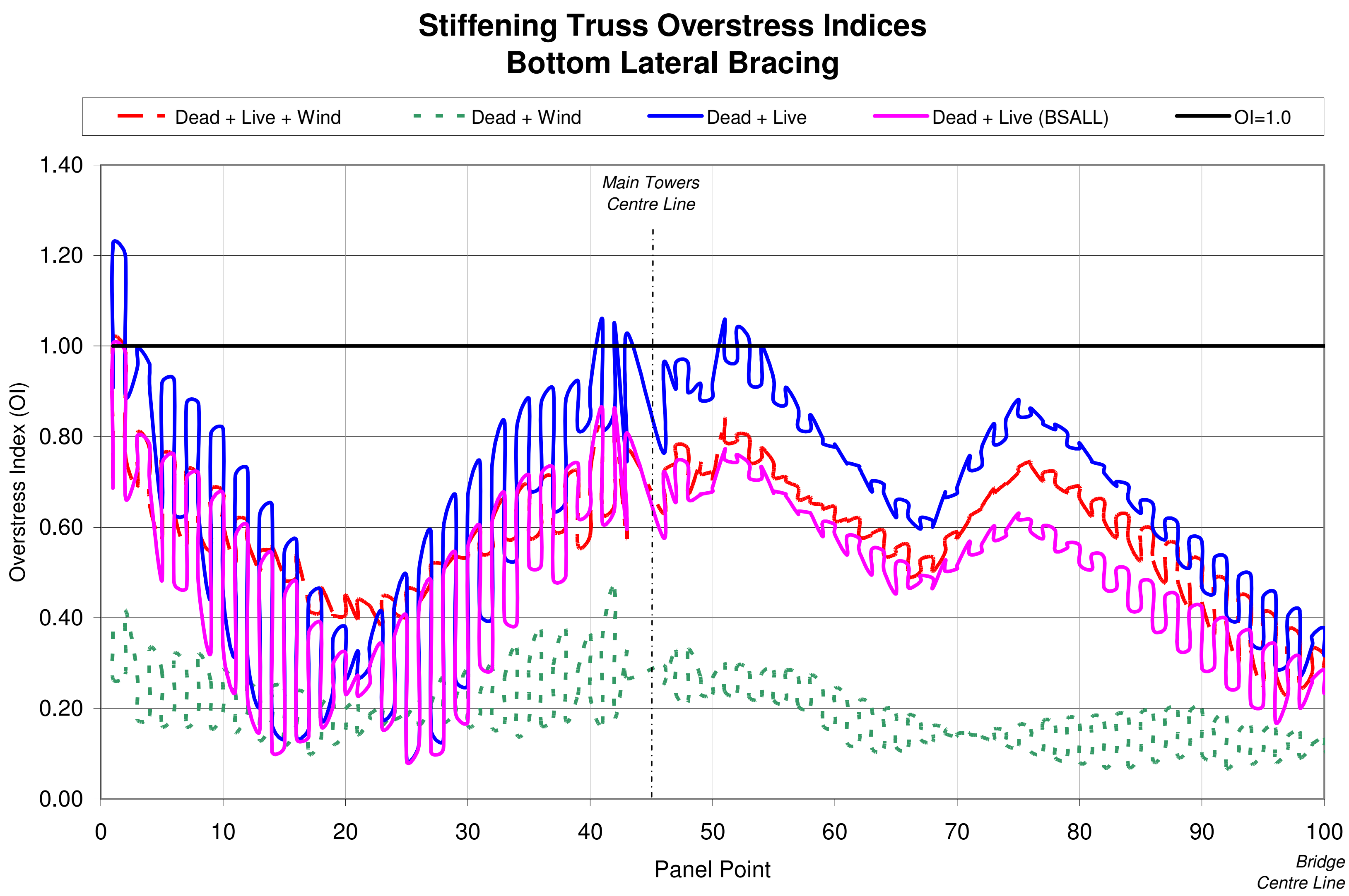

Figure 10 – Graph of Bottom Lateral Bracing Overstress Indices.

5.5 Cross Girders including Footway Brackets

5.5.1 General

The overstress indices for the cross girders including footway brackets are detailed in Appendix B. A summary of the critical overstress indices is provided in Table 7.

The critical load combinations for the cross girders were:

- Loading scenarios that induced torsion of the suspended structure produced the greatest stresses in the cross girders. The arrangement of HA loading for torque on the main span was such that a single carriageway was loaded for a length 330m from one main tower and the opposite carriageway loaded for a length of 200m from the opposite main tower. The total loaded length for the critical load combination was 530m. The arrangement of HA loading for torque on the side span consisted of a single carriageway loaded for the full span.

- Footway loading in combinations for the torque effects was applied in a similar manner to the HA or BSALL loading. Therefore a single footway adjacent to the loaded carriageway was loaded. This resulted in only a single footway being loaded at any section of the bridge. Loaded lengths for the footway loading were the same as the coexistent HA or BSALL.

- Load combinations incorporating HB or AIL (Abnormal Indivisible Load), i.e. Wynns Trailer configurations, were analysed. However these scenarios did not produce the maximum stresses in the cross girders.

- Load combinations comprising dead and wind load produced a small number of overstressed elements. The wind loading applied in these combinations consisted of the maximum wind load for bridges without live load applied to the span under consideration. The remaining spans were loaded with wind load calculated for locations that have a relieving effect on the element under consideration.

- Load combinations comprising dead, HA and wind loading were analysed. However these scenarios did not produce overstresses in the cross girders.

Cross Girder	Loadcase	Limit State	Stress Indices	Cross Girder / Member
Main members	Dead + Wind	ULS	1.26	CG 6 – Side span Panel Point 44
	Dead + HA	ULS	1.38	CG 1 – Side span Panel Point 1
	Dead + BSALL	ULS	1.125	
	Dead + HA	ULS	1.02	CG's 8 & 11 – Main span Panel Point 47
Splice & Gusset Plates	Dead + Wind	ULS	0.46	CG 6 – Side span Panel Point 44
	Dead + HA	ULS	1.33	Connecting cross girder to bottom chord
	Dead + BSALL	ULS	1.06	Connecting cross girder to bottom chord
Bolts	Dead + Wind	ULS SLS	0.22 0.28	CG 6 – Side span Panel Point 44
	Dead + HA	ULS SLS	0.66 1.49	CG 1 – Side span Panel Point 1
	Dead + BSALL	SLS	1.22	
	Dead + HA	ULS SLS	<1.00 <1.00	CG's 8 & 11 – Main span Panel Point 47

Notes: The loadcase description "Dead" refers to both dead and superimposed dead loading.

Table 7 – Cross Girder Summary of Overstress Indices

5.5.2 Cross Girders Main Members

The assessment found a total of four cross girders with overstressed members due to the application of the critical load combination of dead and HA. These cross girders are located at panel points 1 and 47, adjacent to the main and side towers.

The main span cross girders at panel point 47 have a single member, which is marginally overstressed at 1.02. This overstressed member forms part of the top chord box girder. The application of the BSALL results in the overstress indices for all main span cross girders main members reducing to less than 1.00.

The side span cross girder at panel point 1 was found to have only one member overstressed with an overstress index of 1.38. This overstressed member was a fabricated I section which is connected to the bottom chord of the stiffening trusses. The application of the BSALL reduces the overstress index in the critical member to 1.125.

The side span cross girder at panel point 44 has a single overstressed member as a result of the application of dead and wind load. The overstressed member forms part of the top chord box girder and has an overstress index of 1.26.

5.5.3 Cross Girder Splices and Gusset Plates

A single gusset plate located in the cross girder at panel point one on the side span was found to be overstressed with an overstress index of 1.33. The gusset plate attaches a diagonal cross girder member to the bottom chord of the stiffening truss.

The overstress index in the critical gusset plate reduces to 1.06 under the application of BSALL loading.

5.5.4 Cross Girder Splice and Gusset Plate Bolts

The overstress indices in the cross girder splice and gusset plate bolts were less than 1.00 at the ultimate limit state. However at the serviceability limit state where the bolts are required to act in friction two cross girders were found to have bolts which were overstressed. The critical cross girders at the serviceability limit state is located at panel points 1 on the side span. The gusset plate bolts for one member in each of the critical cross girders were overstressed.

The overstress index in the critical bolts at serviceability limit state for panel point one cross girder reduced to 1.22 when the BSALL was applied. No other overstresses were found in the cross girders.

6.0 ASSESSMENT SUMMARY

The suspended structure of the Forth Road Bridge was found to be overstressed under a variety of load combinations. The assessment load combinations can be grouped into the following distinct categories:

A. Dead and HA load.

B. Dead and wind load.

C. Dead, HA and wind load.

D. Dead and BSALL.

E. Dead, BSALL and 50 mph wind.

The extent and degree of overstress in the suspended structure due to load combinations A and C is detailed in section 5.0 of this report. The percentage of elements overstressed is summarised in Table 8.

Table 8 – Percentage of elements overstressed due to load combination categories A and C.

Element	**Main Plates**	**Splice / Gusset Plates**	**Bolts**
Top Chords	88 %	90 %	73 % (SLS)
Bottom Chords	86 %	94 %	57 % (SLS)
Diagonals	3 % (ULS) 1 % (SLS)	1 %	1 % (SLS)
Verticals	0 %	0 %	0 %
Top Lateral Bracing	23 %	3 %	23 % (SLS)
Bottom Lateral Bracing	4 %	1 %	10 % (SLS)
Cross Girders	2 %	1 %	1 % (SLS)

Notes : 1. ULS and SLS refer to ultimate and serviceability limit states respectively.
2. Unless noted otherwise the percentage relates to the ULS overstresses.

The extent and degree of overstress in the suspended structure due to load combinations B, D and E is detailed in section 5.0 of this report. Load combinations which can be categorised as B, D and E represent the operational restrictions imposed by FETA. The percentage of elements overstressed is summarised in Table 9.

Table 9 – Percentage of elements overstressed due to load combination categories B, D and E.

Element	**Main Plates**	**Splice / Gusset Plates**	**Bolts**
Top Chords	46 %	82 %	71 % (SLS)
Bottom Chords	75 %	63 %	39 % (SLS)
Diagonals	1 %	0 %	0 %
Verticals	0 %	0 %	0 %
Top Lateral Bracing	12 %	0.5 %	5.5 % (SLS)
Bottom Lateral Bracing	1 %	0 %	3 % (SLS)
Cross Girders	2 %	1 %	1 % (SLS)

Notes : 1. ULS and SLS refer to ultimate and serviceability limit states respectively.
2. Unless noted otherwise the percentage relates to the ULS overstresses.

Table 10 summarises the extent of overstressed elements due to load combination B only.

Table 10 – Percentage of elements overstressed due to load combination category B.

Element	**Main Plates**	**Splice / Gusset Plates**	**Bolts**
Top Chords	44 %	82 %	71 % (SLS)
Bottom Chords	75 %	45 %	39 % (SLS)
Diagonals	0 %	0 %	0 %
Verticals	0 %	0 %	0 %
Top Lateral Bracing	11 %	0.5 %	5 % (SLS)
Bottom Lateral Bracing	0 %	0 %	0 % (SLS)
Cross Girders	1 %	0 %	0 % (SLS)

Notes : 1. ULS and SLS refer to ultimate and serviceability limit states respectively.
2. Unless noted otherwise the percentage relates to the ULS overstresses.

It can be seen from table 9 that a significant portion of the chords of the stiffening trusses are overstressed under operational loading. However overstresses in the remaining elements forming the trusses and cross girders are limited. Table 10 demonstrates that a significant portion of the stiffening truss chords are overstressed due to dead load and maximum wind loading only.

APPENDIX A – Panel Point Locations

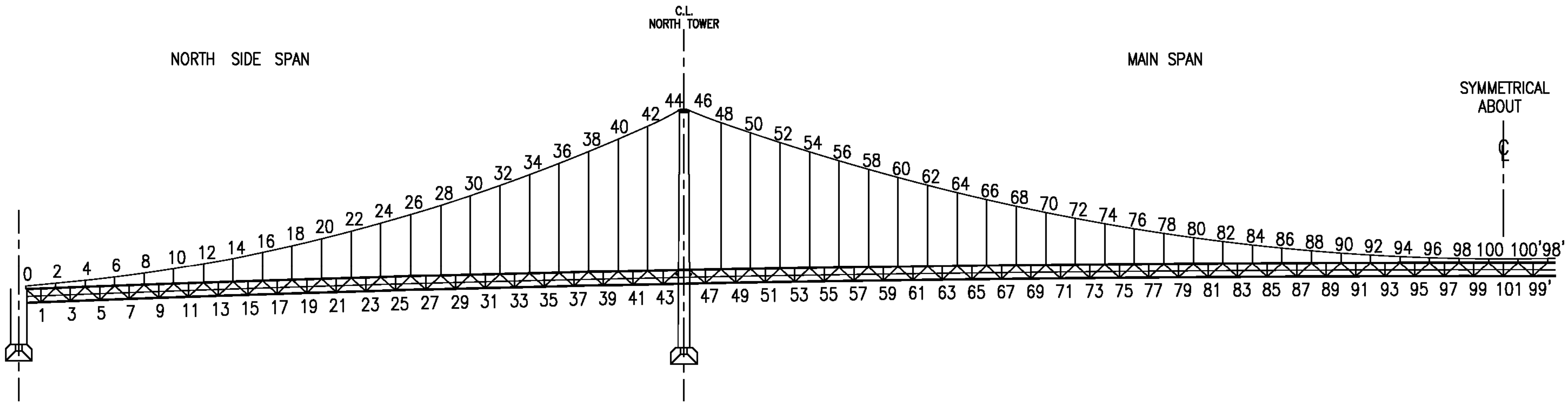

Figure 11 – Panel Point Numbers.

APPENDIX B – Tabulated Overstress Indices

TABLE B.1 –OVERSTRESS INDICES IN TOP CHORD AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point						Peak OI		
	Side Span			Main Span					
	8	22	36	52	70	100	OI	Panel Point	Compressive/ Tensile
Dead + HA Live Load	1.35	1.36	1.22	1.12	1.1	1.09	1.46	10	Compressive
Dead + Wind Load	0.64	0.9	0.65	0.74	1.12	1.18	1.24	94	Compressive
Dead + HA Live + Wind Load	1.34	1.54	1.22	1.23	1.33	1.39	1.54	22	Compressive
Dead + HA Live + Wind Load (Reversal Case)	0.34	0.48	0.41	–	–	–	0.48	22	Compressive
Dead + BSALL + Reduced Wind Load	0.84	0.96	0.77	0.84	0.91	0.98	1.04	60	Compressive
Dead + BSALL Load	–	–	–	–	–	–	1.03	10	Compressive
Bolts:- Dead + HA Live + Wind Load	–	–	–	–	–	–	0.59	22	–
Splice Plates:- Dead + HA Live + Wind Load	–	–	–	–	–	–	1.62	20	Compressive
Splice Plates:- Dead + BSALL + Reduced Wind Load	–	–	–	–	–	–	1.04	20	Compressive
Splice Plates:- Dead + Wind Load	–	–	–	–	–	–	1.75	78	Tensile
Gusset Plates:- Dead + HA Live + Wind	See note below			See note below			See note below		

Note : The gusset plates are overstressed when the main chord member is overstressed. However the extent of this overstress is limited to an area local to the interface with the main member plates. The stress in the gusset plate reduces as the gusset plate has a tapered increases in depth from the interface.
The loadcase description "Dead" refers to both dead and superimposed dead loading.

TABLE B.2 - OVERSTRESS INDICES IN BOTTOM CHORD AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point						Peak OI		
	Side Span			Main Span			OI	Panel Point	Compressive/ Tensile
	7	23	37	53	71	101			
Dead + HA Live Load	1.19	1.37	1.14	1.12	1.1	0.99	1.43	14	Tensile
Dead + Wind Load	0.81	1.3	1	0.99	1.24	1.25	1.34	70	Compressive
Dead + HA Live + Wind Load	1.09	1.39	1	1.17	1.22	1.13	1.47	21	Tensile
Dead + HA Live + Wind Load (Reversal Case)	0.5	0.76	0.62	–	–	–	0.76	23	Compressive
Dead + BSALL + Reduced Wind Load	0.69	0.88	0.64	0.79	0.81	0.77	0.91	21	Tensile
Dead + BSALL Load	–	–	–	–	–	–	1.02	14	Tensile
Bolts:- Dead + HA Live + Wind Load	–	–	–	–	–	–	0.65	21	–
Splice Plates:- Dead + HA Live + Wind Load	–	–	–	–	–	–	1.8	21	Tensile
Splice Plates:- Dead + BSALL + Reduced Wind Load	–	–	–	–	–	–	1.16	21	Tensile
Splice Plates:- Dead + Wind Load	–	–	–	–	–	–	1.46	77	Tensile
Gusset Plates:- Dead + HA Live + Wind	See note below			See note below			See note below		

Note : The gusset plates are overstressed when the main chord member is overstressed. However the extent of this overstress is limited to an area local to the interface with the main member plates. The stress in the gusset plate reduces as the gusset plate has a tapered increases in depth from the interface.
The loadcase description "Dead" refers to both dead and superimposed dead loading.

TABLE B.3 – OVERSTRESS INDICES IN DIAGONALS AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point				Peak OI	
	Side Span		Main Span			
	22	44	46	101	OI	Panel Point
Dead + Wind Load:						
Tensile Force	0.28	0.18	0.3	0.3	0.49	58
Compressive Force		0.29	0.31	0.24	0.51	50
Dead + HA Live Load, Maximum Shear:						
Tensile Force	–	0.92	1.01		1.05	0
Compressive Force	0.6			0.9	1.13	47
Dead + HA Live Load, Maximum Torsion:						
Tensile Force	0.25	0.85	0.92	0.33	1.29	0
Compressive Force	–			–	1.05	47
Dead + BSALL, Maximum Torsion:						
Tensile Force	–	–	–	–	1.02	0
Bolts:- Dead + HA Live Load	–	–	–	–	0.55	0
Gusset Plates:- Dead + HA Live Load, Max. Torsion	–	–	–	–	1.2	0
Gusset Plates:- Dead + BSALL, Max. Torsion	–	–	–	–	0.95	0

Note: The loadcase description "Dead" refers to both dead and superimposed dead loading.

FAIRHURST

TABLE B.4 – OVERSTRESS INDICES IN VERTICALS AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point				Peak OI	
	Side Span		Main Span			
	22	44	46	101	OI	Panel Point
Dead + Wind Load						
Tensile Force	–	–	–	–	–	–
Compressive Force	0.3	0.17	0.09	0.08	0.36	100
Dead + HA Live Load, Maximum Shear:						
Tensile Force	–	0.8	0.25	–	0.8	44
Compressive Force	0.65	–	–	0.27	0.65	22
Dead + HA Live Load, Maximum Torsion:						
Tensile Force	–	0.96	–	–	0.96	44
Compressive Force	0.46	–	0.51	0.21	0.52	43
Dead + BSALL, Maximum Torsion:						
Tensile Force	–	–	–	–	0.78	44
Bolts:- Dead + HA Live Load	–	–	–	–	<1.00	

Note: The loadcase description "Dead" refers to both dead and superimposed dead loading.

TABLE B.5 – OVERSTRESS INDICES IN TOP LATERALS AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point				Peak OI	
	Side Span		Main Span			
	22	44	46	101	OI	Panel Point
Dead + Wind Load:						
Tensile Force	0.15	0.78	0.93	0.14	0.98	47
Compressive Force	0.28	1.25	1.28	0.19	1.74	0
Dead + HA Live Load, Maximum Torsion:						
Tensile Force	–	0.6	0.67	0.17	0.77	49
Compressive Force	0.54	1.04	1	0.48	1.6	2
Dead + BSALL, Maximum Torsion:						
Compressive Force	–	–	–	–	1.28	2
Dead + Wind + HA Live Load						
Tensile Force		0.76	0.85		0.93	0
Compressive Force	0.77	1.28	1.27	0.4	1.62	2
Dead + BSALL + 50mph Wind:						
Compressive Force	–	–	–	–	1.24	2
Bolts:- Dead + Wind + HA Live Load, Max Torsion:	–	–	–	–	0.84	48
Gussets:- Dead + Wind + HA Live Load, Max Torsion:	–	–	–	–	1.17	0

Note: The loadcase description “Dead” refers to both dead and superimposed dead loading.

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TABLE B.6 – OVERSTRESS INDICES IN BOTTOM LATERALS AT THE ULTIMATE LIMIT STATE

Load Combination	Panel Point				Peak OI	
	Side Span		Main Span			
	22	44	46	101	OI	Panel Point
Dead + Wind Load:						
Tensile Force	0.19	0.27	0.25	0.13	0.46	42
Compressive Force	–	0.33	0.3	–	0.33	44
Dead + HA Live Load, Maximum Torsion:						
Tensile Force	0.35	0.74	0.76	0.38	1.23	1
Compressive Force	–	1.03	0.96	0.18	1.06	51
Dead + BSALL, Maximum Torsion:						
Tensile Force	–	–	–	–	1	1
Dead + Wind + HA Live Load						
Tensile Force	0.43			–	1.02	1
Compressive Force	–	0.77	0.72	0.32	0.77	44
Bolts:- Dead + HA Live Load, Max Torsion:	–	–	–	–	0.86	1
Gussets:- Dead + HA Live Load, Max Torsion:	–	–	–	–	1.01	1

Note: The loadcase description “Dead” refers to both dead and superimposed dead loading.

TABLE B.7a – OVERSTRESS INDICES IN THE CRITICAL CROSS GIRDERS AT THE ULTIMATE LIMIT STATE

Main Span				Side Span			
Cross Girder Type 8 & 11				Cross Girder Type 1			
Member	**OI**	**Load Effect**	**Location**	**Member**	**OI**	**Load Effect**	**Location**
M1a	0.237	T	FB Top Chord	**S19a**	0.702	T	FB Top Chord
M1b	0.237	T	FB Top Chord	**S19b**	0.702	T	FB Top Chord
M1c	0.237	T	FB Top Chord	**S19c**	0.702	T	FB Top Chord
M1d	0.473	C	FB Bottom Chord	**S2a**	0.538	C	FB Bottom Chord
M1e	0.473	C	FB Bottom Chord	**S2b**	0.538	C	FB Bottom Chord
M1f	0.473	C	FB Bottom Chord	**S2c**	0.538	C	FB Bottom Chord
M2a	0.004	T	FB Diagonal	**S3a**	0.009	T	FB Diagonal
M2b	0.025	C	FB Diagonal	**S3b**	0.04	C	FB Diagonal
M2c	0.045	T	FB Diagonal	**S3c**	0.037	T	FB Diagonal
M2d	0.33	C	FB Diagonal	**S3d**	0.288	C	FB Diagonal
M18	0.299	T	MCG Top Box Section	**S4**	0.492	C	MCG Top Box Section
M19	1.019	C	MCG Top Box Section	**S5**	0.713	C	MCG Top Box Section
M20	1.012	C	MCG Top Box Section	**S6**	0.646	C	MCG Top Box Section
M21	0.635	C	MCG Top Box Section	**S7**	0.725	C	MCG Top Box Section
M22	0.7	C	MCG Top Box Section	**S8**	0.468	C	MCG Top Box Section
M23	0.249	C	MCG Top Box Section	**S9**	0.52	C	MCG Diagonals
M24	0.674	C	MCG Diagonal to BC	**S10**	0.298	T	MCG Diagonals
M25	0.201	T	MCG Diagonals	**S11**	0.17	C	MCG Diagonals
M26a	0.252	C	MCG Diagonals	**S12a**	0.692	C	MCG Diagonals
M27a	0.46	C	MCG Diagonals	**S12b**	0.47	C	MCG Diagonals
M28a	0.117	T	MCG Diagonals	**S13**	1.38	C	MCG Diagonal to BC
M29a	0.09	T	MCG Diagonal to Centre	**S14**	0.369	T	MCG Diagonal to Centre

Abbreviations:

Members : FB – Footway Bracket
MCG – Main Cross Girder
BC – Bottom Chord
Load Effect : C – Compression
T – Tension

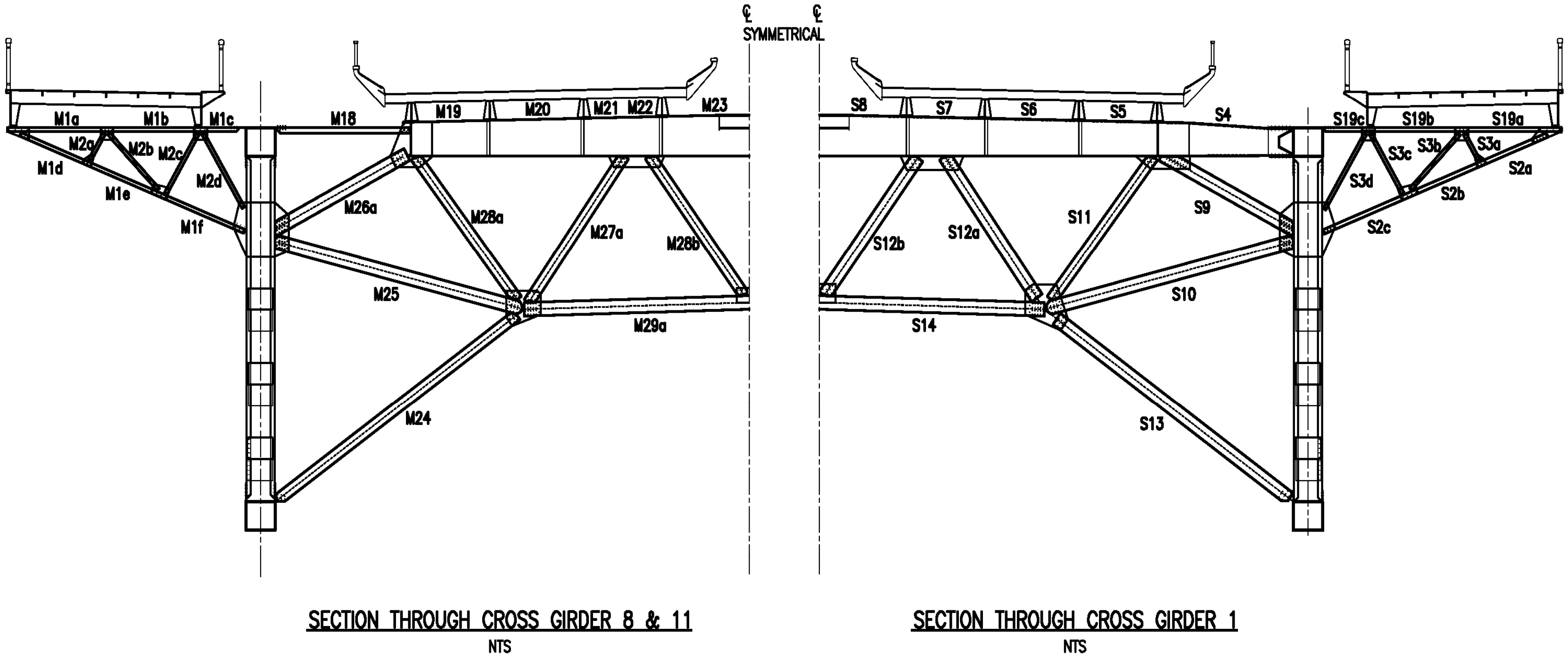

Figure 12 – Cross Girder member references for Types 1, 8 & 11.

TABLE B.7b – OVERSTRESS INDICES IN THE CRITICAL CROSS GIRDERS AT THE ULTIMATE LIMIT STATE FOR DEAD + WIND LOAD

Main Span				Side Span			
Cross Girder Type 7				Cross Girder Type 6			
Member	**OI**	**Load Effect**	**Location**	**Member**	**OI**	**Load Effect**	**Location**
M1a	0.101	T	FB Top Chord	**S19a**	0.219	T	FB Top Chord
M1b	0.101	T	FB Top Chord	**S19b**	0.219	T	FB Top Chord
M1c	0.101	T	FB Top Chord	**S19c**	0.219	T	FB Top Chord
M1d	0.116	C	FB Bottom Chord	**S2a**	0.068	C	FB Bottom Chord
M1e	0.116	C	FB Bottom Chord	**S2b**	0.068	C	FB Bottom Chord
M1f	0.116	C	FB Bottom Chord	**S2c**	0.068	C	FB Bottom Chord
M2a	0.002	T	FB Diagonal	**S3a**	0.005	T	FB Diagonal
M2b	0.015	C	FB Diagonal	**S3b**	0.018	C	FB Diagonal
M2c	0.012	T	FB Diagonal	**S3c**	0.230	T	FB Diagonal
M2d	0.066	C	FB Diagonal	**S3d**	0.058	C	FB Diagonal
M3	0.765	C	MCG Top Box Section	**S20**	1.256	C	MCG Top Box Section
M4	0.712	C	MCG Top Box Section	**S21**	1.256	C	MCG Top Box Section
M5	0.881	C	MCG Top Box Section	**S22**	0.883	C	MCG Top Box Section
M6	0.899	C	MCG Top Box Section	**S23**	0.820	C	MCG Top Box Section
M7	0.899	C	MCG Top Box Section	**S24**	0.820	C	MCG Top Box Section
M8	0.879	C	MCG Top Box Section	**S25**	0.776	C	MCG Top Box Section
M9	0.879	C	MCG Top Box Section	**S26**	0.776	C	MCG Top Box Section
M10	0.643	C	MCG Top Box Section	**S27**	0.911	C	MCG Top Box Section
M11	0.057	C	MCG Top Box Section	**S28**	0.063	C	MCG Top Box Section
M12	0.238	C	MCG Diagonals	**S29**	0.468	C	MCG Diagonals
M13	0.383	C	MCG Diagonals	**S30a**	0.369	T	MCG Diagonals
M14a	0.314	C	MCG Diagonals	**S30b**	0.345	C	MCG Diagonals
M15	0.184	T	MCG Diagonals	**S31a**	0.276	T	MCG Diagonals
M14b	0.260	C	MCG Diagonal to Centre	**S31b**	0.227	T	MCG Diagonal to Centre
M16	0.353	T	MCG Diagonal to Centre	**S30c**	0.239	C	MCG Diagonal to Centre
M17	0.128	C	MCG Vertical	**S32**	0.081	C	MCG Vertical

Abbreviations:

Members : FB – Footway Bracket
MCG – Main Cross Girder
BC – Bottom Chord
Load Effect : C – Compression
T – Tension

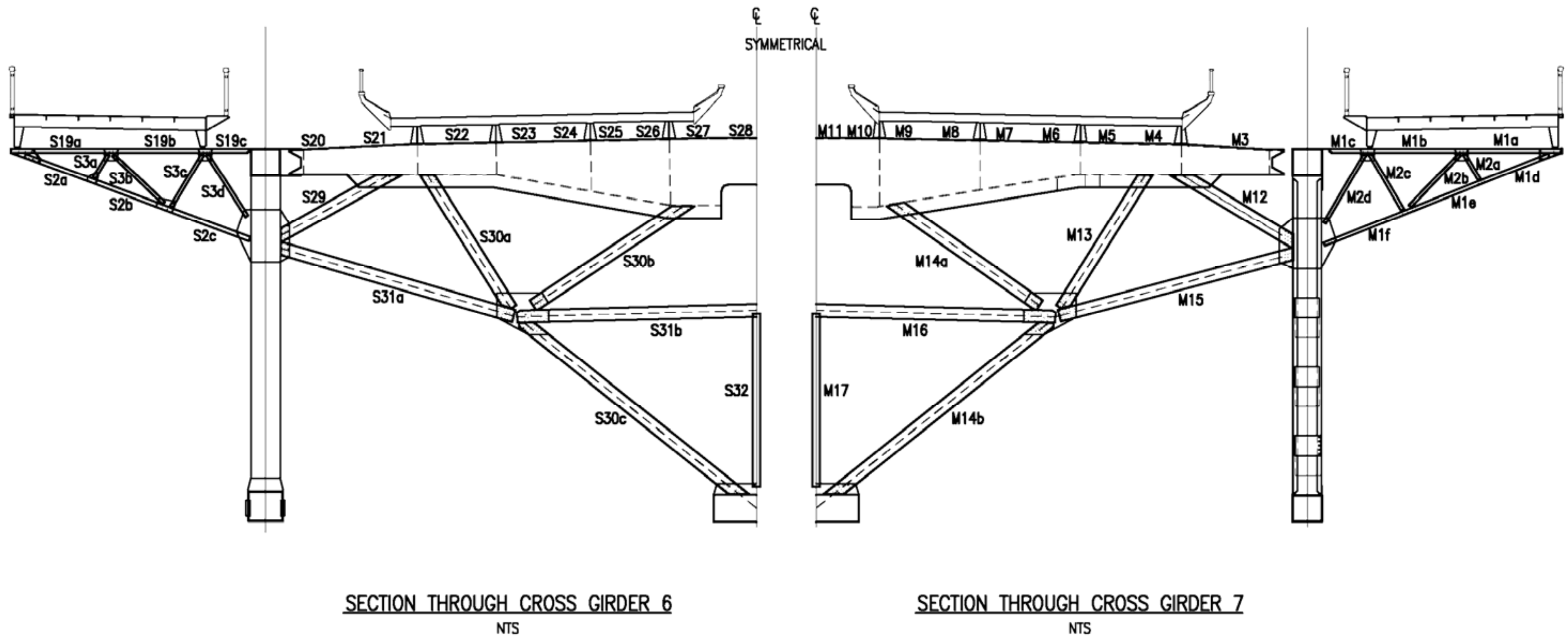

Figure 13 – Cross Girder member references for Types 6 & 7.

TABLE B.8 – SERVICEABILITY LIMIT STATE SUMMARY

Member	Location	Critical Loadcase	Panel Points OI > 1.00	Peak OI (Panel Point)	OI due to Dead + Wind only
Vertical Member:-	Sidespan	Dead + HA Live Loading (Torsion)		0.66 (pp 44)	0.26 (pp 100)
Diagonal Member:-	Sidespan	Dead + HA Live Loading (Torsion)		0.88 (pp 0)	0.37 (pp 50)
Top Chord Bolts:-	Sidespan	Dead + HA Live Loading	4 - 10	1.86 (pp 10)	1.16 (pp 10)
	Sidespan	Dead + HA Live + Wind Loading	12 - 38	2.12 (pp 22)	1.43 (pp 22)
	Mainspan	Dead + HA Live + Wind Loading	48 - 64	1.74 (pp 62)	1.18 (pp 62)
	Mainspan	Dead + HA Live + Wind Loading	66 - 78	1.75 (pp 68)	1.41 (pp 76)
	Mainspan	Dead + Wind Loading	80 - 100	1.41 (pp 80)	1.41 (pp 80)
Bottom Chord Bolts:-	Sidespan	Dead + HA Live Loading	7 - 13	1.44 (pp 13)	0.82 (pp 13)
	Sidespan	Dead + HA Live + Wind Loading	15 - 35	1.55 (pp 21)	0.94 (pp 21)
	Mainspan	Dead + HA Live + Wind Loading	53 - 65	1.33 (pp 61)	1.02 (pp 63)
	Mainspan	Dead + HA Live + Wind Loading	67 - 77	1.33 (pp 69)	1.09 (pp 69)
	Mainspan	Dead + Wind Loading	79 - 101	1.12 (pp 89)	1.12 (pp 89)
Diagonal Bolts:-	Sidespan	Dead + HA Live Loading (Torsion)	0	1.2	< 1.00
Top Lateral Bolts:-	Sidespan	Dead + HA Live + Wind Loading	0-6	1.38 (pp 2)	1.26 (pp 0)
	Sidespan	Dead + HA Live + Wind Loading	36-44	1.28 (pp42)	1.07 (pp42)
	Mainspan	Dead + HA Live + Wind Loading	47-55	1.47 (pp 48)	1.12 (pp 48)
Bottom Lateral Bolts:-	Sidespan	Dead + HA Live Loading (Torsion)	1 - 7, 37- 42	1.31 (pp 1)	< 1.00
	Mainspan	Dead + HA Live Loading (Torsion)	47 - 59	1.29 (pp 51)	< 1.00

Note: The loadcase description "Dead" refers to both dead and superimposed dead loading.