Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia
e il Continente Organismo di Diritto Pubblico
(Legge n° 1158 del 17 dicembre 1971, modificata dal D.Lgs. n°114 del 24 aprile 2003)

EurolinK

PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

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IMPREGILO S.p.A. (MANDATARIA)
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PS0016_F0

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Tipo di sistema	SOVRASTRUTTURE
Raggruppamento di opere/attività	TORRI
Opera - tratto d'opera - parte d'opera	General
Titolo del documento	Design Report – Cross Beams, Annex

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REV	DATA	DESCRIZIONE	REDATTO	VERIFICATO	APPROVATO
F0	20/06/2011	EMISSIONE FINALE	MJK	JJL	CHSX/LSJ

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INDICE

1 Introduction

This report presents design calculations for the tower cross beams.

The design is based on that shown in the Tender Design.

In this project phase it was found advantageous to introduce the following changes to the tender design:

- Flat plate longitudinal stiffeners on the flanges and webs replace the T-shaped longitudinal stiffeners; and
- Braced frames replace the moment resisting frame transverse stiffening..

Calculations are typically based on the global IBDAS model version 3.3f.

1.1 Outline

This report is organized into the following sections:

- Section 1 includes this introduction and outline;
- Section 2 provides a list of reference materials, including design specifications, design codes, reference drawings and complementary reports;
- Section 3 provides details of the materials used in the cross beam design;
- Section 4 provides a reference to the reports describing the design principles used in the tower design;
- Section 5 provides design calculations for the cross beam components. To allow for easy cross referencing between tower design reports, the calculations are presented in the same order as the components are described in CG.10.00-P-RX-D-P-SV-T4-00-00-00-00-01 “Specialist Technical Design Report, Towers.”

2 Design References

2.1 Design Specifications

CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02 - “Design Basis, Structural, Annex,” COWI 2010

GCG.F.05.03 “Design Development – Requirements and Guidelines,” Stretto di Messina, 2004 October 22.

GCG.G.03.02 “Structural Steel Works and Protective Coatings,” Stretto di Messina, 2004 July 30.

2.2 Design Codes

“Norme tecniche per le costruzioni,” 2008 (NTC08).

EN 1991 Eurocode 1: Actions on Structures – Part 2: Traffic loads on bridges

EN 1993 Eurocode 3: Design of Steel Structures – Part 1-1: General rules and rules for buildings

EN 1993 Eurocode 3: Design of Steel Structures – Part 1-5: Plated structural elements

EN 1993 Eurocode 3: Design of Steel Structures – Part 1-8: Design of joints

EN 1993 Eurocode 3: Design of Steel Structures – Part 1-9: Fatigue

EN 1993 Eurocode 3: Design of Steel Structures – Part 2: Steel Bridges

Rete Ferroviaria Italia - Istruzione No. 44F “Verifiche a fatica dei ponti ferroviari”

2.3 Drawings

The reference tower design drawings for this report are listed in Table 2-1.

Drawing Title	Drawing Number
Tower Sicilia - General Arrangement	CG.10.00-P-AX-D-P-SV-T4-TS-00-00-00-01_0
Typical - Leg - Cross Section & Vertical Joints	CG.10.00-P-WX-D-P-SV-T4-TO-00-00-00-01_0
Tower Sicilia - Leg - Sections & Plate Thicknesses	CG.10.00-P-WX-D-P-SV-T4-TS-00-00-00-01_0
Typical - Leg - Cross Diaphragms	CG.10.00-P-AX-D-P-SV-T4-TO-00-D0-00-01_0
Typical - Leg - Cross Diaphragms, Details	CG.10.00-P-BX-D-P-SV-T4-TO-00-D0-00-01_0

Typical - Leg - Horizontal Joints	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-01_0
Typical - Leg - Horizontal Joints, Details	CG.10.00-P-BX-D-P-SV-T4-TO-00-00-00-01_0
Typical - Cross Beam no. 1	CG.10.00-P-AX-D-P-SV-T4-TO-T0-00-00-01_0
Typical - Cross Beam no. 2	CG.10.00-P-AX-D-P-SV-T4-TO-T0-00-00-02_0
Typical - Cross Beam no. 3	CG.10.00-P-AX-D-P-SV-T4-TO-T0-00-00-03_0
Typical - Cross Beams - Details	CG.10.00-P-BX-D-P-SV-T4-TO-T0-00-00-01_0
Typical - Cross Beam Connection to Tower leg	CG.10.00-P-WX-D-P-SV-T4-TO-T0-00-00-02_0
Typical - Connection from Girder	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-03_0
Typical - Base Section 1	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-04_0
Typical - Base Section 2	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-05_0
Typical - Base Section, Details	CG.10.00-P-BX-D-P-SV-T4-TO-00-00-00-02_0
Typical - Top Section	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-06_0
Typical - Tuned Mass Dampers - Support Structure	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-07_0
Typical - Tuned Mass Dampers	CG.10.00-P-AX-D-P-SV-T4-TO-00-00-00-08_0
Typical - Leg - Steelwork Modifications 1	CG.10.00-P-BX-D-P-SV-T4-TO-00-00-00-04_0
Typical - Leg - Steelwork Modifications 2	CG.10.00-P-BX-D-P-SV-T4-TO-00-00-00-05_0
Typical - Cross Beams - Steelwork Modifications	CG.10.00-P-BX-D-P-SV-T4-TO-T0-00-00-06_0
Tower Calabria - General Arrangement	CG.10.00-P-AX-D-P-SV-T4-TC-00-00-00-01_0
Tower Calabria - Leg - Sections & Plate Thicknesses	CG.10.00-P-WX-D-P-SV-T4-TC-00-00-00-01_0

Table 2-1: Reference tower drawings.

2.3.1 Complementary Reports

The tower design reports listed in Table 2-2 provide supplementary information about the tower design principles and verifications.

Report Title	Report Number
Specialist Technical Design Report, Towers	CG.10.00-P-RX-D-P-SV-T4-00-00-00-00-01
General Design Principles	CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01
Design Report – Tower Legs	CG.10.00-P-CL-D-P-SV-T4-00-00-00-00-01
Design Report - Tower Base	CG.10.00-P-CL-D-P-SV-T4-00-00-00-00-03

Table 2-2: Reference tower design reports.

3 Materials

The mechanical properties of the tower construction materials are described in this section.

3.1 Structural Steel

Tower structural components are generally fabricated from Grade S460 ML structural steel with the exception of: the hot-rolled circular hollow sections comprising the cross beam internal bracing members, the tower base plate and the base anchorage stiffening plates, which are fabricated from Grade S355 ML structural steel. All structural steels shall be produced in accordance with EN 10025-4. The steels are assumed to have the minimum mechanical properties listed in Table 3-1, in accordance with NTC08 Section 11.3.4.1. As an exception to the standard requirements of NTC08 and EN 10025-4 the mechanical properties of the steel shall not vary with material thickness for thicknesses up to 110 mm for S460ML steel and up to 150 mm for S355ML steel. The feasibility of the production of steel with the required properties has been confirmed.

Grade	Yield Strength, f_{yk} (MPa)	Tensile Strength, f_{tk} (MPa)
S 355 ML	355	470
S 460 ML	460	540

Table 3-1: Structural steel mechanical properties for thicknesses up to 110 mm for S460ML steel and up to 150 mm for S355ML steel.

All structural steel is also assumed to have the following properties, in accordance with NTC08 Section 11.3.4.1:

- Elastic modulus: $E = 210{,}000$ MPa
- Poisson's ratio: $\nu = 0.3$

- Shear modulus: $G = 80{,}770$ MPa
- Coefficient of thermal expansion: $\alpha = 12 \times 10^{-6} / °C$
- Density: $\rho = 7{,}850$ kg/m^3

The material partial factors (safety coefficients) used to verify structural steel elements are in accordance with NTC08 Sections 4.2.4.1.1, 4.2.4.1.4 and are listed in Table 3-2.

Verification	Partial Factor
Resistance of Class 1, 2, 3 and 4 sections	$\gamma_{M0} = 1.05$
Resistance to instability of members in road and rail bridges	$\gamma_{M1} = 1.10$
Resistance to fracture of sections under tension (weakened by holes)	$\gamma_{M2} = 1.25$
Fatigue resistance (useful fatigue life criterion with significant failure consequences)	$\gamma_{mf} = 1.35$

Table 3-2: Material partial factors for structural steel.

3.2 Welding Consumables

Welding consumables shall comply with the requirements of EN 1993-1-8 Section 4.2.

Welding procedures shall be selected so as to not reduce the properties of the thermo-mechanically processed plates.

The material partial factor, $\gamma_{M2} = 1.25$, used to verify welded connections and splices is in accordance with NTC08 Section 4.2.8.1.1.

4 Design Principles

The design principles are primarily described in CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01 "General Design Principles."

Summaries and discussions of verification results are provided in CG.10.00-P-RX-D-P-SV-T4-00-00-00-00-01 "Specialist Technical Design Report, Towers."

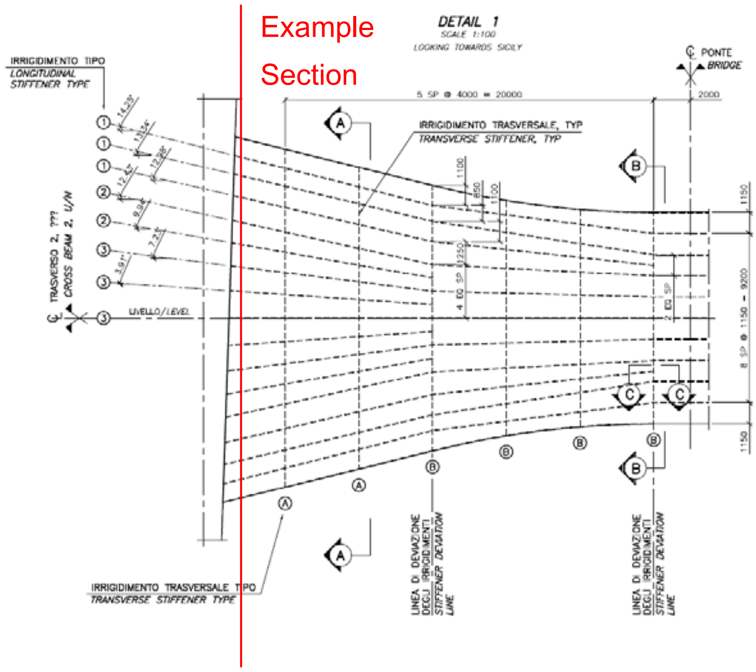
5 Cross Beams

5.1 Longitudinal Elements

5.1.1 Introduction

The design of the longitudinal steel in the cross beams is based on EN 1993-1-5 and EN 1993-1-1, as described in CG.10.00-P-RX-D-P-SV-T4-00-00-00-00-01 “Specialist Technical Design Report, Towers.”. The materials, limit states and design procedure for the longitudinal steel in the cross beams is described in CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01 “General Design Principles” and in the preceding sections. The following provides a further description of the design procedure for the cross beams by means of sample calculations for a typical cross beam section. A summary of maximum utilization ratios is also presented for all sections within the three cross beams.

The following sample calculations pertain to the end of cross beam 2 for the Sicilia Tower. The following figures illustrate the location of the section and the relevant plate dimensions.



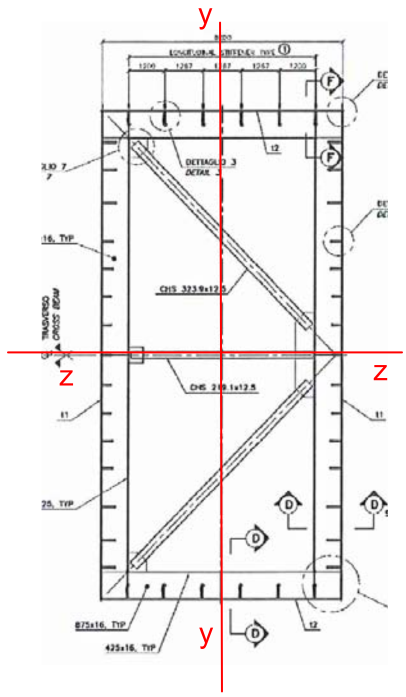
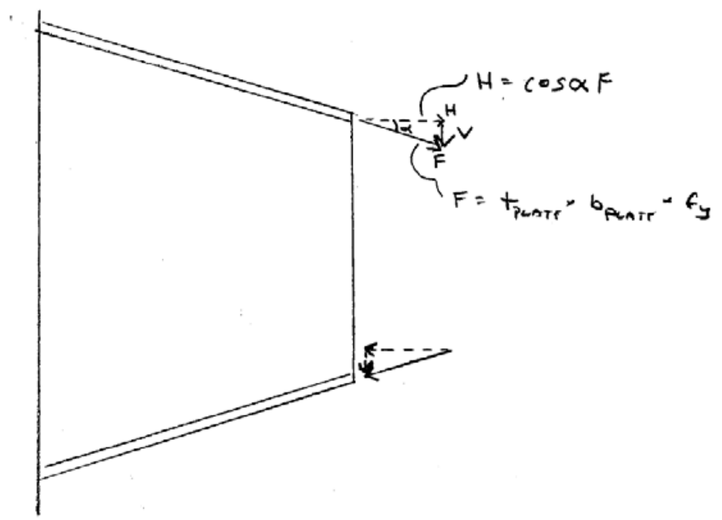


Plate and Stiffener Dimensions for Cross Beam 2 – End Section

	Web	Flange	Stiff Type 1	Stiff Type 2	Stiff Type 3
Dimensions	40 mm	35 mm	525 x 53	400 x 40	300 x 30

5.1.2 Section Properties

The section properties of the cross beam must take into account the variable depth of the cross beams as well as variation in stiffener spacing. Furthermore, for the components of the cross section that are not horizontal, such as the flanges and web stiffeners, a reduction was applied to the thickness of the plates. The reduced thickness that was used in the calculations is the projected thickness in the vertical plane. This can be alternatively thought of as the horizontal component of the force in the plate. The vertical component of the plate force will act to carry a portion of the vertical shear. This concept is illustrated in the following sketch:



An additional reduction in section properties was required for the sections near the face of the tower legs to account for shear lag effects. Based on the design of the cross beam connection to the tower legs as well as the local model in this area, the reduction factor for shear was determined to be 0.84. This reduction factor is applied to both the top and bottom flanges of the cross beams.

For the cross section and plate dimensions shown above, the gross section properties of the cross section are calculated as follows:

Section Property		Plates	Stiffeners	Total	
		Gross	Gross	Gross	Name
A	(mm^2)	2.03E+06	8.08E+05	**2.84E+06**	*Ag, Ae*
y-coord.	(mm)	0	0	**0**	*yg,ye*
z-coord.	(mm)	4000	4000	**4000**	*zg, ze*
I_y	(mm^4)	5.93E+13	2.16E+13	8.09E+13	
I_z	(mm^4)	9.54E+13	4.75E+13	1.43E+14	
I_Y	(mm^4)			**3.54E+13**	
I_Z	(mm^4)			**1.43E+14**	
Iyz	(mm^4)	**4.91E+13**	**2.33E+13**		
I_{ZY}	(mm^4)			0.00E+00	
Principal Axis					
Angle	(rad)			**0.00E+00**	
I_{1_Y}	(mm^4)			**3.54E+13**	*IgY, IeY*
I_{2_Z}	(mm^4)			**1.43E+14**	*IgZ, IeZ*

Similarly the section properties of all sections of the cross beam are as follows:

Cross Beam 1 Section Properties

Distance from CL Bridge (mm)	Depth of of Cross Beam (mm)	Area m^2	Iz m^4	Iy m^4
-29.53	21793	2.44	31	150
-19.69	17234	2.28	27	93
-9.84	12738	2.05	24	48
0.00	11500	1.88	21	36
9.84	12738	2.05	24	48
19.69	17234	2.28	27	93
29.53	21793	2.44	31	150

Cross Beam 2 Section Properties

Distance from CL Bridge (mm)	Depth of of Cross Beam (mm)	Area m^2	Iz m^4	Iy m^4
-25.14	19721	2.84	35	143
-16.76	15785	2.67	32	91
-8.38	12317	2.29	27	48
0.00	11500	2.11	25	39
8.38	12317	2.29	27	48
16.76	15785	2.67	32	91
25.14	19721	2.84	35	143

Cross Beam 3 Section Properties

Distance from CL Bridge (mm)	Depth of of Cross Beam (mm)	Area m^2	Iz m^4	Iy m^4
-20.74	17649	2.57	30	109
-13.83	14338	2.39	27	74
-6.91	11984	2.22	25	46
0.00	11500	2.07	23	40
6.91	11984	2.22	25	46
13.83	14338	2.39	27	74
20.74	17649	2.57	30	109

5.1.3 Global Design Loads

From the global IBDAS model the sectional forces matrices corresponding to a given combination are provided at 7 locations over the length of the cross beams, including sections at the face of the tower and a section at the centreline of the bridge. The sectional force effects matrices provide the maximum and minimum loads for each force effect as well as the concurrent values for the off-diagonal effects.

For the cross beams the critical load combinations are ULS wind, SILS wind and ULS seismic. Due to the difference in the partial safety factor for ULS and SILS (1.1 versus 1.0), the largest forces do not always correspond to the largest utilization ratio. Typically ULS and SILS wind produce roughly the same utilization ratios due to the difference in partial safety factor.

For the example cross beam section being considered, results for ULS wind load combination are provided as it results in the largest utilization ratios. The load factors for the ULS wind load combination are:

ULS 6: µPP + (0.9/1.5)PN + (1.1)QA + (1.0)VV + (0/1)VT

The following tables show the section force effects matrix for cross beam #2 at the face of the tower under the governing ULS wind load combination and temperature effects. Because the global model only considers a single wind direction within a given load combination, the values used herein are for transverse wind from the south. For the cross beams, transverse wind from the North will produce results that are approximately equal in magnitude and opposite in sign. The final verification considered wind in 8 different directions as shown in later sections. Also from the tables it can be seen that temperature effects are insignificant for the cross beams.

Sectional forces for IBDAS standard load combination (not including uniform temp)

Case	Criteria	Ns[MN]	My[MNm]	Mz[MNm]	Vy[MN]	Vz[MN]	Mt[MNm]	y[m]	z[m]
6901	min NS	-8	0	-2866	-118	0	5	-25	249
6901	max NS	3	6	-95	-3	0	-11	-25	249
6901	min MY	-5	-57	-2736	-111	-2	88	-25	249
6901	max MY	2	54	37	0	1	-77	-25	249
6901	min MZ	-6	-42	-3221	-128	-2	77	-25	249
6901	max MZ	2	40	125	1	1	-72	-25	249
6901	min VY	-6	-42	-3221	-128	-2	77	-25	249
6901	max VY	2	40	125	1	1	-72	-25	249
6901	min L001	2	54	56	1	1	-77	-25	249
6901	max L001	-6	-56	-3149	-127	-2	82	-25	249
6901	min L002	2	40	124	1	1	-74	-25	249
6901	max L002	-6	-42	-3220	-128	-2	78	-25	249

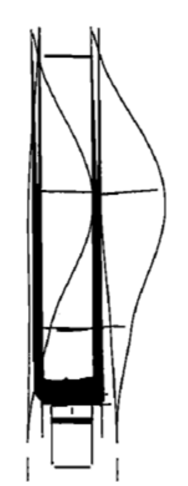
Sectional forces for IBDAS Uniform Temperature Loading

Case	Criteria	Ns[MN]	My[MNm]	Mz[MNm]	Vy[MN]	Vz[MN]	Mt[MNm]	y[m]	z[m]
4510	min NS	0	-1	0	0	0	0	-25	249
4510	max NS	0	1	-1	0	0	0	-25	249
4510	min MY	0	-1	0	0	0	0	-25	249
4510	max MY	0	1	-1	0	0	0	-25	249
4510	min MZ	0	1	-1	0	0	0	-25	249
4510	max MZ	0	-1	0	0	0	0	-25	249
4510	min VY	0	1	-1	0	0	0	-25	249
4510	max VY	0	-1	0	0	0	0	-25	249
4510	min L001	0	1	-1	0	0	0	-25	249
4510	max L001	0	-1	0	0	0	0	-25	249
4510	min L002	0	1	-1	0	0	0	-25	249
4510	max L002	0	-1	0	0	0	0	-25	249

5.1.4 Global Stability of the Tower Legs

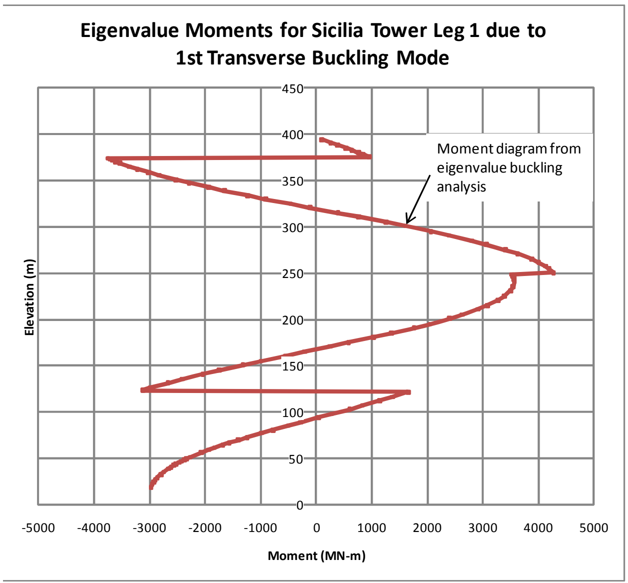
As the cross beams are responsible for much of the transverse stability of the towers, there will be additional force effects that arise due to transverse buckling of the tower. These forces must be added in addition to the sectional forces from the IBDAS global model, shown above. The forces in the tower legs due to global buckling are calculated in accordance with the procedure specified in CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01 "General Design Principles."

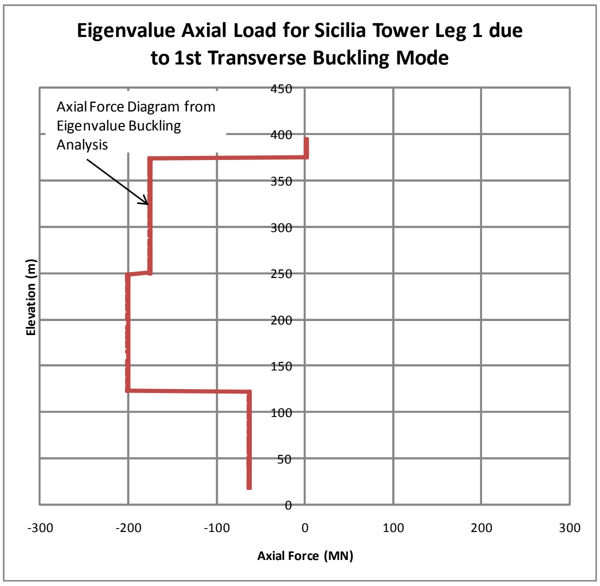
The following table presents the two relevant transverse buckling modes that were considered for the tower design and result in additional forces for the cross beams.

Transverse Buckling Mode 1	Transverse Buckling Mode 2
	

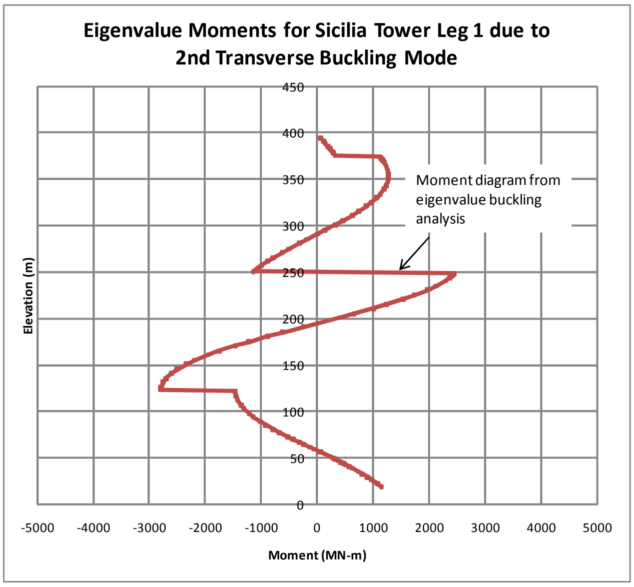
For the two transverse buckling modes considered, the eigenvalue moments are shown in the following figures. The resulting moments in the cross beams are indicated by the change in transverse moments in the tower legs. The resulting shears in the cross beams are indicated by the change in axial loads in the tower legs.

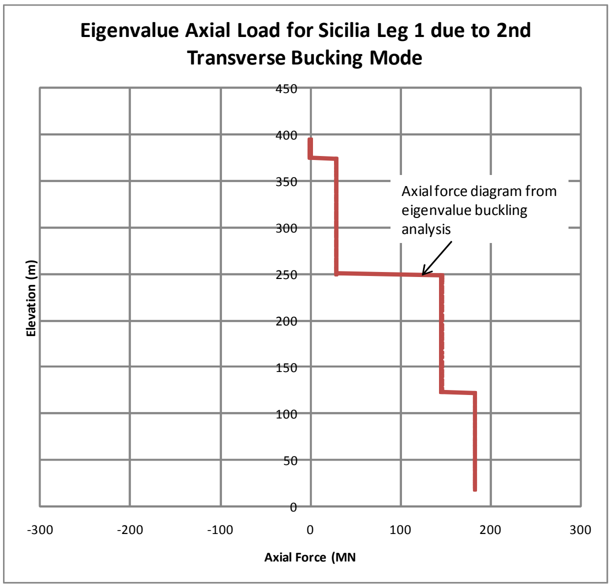
1st Transverse Buckling Mode





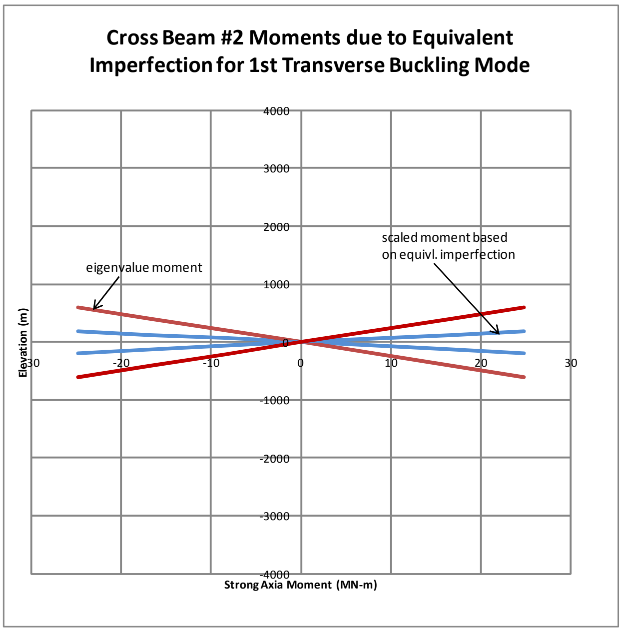
2nd Transverse Buckling Mode

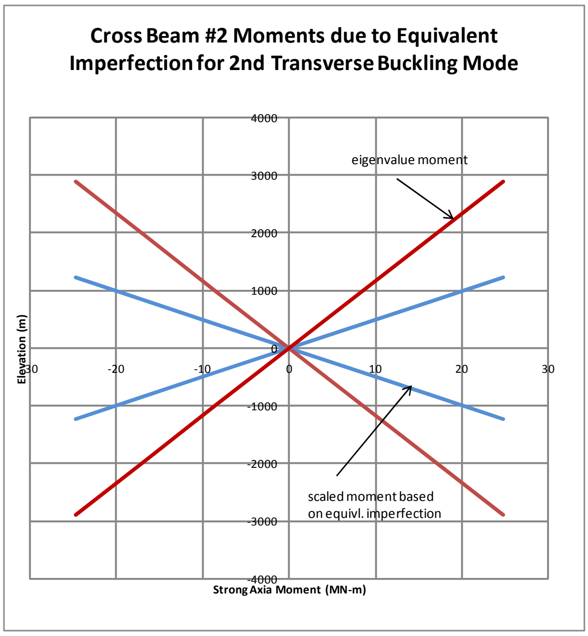




The imperfection moments for the cross beams are then taken as the scaled values using the calculated equivalent imperfection for the transverse buckling of the tower. The procedure used to calculate equivalent imperfection is provided in CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01 "General Design Principles" and resulting values for the tower legs are presented in CG.10.00-P-CL-D-P-SV-T4-00-00-00-00-01 "Design Report – Tower Legs."

The following figures show the results of this analysis for the Cross Beam #2 being considered here, including the eigenvalue moments for the two transverse buckling modes as well as scaled moments based on the calculated equivalent imperfections used in the tower buckling analysis.





From the figures, it can be seen that the first buckling mode produces very little moment in cross beam #2. However, the 2nd transverse buckling mode will result in substantial forces for the global cross beam design. Furthermore, the moments shown above will have a corresponding shear force. Because the cross beams are fixed end members with nearly all loading applied at the ends, the shear forces are directly proportional to the crossbeam moments and length. For example section at cross beam #2, at the face of the tower, the resulting section forces due to the equivalent imperfection will therefore be:

1st Longitudinal Buckling Mode

Moment	0	MN-m
Shear	0	MN

1st Transverse Buckling Mode

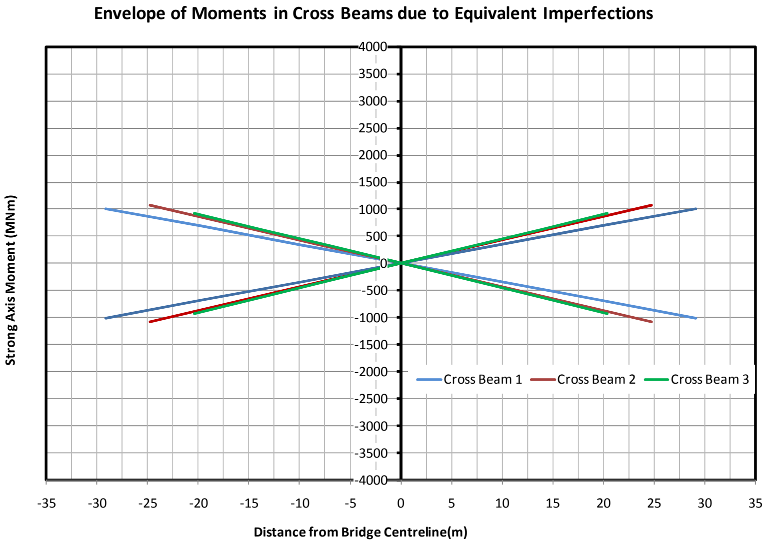
Moment	187	MN-m
Shear	8	MN

2nd Transverse Buckling Mode

Moment	1224	MN-m
Shear	49	MN

These section forces must be taken as plus/minus and are added to the section forces from the global model shown previously. Only one buckling mode needs to be considered at a time, therefore, stresses are calculated for each buckling mode and maximum stress for each point on the cross section are used for the overall design.

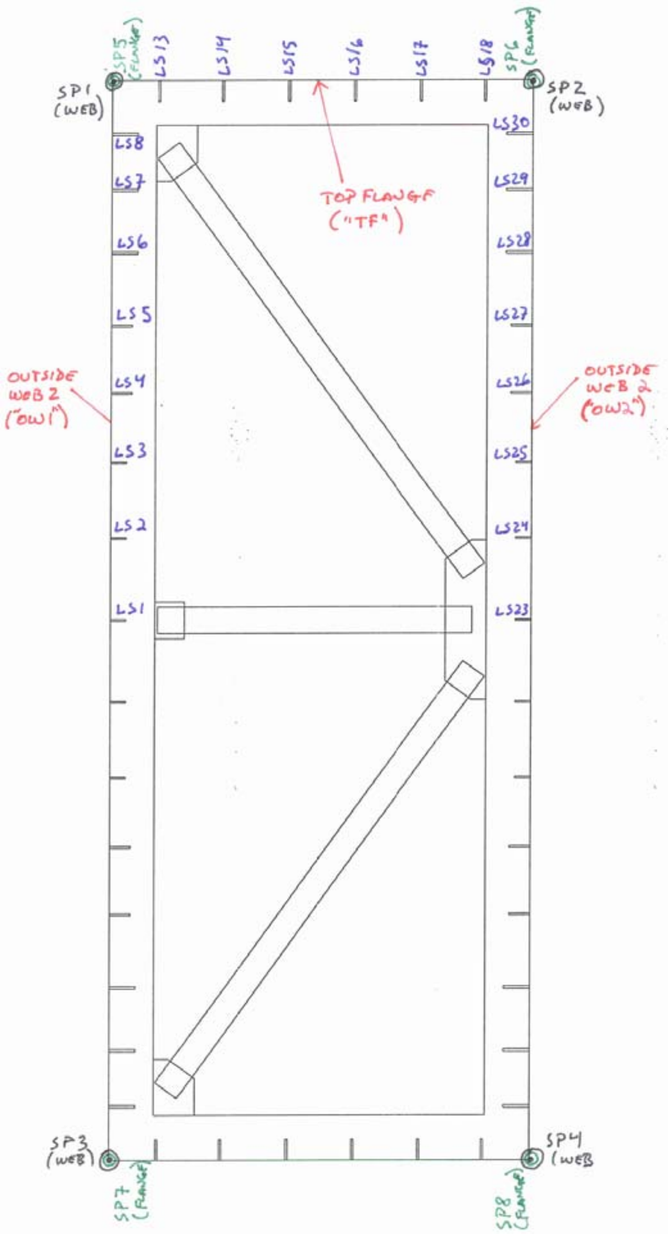
Using the same procedure, the envelope of moments and shears to account for the equivalent imperfections in the towers are calculated for the all three cross beams.



5.1.5 Capacity of the Cross Section for Longitudinal Compressive Stresses

As described in the general design principles, the capacity of the cross beam cross section for longitudinal stresses was determined by calculating the buckling capacity of each longitudinal stiffener and unstiffened corner of the cross section. The buckling capacity of the longitudinal stiffeners is a based on reduction factors for both local buckling of the main plates and the column-like buckling of the stiffener and associated the tributary width of the main plate. The buckling capacity of the unstiffened corners includes only reductions for local plate buckling as the adjacent intersecting main plate will prevent any overall column like buckling in these areas.

The following sketch shows the designations used for the cross section in the spreadsheet calculations to follow. Each longitudinal stiffener is assigned a unique name with the prefix “LS” and stresses for a given stiffener are conservatively calculated at the intersection of the stiffener and main plate. The unstiffened corner stress points are designated as “SP”. At the corners of the cross section, two separate capacities are calculated, one for the web plate and one for the flange plate. This is required as the difference in plate thickness results in different capacities as well as differences in shear stresses. As the cross section is symmetrical, only one-half of the cross section needs to be specified, although stresses are calculated for all points on the cross section. Therefore, each longitudinal stiffener will have two stress values, representing each half of the cross section.



The following tables show the capacity of each longitudinal stiffener and unstiffened corner for longitudinal compression stresses. The capacities are for Cross Beam # 2 at the face of the tower, which is being used as an example herein.

Capacity of Longitudinal Stiffeners for Compressive Stresses

Name			LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8	LS13	LS14	LS15
cross section type			2	2	2	2	2	2	2	2	2	2	2
No. in sec			1	2	2	2	2	2	2	2	2	2	2
Type			T3	T3	T3	T2	T2	T1	T1	T1	T1	T1	T1
	Reference	Unit											
Plate #1													
b_{pl}		[mm]	1461	1461	1356	1246	1210	1358	1172	1030	900	1200	1266.66
t_{pl}		[mm]	40	40	40	40	40	40	40	40	35	35	35
$\psi_{,pl}$	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,pl}$	5: Table 4.1	[-]	4	4	4	4	4	4	4	4	4	4	4
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.7148	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,pl}$	5: (4.4)	[-]	0.88	0.88	0.82	0.74	0.72	0.80	0.69	0.60	0.60	0.81	0.85
ρ_{pl}	5: (4.4)	[-]	0.85	0.85	0.89	0.95	0.96	0.90	0.99	1.00	1.00	0.90	0.87
$b_{pl,eff}$		[mm]	1244.04	1244.04	1213.23	1180.76	1166.62	1227.24	1157.81	1030.00	900.00	1081.43	1101.01
Plate #2													
b_{pl}		[mm]	1461.00	1356.00	1246.00	1210.00	1358.00	1172.00	1030.00	1027.50	1200.00	1266.66	1266.66
t_{pl}		[mm]	40	40	40	40	40	40	40	40	35	35	35
$\psi_{,pl}$	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,pl}$	5: Table 4.1	[-]	4	4	4	4	4	4	4	4	4	4	4
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.7148	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,pl}$	5: (4.4)	[-]	0.88	0.82	0.75	0.72	0.81	0.69	0.60	0.60	0.81	0.85	0.85
ρ_{pl}	5: (4.4)	[-]	0.85	0.89	0.94	0.96	0.90	0.99	1.00	1.00	0.90	0.87	0.87
$b_{pl,eff}$		[mm]	1244.04	1213.23	1175.10	1166.62	1219.66	1157.81	1030.00	1027.50	1081.43	1101.01	1101.01
Total Plate													
tpl		[mm]	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	35.00	35.00	35.00
b_total gross		[mm]	1461.00	1408.50	1301.00	1228.00	1284.00	1265.00	1101.00	1028.75	1050.00	1233.33	1266.66
b_total effec		[mm]	1244.04	1228.63	1194.16	1173.69	1193.14	1192.53	1093.90	1028.75	990.71	1091.22	1101.01
$\rho_{pl,\ composite}$			0.85	0.87	0.92	0.96	0.93	0.94	0.99	1.00	0.94	0.88	0.87
Stiffener web													
h_w		[mm]	300	300	300	400	400	525	525	525	525	525	525
t_w		[mm]	30	30	30	40	40	53	53	53	53	53	53
ψ_w	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,w}$	5: Table 4.1	[-]	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,w}$	5: (4.4)	[-]	0.75	0.75	0.75	0.75	0.75	0.74	0.74	0.74	0.74	0.74	0.74
ρ_w	5: (4.4)	[-]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$h_{w,eff}$		[mm]	299.40	299.40	299.40	399.20	399.20	525.00	525.00	525.00	525.00	525.00	525.00
$t_{w,eff.\ equiv.}$		[mm]	29.94	29.94	29.94	39.92	39.92	53.00	53.00	53.00	53.00	53.00	53.00
Column Buckling of Longitudinal Stiffener													
L_{cr}		[mm]	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
α	1: Table 6.1	[-]	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Gross section													
A_c		[mm^2]	67440	65340	61040	65120	67360	78425	71865	68975	64575	70992	72158
S		[mm^3]	2.88E+06	2.84E+06	2.75E+06	4.82E+06	4.87E+06	9.43E+06	9.30E+06	9.24E+06	8.92E+06	9.03E+06	9.05E+06
y_o (from t/o plate)		[mm]	43	43	45	74	72	120	129	134	138	127	125
I_{xx}		[mm^4]	4.24E+08	4.22E+08	4.20E+08	1.16E+09	1.16E+09	3.21E+09	3.21E+09	3.21E+09	3.12E+09	3.12E+09	3.12E+09
I		[mm^4]	3.007E+08	2.993E+08	2.962E+08	8.040E+08	8.106E+08	2.079E+09	2.006E+09	1.969E+09	1.884E+09	1.970E+09	1.984E+09
Effective section													
$A_{c,eff}$		[mm^2]	58743	58127	56749	62915	63693	75526	71581	68975	62500	66018	66360
S_{eff}		[mm^3]	2.6991E+06	2.6868E+06	2.6592E+06	4.7648E+06	4.7804E+06	9.3711E+06	9.2922E+06	9.2401E+06	8.8848E+06	8.9463E+06	8.9523E+06
$y_{o,eff}$ (from t/o plate)		[mm]	45.95	46.22	46.86	75.73	75.05	124.08	129.81	133.96	142.16	135.51	134.90
$I_{xx,eff}$		[mm^4]	4.169E+08	4.165E+08	4.158E+08	1.154E+09	1.154E+09	3.211E+09	3.209E+09	3.207E+09	3.116E+09	3.117E+09	3.118E+09
$I_{,eff}$		[mm^4]	2.928E+08	2.923E+08	2.912E+08	7.929E+08	7.954E+08	2.048E+09	2.002E+09	1.969E+09	1.853E+09	1.905E+09	1.910E+09
Buckling													
eplate		mm	23	23	25	54	52	100	109	114	121	110	108
estiff		mm	147	147	145	166	168	182	173	169	159	170	172
emax		mm	147	147	145	166	168	182	173	169	159	170	172
i		mm	66.77198967	67.67890322	69.65892431	111.1153802	109.7014912	162.8012034	167.064916	168.9741255	170.8238657	166.5811857	165.8128284
αe			0.689	0.685	0.677	0.624	0.628	0.591	0.583	0.580	0.574	0.582	0.583
$\sigma_{cr,sl}$		MPa	578	593	629	1599	1559	3433	3616	3699	3780	3595	3562
bc/bs1			1	1	1	1	1	1	1	1	1	1	1
$\sigma_{cr,c}$		MPa	578	593	629	1599	1559	3433	3616	3699	3780	3595	3562
βac			0.87	0.89	0.93	0.97	0.95	0.96	1.00	1.00	0.97	0.93	0.92
λc			0.833	0.830	0.825	0.527	0.528	0.359	0.356	0.353	0.343	0.345	0.345
Φ	1: (6.49)	[-]	1.06	1.06	1.05	0.74	0.74	0.61	0.61	0.61	0.60	0.60	0.60
χ			0.58	0.58	0.59	0.79	0.79	0.90	0.91	0.91	0.92	0.91	0.91

Overall critical stress

(Use gamma_m1, use gamma =1.0 for SILS))

Min value	**210.8**	**216.2**	**228.1**	**320.2**	**312.8**	**364.0**	**377.7**	**380.2**	**370.6**	**355.3**	**351.3**
Total reduction	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91	0.89	0.85	0.84

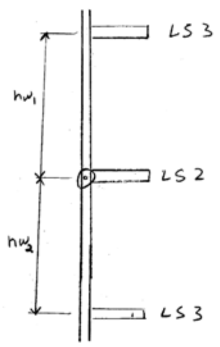
Name			LS16	LS17	LS18	LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
cross section type			2	2	2	2	2	2	2	2	2	2	2
No. in sec			2	2	2	1	2	2	2	2	2	2	2
Type			T1	T1	T1	T3	T3	T3	T2	T2	T1	T1	T1
	Reference	Unit											
Plate #1													
b_{pl}		[mm]	1266.66	1266.66	1200	1461	1461	1356	1246	1210	1358	1172	1030
t_{pl}		[mm]	35	35	35	40	40	40	40	40	40	40	40
$\psi_{,pl}$	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,pl}$	5: Table 4.1	[-]	4	4	4	4	4	4	4	4	4	4	4
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,pl}$	5: (4.4)	[-]	0.85	0.85	0.81	0.88	0.88	0.82	0.74	0.72	0.80	0.69	0.60
ρ_{pl}	5: (4.4)	[-]	0.87	0.87	0.90	0.85	0.85	0.89	0.95	0.96	0.90	0.99	1.00
$b_{pl,eff}$		[mm]	1101.01	1101.01	1081.43	1244.04	1244.04	1213.23	1180.76	1166.62	1227.24	1157.81	1030.00
Plate #2													
b_{pl}		[mm]	1266.66	1200.00	900.02	1461.00	1356.00	1246.00	1210.00	1358.00	1172.00	1030.00	1027.50
t_{pl}		[mm]	35	35	35	40	40	40	40	40	40	40	40
$\psi_{,pl}$	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,pl}$	5: Table 4.1	[-]	4	4	4	4	4	4	4	4	4	4	4
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,pl}$	5: (4.4)	[-]	0.85	0.81	0.60	0.88	0.82	0.75	0.72	0.81	0.69	0.60	0.60
ρ_{pl}	5: (4.4)	[-]	0.87	0.90	1.00	0.85	0.89	0.94	0.96	0.90	0.99	1.00	1.00
$b_{pl,eff}$		[mm]	1101.01	1081.43	900.02	1244.04	1213.23	1175.10	1166.62	1219.66	1157.81	1030.00	1027.50
Total Plate													
tpl		[mm]	35.00	35.00	35.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00	40.00
b_total gross		[mm]	1266.66	1233.33	1050.01	1461.00	1408.50	1301.00	1228.00	1284.00	1265.00	1101.00	1028.75
b_total effec		[mm]	1101.01	1091.22	990.72	1244.04	1228.63	1194.16	1173.69	1193.14	1192.53	1093.90	1028.75
$\rho_{pl, composite}$			0.87	0.88	0.94	0.85	0.87	0.92	0.96	0.93	0.94	0.99	1.00
Stiffener web													
h_w		[mm]	525	525	525	300	300	300	400	400	525	525	525
t_w		[mm]	53	53	53	30	30	30	40	40	53	53	53
ψ_w	5: Table 4.1	[-]	1	1	1	1	1	1	1	1	1	1	1
$K_{\sigma,w}$	5: Table 4.1	[-]	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43	0.43
f_y		[MPa]	460	460	460	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	[-]	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,w}$	5: (4.4)	[-]	0.74	0.74	0.74	0.75	0.75	0.75	0.75	0.75	0.74	0.74	0.74
ρ_w	5: (4.4)	[-]	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$h_{w,eff}$		[mm]	525.00	525.00	525.00	299.40	299.40	299.40	399.20	399.20	525.00	525.00	525.00
$t_{w,eff. equiv.}$		[mm]	53.00	53.00	53.00	29.94	29.94	29.94	39.92	39.92	53.00	53.00	53.00
Column Buckling of Longitudinal Stiffener													
L_{cr}		[mm]	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000	4000
α	1: Table 6.1	[-]	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49	0.49
Gross section													
A_c		[mm^2]	72158	70992	64575	67440	65340	61040	65120	67360	78425	71865	68975
S		[mm^3]	9.05E+06	9.03E+06	8.92E+06	2.88E+06	2.84E+06	2.75E+06	4.82E+06	4.87E+06	9.43E+06	9.30E+06	9.24E+06
y_o (from t/o plate)		[mm]	125	127	138	43	43	45	74	72	120	129	134
I_{xx}		[mm^4]	3.12E+09	3.12E+09	3.12E+09	4.24E+08	4.22E+08	4.20E+08	1.16E+09	1.16E+09	3.21E+09	3.21E+09	3.21E+09
I		[mm^4]	1.984E+09	1.970E+09	1.884E+09	3.007E+08	2.993E+08	2.962E+08	8.040E+08	8.106E+08	2.079E+09	2.006E+09	1.969E+09
Effective section													
$A_{c,eff}$		[mm^2]	66360	66018	62500	58743	58127	56749	62915	63693	75526	71581	68975
S_{eff}		[mm^3]	8.9523E+06	8.9463E+06	8.8848E+06	2.6991E+06	2.6868E+06	2.6592E+06	4.7648E+06	4.7804E+06	9.3711E+06	9.2922E+06	9.2401E+06
$y_{o,eff}$ (from t/o plate)		[mm]	134.90	135.51	142.16	45.95	46.22	46.86	75.73	75.05	124.08	129.81	133.96
$I_{xx,eff}$		[mm^4]	3.118E+09	3.117E+09	3.116E+09	4.169E+08	4.165E+08	4.158E+08	1.154E+09	1.154E+09	3.211E+09	3.209E+09	3.207E+09
$I_{,eff}$		[mm^4]	1.910E+09	1.905E+09	1.853E+09	2.928E+08	2.923E+08	2.912E+08	7.929E+08	7.954E+08	2.048E+09	2.002E+09	1.969E+09
Buckling													
eplate		mm	108	110	121	23	23	25	54	52	100	109	114
estiff		mm	172	170	159	147	147	145	166	168	182	173	169
emax		mm	172	170	159	147	147	145	166	168	182	173	169
i		mm	165.8128284	166.5811857	170.8236353	66.77198967	67.67890322	69.65892431	111.1153802	109.7014912	162.8012034	167.064916	168.9741255
αe			0.583	0.582	0.574	0.689	0.685	0.677	0.624	0.628	0.591	0.583	0.580
$\sigma_{cr,sl}$		MPa	3562	3595	3780	578	593	629	1599	1559	3433	3616	3699
bc/bs1			1	1	1	1	1	1	1	1	1	1	1
$\sigma_{cr,c}$		MPa	3562	3595	3780	578	593	629	1599	1559	3433	3616	3699
βac			0.92	0.93	0.97	0.87	0.89	0.93	0.97	0.95	0.96	1.00	1.00
λc			0.345	0.345	0.343	0.833	0.830	0.825	0.527	0.528	0.359	0.356	0.353
Φ	1: (6.49)	[-]	0.60	0.60	0.60	1.06	1.06	1.05	0.74	0.74	0.61	0.61	0.61
χ			0.91	0.91	0.92	0.58	0.58	0.59	0.79	0.79	0.90	0.91	0.91
Overall critical stress													
(Use gamma_m1, use gamma =1.0 for SILS))													
Min value			351.3	355.3	370.6	210.8	216.2	228.1	320.2	312.8	364.0	377.7	380.2
Total reduction			0.84	0.85	0.89	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91

Capacity of Unstiffened Corners for Compressive Stresses

		SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
		9860.5	9860.5	-9860.5	-9860.5	9860.5	9860.5	-9860.5	-9860.5
		3979.999	-3980	3979.999	-3980	3979.999	-3980	3979.999	-3980
Plate		OW1	OW2	OW1	OW2	TF	TF	TF	TF
Corner Spacing		1027.5	1027.5	1027.5	1027.5	900.02	900.02	900.02	900.02
plate thickness		40	40	40	40	35	35	35	35
$\Psi_{,pl}$	5: Table 4.1	1	1	1	1	1	1	1	1
$K_{\sigma,pl}$	5: Table 4.1	4	4	4	4	4	4	4	4
f_y	[MPa]	460	460	460	460	460	460	460	460
ε	5: (4.4 (2))	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
$\lambda_{p,pl}$	5: (4.4)	0.60	0.60	0.60	0.60	0.60	0.60	0.60	0.60
ρ_{pl}	5: (4.4)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
max stress (use gamma_m1)		418	418	418	418	418	418	418	418

5.1.6 Capacity of the Cross Section for Shear Stresses

In addition to the capacity of the cross section for compressive stresses, the capacities for shear stresses were also calculated. The shear capacity considered both overall shear buckling of the entire panel as well as sub-panel buckling of plates between the longitudinal stiffeners. Shear buckling of the overall panel (e.g., the entire depth of the web) was determined using 1993-1-5: Annex A.3. Similar to compressive stress capacities, shear capacities were determined for each point on the cross section. The stress points and designations are the same as shown previously. Because the stress points on the cross section are located at the longitudinal stiffeners, the shear capacity at these locations was taken as the minimum of the shear buckling of the overall panel or the shear buckling capacity of either sub-panel adjacent to the given longitudinal stiffener. An example of this is shown below, where the shear capacity of the stress point "LS2" is taken as the minimum capacity of the sub-panels with depths hw1 or hw2.



The following are the calculations for the shear capacities of each stress point on the cross section. Once again capacities provided are for Cross Beam #2 at the face of the tower.

Determine Shear Buckling Capacities

use EN 1993 1-5 Annex A.3

fy	460	
ε	0.71	
η	1	(use 1.0 per CMK recommedation)
γm1	1.1	

WEB PANEL

First Consider Shear Buckling of Entire Panel

	#	h	t	plate thk	2x15εt	Area	y_bar	ΣI'x	Σad^2	Isl	use 1/3 of Isl 3 -1-5 cl 5.3 (4)
LS1	1	300	30	40	852	43080	56	72044000	205761560	277805560	92601853
LS2	2	300	30	40	852	43080	56	72044000	205761560	277805560	92601853
LS3	2	300	30	40	852	43080	56	72044000	205761560	277805560	92601853
LS4	2	400	40	40	852	50080	90	217877333	526987859	744865193	248288398
LS5	2	400	40	40	852	50080	90	217877333	526987859	744865193	248288398
LS6	2	525	53	40	852	61905	147	643649469	1222491746	1.866E+09	622047072
LS7	2	525	53	40	852	61905	147	643649469	1222491746	1.866E+09	622047072
LS8	2	525	53	40	852	61905	147	643649469	1222491746	1.866E+09	622047072

Total Isl **5.19E+09** mm^4
(x 2 for entire panel)

Web Parameters

hw	19721
tw	40
a	4000
hw/a	4.93025
a/hw	0.20282947
kτsl	631.58
kτ	765.37882
λw	0.67112091
Xw	**1** **(for entire panel)**

Check Shear Buckling of Each sub-Panel

Web 1
Web 2

	sub-panel hw 1	sub-panel hw2	max subpanel	t	a/hw,i	hw,i/a	kτ,i	λw	sub panel **Xw**	Total panel **Xw**	Governing **Xw**	Max von mises stress **(Xw fy)/gm_1**
LS1	1461	1461	1461	40	2.737851	0.36525	5.8736	0.5676	1.000	1	1.000	418.2
LS2	1461	1356	1461	40	2.737851	0.36525	5.8736	0.5676	1.000	1	1.000	418.2
LS3	1356	1246	1356	40	2.949853	0.339	5.7997	0.5301	1.000	1	1.000	418.2
LS4	1246	1210	1246	40	3.210273	0.3115	5.7281	0.4901	1.000	1	1.000	418.2
LS5	1210	1358	1358	40	2.945508	0.3395	5.8010	0.5308	1.000	1	1.000	418.2
LS6	1358	1172	1358	40	2.945508	0.3395	5.8010	0.5308	1.000	1	1.000	418.2
LS7	1172	1030	1172	40	3.412969	0.293	5.6834	0.4628	1.000	1	1.000	418.2
LS8	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS9	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS10	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS11	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS12	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS23	1461	1461	1461	40	2.737851	0.36525	5.8736	0.5676	1.000	1	1.000	418.2
LS24	1461	1356	1461	40	2.737851	0.36525	5.8736	0.5676	1.000	1	1.000	418.2
LS25	1356	1246	1356	40	2.949853	0.339	5.7997	0.5301	1.000	1	1.000	418.2
LS26	1246	1210	1246	40	3.210273	0.3115	5.7281	0.4901	1.000	1	1.000	418.2
LS27	1210	1358	1358	40	2.945508	0.3395	5.8010	0.5308	1.000	1	1.000	418.2
LS28	1358	1172	1358	40	2.945508	0.3395	5.8010	0.5308	1.000	1	1.000	418.2
LS29	1172	1030	1172	40	3.412969	0.293	5.6834	0.4628	1.000	1	1.000	418.2
LS30	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS31	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS32	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS33	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2
LS34	1030	1027.5	1030	40	3.883495	0.2575	5.6052	0.4096	1.000	1	1.000	418.2

FLANGE PANELS

First Consider Shear Buckling of Entire Panel

		h	t	plate thk	2x15εt	Area	y_bar	ΣI'x	Σad^2	Isl	use 1/3 of Isl 3-1-5 cl 5.3 (4)
LS13	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
LS14	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
LS15	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
LS16	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
LS17	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
LS18	2	525	53	35	745.5	53917.5	162	641769078	1055691879	1.697E+09	565820319
										Total Isl	**3.395E+09** mm^4

Flange Parameters

hw	8000
tw	35
a	4000
hw/a	2
a/hw	0.5
kτsl	200.89
kτ	226.248119
λw	0.57226805
Xw	**1** **(for entire panel)**

Check Shear Buckling of Each Sub Panel

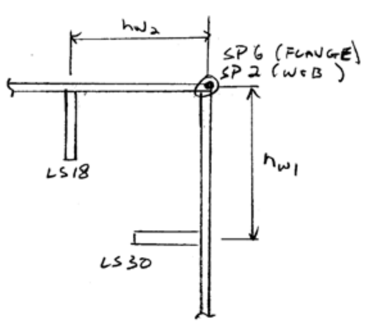
	hw 1	hw2	max hw, subpanel	t	a/hw	hw/a	kτ	λw	sub panel **Xw**	Total panel **Xw**	Governing **Xw**	**Xw x fy/gm_1**
LS13	900	1200	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2
LS14	1200	1266.66	1266.66	35	3.157911	0.316665	5.74110689	0.5688061	1.000	1	1.00	418.2
LS15	1266.66	1266.66	1266.66	35	3.157911	0.316665	5.74110689	0.5688061	1.000	1	1.00	418.2
LS16	1266.66	1266.66	1266.66	35	3.157911	0.316665	5.74110689	0.5688061	1.000	1	1.00	418.2
LS17	1266.66	1200	1266.66	35	3.157911	0.316665	5.74110689	0.5688061	1.000	1	1.00	418.2
LS18	1200	900.02	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2
LS19	1200	900.02	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2
LS20	1200	900.02	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2
LS21	1200	900.02	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2
LS22	1200	900.02	1200	35	3.333333	0.3	5.7	0.5408114	1.000	1	1.00	418.2

SUMMARY OF SHEAR BUCKLING CAPACITY FOR ALL STIFFENERS

Stiff	Governing Xw	Xw fy/gm_1
LS1	1.000	418
LS2	1.000	418
LS3	1.000	418
LS4	1.000	418
LS5	1.000	418
LS6	1.000	418
LS7	1.000	418
LS8	1.000	418
LS9	1.000	418
LS10	1.000	418
LS11	1.000	418
LS12	1.000	418
LS23	1.000	418
LS24	1.000	418
LS25	1.000	418
LS26	1.000	418
LS27	1.000	418
LS28	1.000	418
LS29	1.000	418
LS30	1.000	418
LS31	1.000	418
LS32	1.000	418
LS33	1.000	418
LS34	1.000	418
LS13	1.000	418
LS14	1.000	418
LS15	1.000	418
LS16	1.000	418
LS17	1.000	418
LS18	1.000	418
LS19	1.000	418
LS20	1.000	418
LS21	1.000	418
LS22	1.000	418

web 1
web 2
flange

Additionally, the shear capacities of the unstiffened corners were determined in a similar fashion to that shown above. The shear capacity of the corners is based on the minimum capacity of the overall panel or the sub-panel depth of the corner space as illustrated below.



Therefore, the capacity associated with stress point "SP2" is based on the thickness of the web plate and uses the sub-panel depth hw1. Likewise, the capacity associated with stress point "SP6" is based on the thickness of the flange plate and uses the sub-panel depth hw2. As mentioned, both cases also consider the shear buckling capacity of the overall panel.

Using the above methodology, the sub-panel shear buckling capacities of each unstiffened corner stress point are as follows.

	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
	9860.5	9860.5	-9860.5	-9860.5	9860.5	9860.5	-9860.5	-9860.5
	3979.999	-3980	3979.999	-3980	3979.999	-3980	3979.999	-3980
Plate	OW1	OW2	OW1	OW2	TF	TF	TF	TF
Design Shear Stress	418.2	418.2	418.2	418.2	418.2	418.2	418.2	418.2

5.1.7 Calculation of Stresses and Utilization Ratios – Longitudinal Compressive Stresses

The section forces along with the section properties shown previously were used to calculate the maximum compressive stresses for each stress point on the cross section. The stress points correspond to the longitudinal stiffeners and corners, for which the compressive capacities were shown in the previous section.

The following tables show the longitudinal stress calculation for each stress point as well as the resulting utilization ratios for longitudinal compressive stresses using the capacities presented previously. The utilization ratios for compressive stresses are calculated as follows

$$UR_{compression} = \frac{\sigma_{design}}{\rho \cdot f_y / \gamma_{M1}}$$

Where ρ is the reduction factor to account for buckling, including both local plate buckling and column-like buckling of the stiffener where applicable. The partial safety factor, γ_{m1}, is taken as 1.1 for ULS combinations and 1.0 for SILS combinations as described in the General Design Principles Report.

All stresses and utilization ratios are for Sicilia Tower Cross Beam #2 at the face of the tower. The loading is ULS wind transverse to the bridge, for which section forces were previously shown.

			PLATE CORNER STRESS POINTS							
Stress point			SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
	side of cross section									
Plate ID			OW1	OW2	OW1	OW2	TF	TF	TF	TF
STRESS	Y	(mm)	9860.5	9860.5	-9860.5	-9860.5	9860.5	9860.5	-9860.5	-9860.5
POINT COOR.	Z	(mm)	3979.999	-3980	3979.999	-3980	3979.999	-3980	3979.999	-3980

			SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8
IBDAS ULS/SILS SECTION FORCES	σ_1 (MPa)	min NS	195	195	-198	-200	195	195	-201	-200
		max NS	7	8	-6	-5	7	8	-6	-5
		min MY	193	180	-184	-197	193	180	-184	-197
		max MY	-8	4	-3	9	-8	4	-3	9
		min MZ	225	216	-220	-229	225	216	-220	-229
		max MZ	-13	-4	5	14	-13	-4	5	14
		min VY	225	216	-220	-229	225	216	-220	-229
		max VY	-13	-4	5	14	-13	-4	5	14
		min L001	-9	3	-2	10	-9	3	-2	10
		max L001	222	209	-213	-226	222	209	-213	-226
		min L002	-13	-3	5	14	-13	-3	5	14
		max L002	225	215	-219	-229	225	215	-219	-229
		MIN	-13	-4	-220	-229	-13	-4	-220	-229
		MAX	225	216	5	14	225	216	5	14
	GOVERNING CASE		min L002	max MZ	min VY	max L002	min L002	max MZ	min VY	max L002

ULS/SILS + Temp	MIN	-13	-4	-220	-229	-13	-4	-220	-229
	MAX	225	216	5	14	225	216	5	14

IMPERFECTION STRESS

1st Transverse Buckling Mode

Moment	187	MN-m								
	σ_1	MAX	13	13	-13	-13	13	13	-13	-13
		MIN	-13	-13	13	13	-13	-13	13	13

2nd Transverse Buckling Mode

Moment	1224	MN-m								
	σ_1	MAX	84	84	-84	-84	84	84	-84	-84
		MIN	-84	-84	84	84	-84	-84	84	84

Envelope of Imperfection Stress

σ_1	MIN	-84	-84	-84	-84	-84	-84	-84	-84
	MAX	84	84	84	84	84	84	84	84

Total Stresses: IBDAS Forces + Temp + Imperfections

σ_1	MIN	-97	-88	-304	-314	-97	-88	-304	-314
	MAX	309	300	89	98	309	300	89	98

CRITICAL STRESS (CAPACITY)	418	418	418	418	418	418	418	418
CORRESP. REDUCTION FACTOR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UTILIZATION RATIO - Compr. Stresses	**0.74**	**0.72**	**0.73**	**0.75**	**0.74**	**0.72**	**0.73**	**0.75**

			Longitudinal Stiffener Stress Points													
Stress point			LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8	LS13	LS14	LS15	LS16	LS17	LS18
	side of cross section		+	+	+	+	+	+	+	+	+	+	+	+	+	+
Plate ID			OW1	OW1	OW1	OW1	OW1	OW1	OW1	OW1	TF	TF	TF	TF	TF	TF
STRESS	Y	(mm)	0	1461	2817	4063	5273	6631	7803	8833	9860.5	9860.5	9860.5	9860.5	9860.5	9860.5
POINT COOR.	Z	(mm)	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	3100.00	1900.00	633.34	-633.32	-1899.98	-3099.98
IBDAS ULS/SILS SECTION FORCES	σ1	min NS	-3	27	54	79	103	130	154	174	195	195	195	195	195	195
	(MPa)	max NS	0	1	2	3	4	5	6	6	7	7	8	8	8	8
		min MY	5	33	58	82	106	132	154	174	192	190	188	186	184	182
		max MY	-5	-6	-6	-7	-7	-7	-7	-8	-7	-5	-3	-1	1	3
		min MZ	3	36	66	94	122	152	179	202	224	222	221	219	218	217
		max MZ	-4	-5	-6	-7	-9	-10	-11	-12	-12	-10	-9	-7	-6	-5
		min VY	3	36	66	94	122	152	179	202	224	222	221	219	218	217
		max VY	-4	-5	-6	-7	-9	-10	-11	-12	-12	-10	-9	-7	-6	-5
		min L001	-5	-6	-7	-7	-8	-8	-9	-9	-8	-6	-4	-2	0	1
		max L001	4	36	66	94	120	150	176	199	220	218	216	214	212	210
		min L002	-4	-5	-6	-8	-9	-10	-11	-12	-12	-10	-9	-7	-6	-4
		max L002	3	36	66	94	122	152	179	202	224	222	221	219	218	216
		MIN	-5	-6	-7	-8	-9	-10	-11	-12	-12	-10	-9	-7	-6	-5
		MAX	5	36	66	94	122	152	179	202	224	222	221	219	218	217
		GOVERNING CASE	max MY	min L001	min L001	min L002	min L002	min L002	min L002	min L002	min L002	max VY	max VY	max MZ	max MZ	max MZ
ULS/SILS + Temp		MIN	-6	-6	-7	-8	-9	-10	-11	-12	-12	-10	-9	-7	-6	-5
		MAX	5	37	66	94	122	152	179	202	224	222	221	220	218	217

IMPERFECTION STRESS

1st Transverse Buckling Mode

Moment	187	MN-m														
	σ1	MAX	0	2	4	5	7	9	10	12	13	13	13	13	13	13
		MIN	0	-2	-4	-5	-7	-9	-10	-12	-13	-13	-13	-13	-13	-13

2nd Transverse Buckling Mode

Moment	1224	MN-m														
	σ1	MAX	0	13	24	35	45	57	67	76	84	84	84	84	84	84
		MIN	0	-13	-24	-35	-45	-57	-67	-76	-84	-84	-84	-84	-84	-84

Envelope of Imperfection Stress

	σ1	MIN	0	-13	-24	-35	-45	-57	-67	-76	-84	-84	-84	-84	-84	-84
		MAX	0	13	24	35	45	57	67	76	84	84	84	84	84	84

Total Stresses: IBDAS Forces + Temp + Imperfections

	σ1	MIN	-6	-19	-31	-42	-54	-67	-78	-87	-96	-95	-93	-92	-90	-89
		MAX	5	49	91	129	167	209	245	278	308	307	306	304	303	301
CRITICAL STRESS (CAPACITY)			211	216	228	320	313	364	378	380	371	355	351	351	355	371
CORRESP. REDUCTION FACTOR			0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91	0.89	0.85	0.84	0.84	0.85	0.89
UTILIZATION RATIO - Compr. Stresses			**0.03**	**0.23**	**0.40**	**0.40**	**0.53**	**0.57**	**0.65**	**0.73**	**0.83**	**0.86**	**0.87**	**0.87**	**0.85**	**0.81**

			Longitudinal Stiffener Stress Points													
Stress point			**LS23**	**LS24**	**LS25**	**LS26**	**LS27**	**LS28**	**LS29**	**LS30**	**LS1**	**LS2**	**LS3**	**LS4**	**LS5**	**LS6**
		side of cross section	+	+	+	+	+	+	+	+	-	-	-	-	-	-
Plate ID			OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW1	OW1	OW1	OW1	OW1	OW1
STRESS	Y	(mm)	0	1461	2817	4063	5273	6631	7803	8833	0	-1461	-2817	-4063	-5273	-6631
POINT COOR.	Z	(mm)	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00
IBDAS ULS/SILS SECTION FORCES	σ_1 (MPa)	min NS	-3	27	54	79	103	130	154	174	-3	-32	-59	-84	-108	-136
		max NS	2	3	4	4	5	6	7	8	0	0	-1	-2	-3	-4
		min MY	-8	20	46	69	93	119	141	161	5	-23	-49	-73	-96	-122
		max MY	7	6	6	6	5	5	5	4	-5	-5	-5	-4	-4	-4
		min MZ	-7	26	57	85	112	143	169	192	3	-30	-61	-89	-116	-147
		max MZ	5	4	3	2	0	-1	-2	-3	-4	-3	-1	0	1	2
		min VY	-7	26	57	85	112	143	169	192	3	-30	-61	-89	-116	-147
		max VY	5	4	3	2	0	-1	-2	-3	-4	-3	-1	0	1	2
		min L001	7	6	6	5	5	4	4	3	-5	-5	-4	-4	-3	-3
		max L001	-8	24	54	81	108	138	164	186	4	-28	-58	-85	-112	-142
		min L002	5	4	3	2	1	-1	-2	-3	-4	-3	-2	0	1	2
		max L002	-7	26	57	85	112	143	169	192	3	-30	-61	-89	-116	-147
		MIN	-8	3	3	2	0	-1	-2	-3	-5	-32	-61	-89	-116	-147
		MAX	7	27	57	85	112	143	169	192	5	0	-1	0	1	2
		GOVERNING CASE	min MY	max NS	max MZ	max MZ	max MZ	max MZ	max MZ	max MZ	max MY	min NS	min VY	min VY	min VY	min VY

ULS/SILS + Temp	MIN	-9	3	3	1	0	-1	-2	-3	-6	-32	-61	-89	-116	-147
	MAX	7	27	57	85	112	143	169	192	5	0	-1	0	1	2

IMPERFECTION STRESS

1st Transverse Buckling Mode

Moment 187 MN-m

σ_1	MAX	0	2	4	5	7	9	10	12	0	-2	-4	-5	-7	-9
	MIN	0	-2	-4	-5	-7	-9	-10	-12	0	2	4	5	7	9

2nd Transverse Buckling Mode

Moment 1224 MN-m

σ_1	MAX	0	13	24	35	45	57	67	76	0	-13	-24	-35	-45	-57
	MIN	0	-13	-24	-35	-45	-57	-67	-76	0	13	24	35	45	57

Envelope of Imperfection Stress

σ_1	MIN	0	-13	-24	-35	-45	-57	-67	-76	0	-13	-24	-35	-45	-57
	MAX	0	13	24	35	45	57	67	76	0	13	24	35	45	57

Total Stresses: IBDAS Forces + Temp + Imperfections

σ_1	MIN	-9	-10	-22	-33	-45	-58	-69	-78	-6	-45	-85	-124	-161	-204
	MAX	7	39	81	120	157	200	236	268	5	12	23	34	46	59

CRITICAL STRESS (CAPACITY)	211	216	228	320	313	364	378	380	211	216	228	320	313	364
CORRESP. REDUCTION FACTOR	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91	0.50	0.52	0.55	0.77	0.75	0.87

UTILIZATION RATIO - Compr. Stresses	**0.04**	**0.18**	**0.36**	**0.37**	**0.50**	**0.55**	**0.63**	**0.71**	**0.03**	**0.21**	**0.37**	**0.39**	**0.52**	**0.56**

Longitudinal Stiffener Stress Points

			LS7	LS8	LS13	LS14	LS15	LS16	LS17	LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
Stress point		side of cross section	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate ID			OW1	OW1	TF	TF	TF	TF	TF	OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2
STRESS POINT COOR.	Y	(mm)	-7803	-8833	-9860.5	-9860.5	-9860.5	-9860.5	-9860.5	0	-1461	-2817	-4063	-5273	-6631	-7803	-8833
	Z	(mm)	4000.00	4000.00	3100.00	1900.00	633.34	-633.32	-1899.98	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00
IBDAS ULS/SILS SECTION FORCES	σ1 (MPa)	min NS	-159	-180	-200	-200	-200	-200	-200	-3	-32	-59	-84	-108	-136	-159	-180
		max NS	-5	-5	-6	-6	-6	-5	-5	2	1	0	-1	-2	-3	-3	-4
		min MY	-145	-165	-186	-188	-190	-192	-194	-8	-36	-62	-86	-109	-135	-158	-178
		max MY	-3	-3	-2	0	2	4	6	7	7	7	8	8	8	9	9
		min MZ	-173	-196	-221	-222	-224	-225	-226	-7	-40	-70	-98	-126	-156	-183	-206
		max MZ	3	4	6	7	9	10	11	5	6	8	9	10	11	12	13
		min VY	-173	-196	-221	-222	-224	-225	-226	-7	-40	-70	-98	-126	-156	-183	-206
		max VY	3	4	6	7	9	10	11	5	6	8	9	10	11	12	13
		min L001	-2	-2	0	2	3	5	7	7	7	8	8	9	9	10	10
		max L001	-168	-190	-214	-216	-218	-220	-222	-8	-41	-70	-98	-125	-154	-180	-203
		min L002	3	4	6	7	8	10	11	5	6	8	9	10	11	12	13
		max L002	-173	-196	-220	-222	-223	-225	-226	-7	-40	-70	-98	-126	-156	-183	-206
		MIN	-173	-196	-221	-222	-224	-225	-226	-8	-41	-70	-98	-126	-156	-183	-206
		MAX	3	4	6	7	9	10	11	7	7	8	9	10	11	12	13
		GOVERNING CASE	min VY	min VY	min VY	min VY	min MZ	min MZ	min MZ	min MY	max L001	max L001	max L002	max L002	max L002	max L002	max L002
ULS/SILS + Temp		MIN	-173	-197	-221	-222	-224	-225	-227	-9	-41	-71	-98	-126	-156	-183	-206
		MAX	3	4	6	7	8	10	11	7	7	8	9	10	11	12	13
IMPERFECTION STRESS																	
1st Transverse Buckling Mode																	
Moment	187	MN-m															
	σ1	MAX	-10	-12	-13	-13	-13	-13	-13	0	-2	-4	-5	-7	-9	-10	-12
		MIN	10	12	13	13	13	13	13	0	2	4	5	7	9	10	12
2nd Transverse Buckling Mode																	
Moment	1224	MN-m															
	σ1	MAX	-67	-76	-84	-84	-84	-84	-84	0	-13	-24	-35	-45	-57	-67	-76
		MIN	67	76	84	84	84	84	84	0	13	24	35	45	57	67	76
Envelope of Imperfection Stress																	
	σ1	MIN	-67	-76	-84	-84	-84	-84	-84	0	-13	-24	-35	-45	-57	-67	-76
		MAX	67	76	84	84	84	84	84	0	13	24	35	45	57	67	76
Total Stresses: IBDAS Forces + Temp + Imperfections																	
	σ1	MIN	-240	-272	-305	-307	-308	-310	-311	-9	-53	-95	-133	-171	-213	-250	-282
		MAX	70	79	90	92	93	94	96	7	20	32	44	55	68	79	89
CRITICAL STRESS (CAPACITY)			378	380	371	355	351	351	355	211	216	228	320	313	364	378	380
CORRESP. REDUCTION FACTOR			0.90	0.91	0.89	0.85	0.84	0.84	0.85	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91
UTILIZATION RATIO - Compr. Stresses			**0.64**	**0.72**	**0.82**	**0.86**	**0.88**	**0.88**	**0.88**	**0.04**	**0.25**	**0.42**	**0.42**	**0.55**	**0.59**	**0.66**	**0.74**

The following tables show the maximum utilization ratios of the previous table for both the unstiffened corners and the longitudinal stiffeners.

Information about governing corner stress point

Max UR	0.75
Governing Stress Point	SP4
reduction factor for governing point	1.000
Governing Case for Max Stress Point	max L002
Ns	-6
My	-42
Mz	-3220

Information about governing longit. stiffener stress point

Max UR	0.88
Governing Stress Point	LS16
Side of Cross Section	-
Governing Case for Max Stress Point	min MZ
reduction factor for governing stiff	0.840
Ns	-6
My	-42
Mz	-3221

5.1.8 Calculation of Stresses and Utilization Ratios – Shear Stresses

Similar to the longitudinal compressive stresses, shear stresses and utilization ratios were determined for all stress points on the cross section. Because the shear capacities of the cross sections are being considered separately for each sub-panel of the web, the actual shear stresses need to be calculated to ensure that no points on the cross section will exceed yield criterion. The shear stresses on the cross section were calculated by determining the shear flow based on VQ/I.

It is important to note that the utilization ratios calculated are intended for eventual use in calculating Von Mises stresses and are calculated as

$$UR_{\text{shear for von Mises}} = \frac{\tau_{design}}{\chi_w \cdot f_y / \gamma_{M1}}$$

Therefore, this utilization ratio does not indicate the actual utilization ratio for shear stress. However, an addition utilization ratio is presented to show that actual shear utilization ratio, which is calculated as:

$$UR_{\text{shear only}} = \frac{\tau_{design}}{\chi_w \cdot f_y / \sqrt{3} \cdot \gamma_{M1}}$$

The partial safety factor, γ_{m1}, is taken as 1.1 for ULS combinations and 1.0 for SILS combinations as described in the General Design Principles Report.

			PLATE STRESS POINTS								Long. Stiffener Stress Points							
Stress point			SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8
											+	+	+	+	+	+	+	+
Plate ID			OW1	OW2	OW1	OW2	TF	TF	TF	TF	OW1	OW1	OW1	OW1	OW1	OW1	OW1	OW1
STRESS	Y	(mm)	9860.5	9860.5	-9860.5	-9860.5	9860.5	9860.5	-9860.5	-9860.5	0	1461	2817	4063	5273	6631	7803	8833
POINT COOR.	Z	(mm)	3979.999	-3980	3979.999	-3980	3979.999	-3980.0	3979.999	-3980	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00
PLATE TYPE			Web	Web	Web	Web	Flange	Flange	Flange	Flange	Web	Web	Web	Web	Web	Web	Web	Web
Plate thick			40	40	40	40	35	35	35	35	40	40	40	40	40	40	40	40
ordinate for verical shear stress distrib			38	38	38	38	44	44	44	44	84	83	81	77	71	64	56	48
IBDAS ULS/SILS SECTION FORCES *(use actual parabolic shear distribution)*	τ (MPa)	min NS	45	45	45	45	53	53	53	53	100	99	95	91	84	75	66	56
		max NS	1	1	1	1	2	2	2	2	3	3	3	3	2	2	2	2
		min MY	43	43	43	43	53	53	53	53	93	92	89	85	79	70	62	53
		max MY	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	0
		min MZ	49	49	49	49	60	60	60	60	108	107	103	98	91	81	71	61
		max MZ	1	1	1	1	3	3	3	3	1	1	1	1	1	1	1	1
		min VY	49	49	49	49	60	60	60	60	108	107	103	98	91	81	71	61
		max VY	1	1	1	1	3	3	3	3	1	1	1	1	1	1	1	1
		min L001	0	0	0	0	3	3	3	3	0	0	0	0	0	0	0	0
		max L001	49	49	49	49	60	60	60	60	107	106	102	97	91	81	71	60
		min L002	0	0	0	0	4	4	4	4	1	1	1	1	1	1	1	1
		max L002	49	49	49	49	60	60	60	60	108	107	103	98	91	81	71	61
		MAX	49	49	49	49	60	60	60	60	108	107	103	98	91	81	71	61
		GOVERNING CASE	min VY	min VY	min VY	min VY	max L002	max L002	max L002	max L002	min VY	min VY	min VY	min VY	min VY	min VY	min VY	min VY
Torsion Stresses *(use avg stress distribution)*	τ (MPa)	min NS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		max NS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		min MY	7	7	7	7	8	8	8	8	7	7	7	7	7	7	7	7
		max MY	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		min MZ	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		max MZ	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		min VY	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		max VY	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		min L001	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		max L001	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7
		min L002	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		max L002	6	6	6	6	7	7	7	7	6	6	6	6	6	6	6	6
		Max	7	7	7	7	8	8	8	8	7	7	7	7	7	7	7	7
ULS/SILS + Temp		Max	56	56	56	56	68	68	68	68	115	114	110	105	98	88	78	68
IMPERFECTION STRESS																		
1st Transverse Buckling Mode																		
Shear	7.8	MN																
	τ	Max	3	3	3	3	3	3	3	3	7	6	6	6	6	5	4	4
2nd Transverse Buckling Mode																		
Shear	49.3	MN																
	τ	Max	19	19	19	19	22	22	22	22	42	41	40	38	35	31	27	23
Envelope of Imperfection Stress																		
		Max	19	19	19	19	22	22	22	22	42	41	40	38	35	31	27	23
Total Stresses: IBDAS Forces + Temp + Imperfections																		
		Max	75	75	75	75	90	90	90	90	156	155	150	143	133	120	105	91
CRITICAL STRESS (CAPACITY)			418	418	418	418	418	418	418	418	418	418	418	418	418	418	418	418
REDUCTION FACTOR			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UTILIZ. RATIO - Shear for Von Mises			**0.18**	**0.18**	**0.18**	**0.18**	**0.21**	**0.21**	**0.21**	**0.21**	**0.37**	**0.37**	**0.36**	**0.34**	**0.32**	**0.29**	**0.25**	**0.22**
UTILIZ. RATIO - Shear Only			**0.31**	**0.31**	**0.31**	**0.31**	**0.37**	**0.37**	**0.37**	**0.37**	**0.65**	**0.64**	**0.62**	**0.59**	**0.55**	**0.50**	**0.44**	**0.38**

			Longit. Stiffener Stress Points													
Stress point			LS13	LS14	LS15	LS16	LS17	LS18	LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
			+	+	+	+	+	+	+	+	+	+	+	+	+	+
Plate ID			TF	TF	TF	TF	TF	TF	OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2
STRESS	Y	(mm)	9860.5	9860.5	9860.5	9860.5	9860.5	9860.5	0	1461	2817	4063	5273	6631	7803	8833
POINT COOR.	Z	(mm)	3100.00	1900.00	633.34	-633.32	-1899.98	-3099.98	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00
PLATE TYPE			Flange	Flange	Flange	Flange	Flange	Flange	Web	Web	Web	Web	Web	Web	Web	Web
Plate thick			35	35	35	35	35	35	40	40	40	40	40	40	40	40
ordinate for verical shear stress distrib			34	21	7	7	21	34	84	83	81	77	71	64	56	48
IBDAS ULS/SILS SECTION FORCES *(use actual parabolic shear distribution)*	τ (MPa)	min NS	41	26	9	9	26	41	100	99	95	91	84	75	66	56
		max NS	1	1	1	1	1	1	3	3	3	3	2	2	2	2
		min MY	42	28	12	12	28	42	93	92	89	85	79	70	62	53
		max MY	3	3	3	3	3	3	0	0	0	0	0	0	0	0
		min MZ	48	31	13	13	31	48	108	107	103	98	91	81	71	61
		max MZ	3	3	3	3	3	3	1	1	1	1	1	1	1	1
		min VY	48	31	13	13	31	48	108	107	103	98	91	81	71	61
		max VY	3	3	3	3	3	3	1	1	1	1	1	1	1	1
		min L001	3	3	3	3	3	3	0	0	0	0	0	0	0	0
		max L001	48	31	13	13	31	48	107	106	102	97	91	81	71	60
		min L002	3	3	3	3	3	3	1	1	1	1	1	1	1	1
		max L002	48	31	13	13	31	48	108	107	103	98	91	81	71	61
		MAX	48	31	13	13	31	48	108	107	103	98	91	81	71	61
	GOVERNING CASE		max L002	max L002	max L001	max L001	max L002	max L002	min VY	min VY	min VY	min VY	min VY	min VY	min VY	min VY
Torsion Stresses *(use avg stress distribution)*	τ (MPa)	min NS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		max NS	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		min MY	8	8	8	8	8	8	7	7	7	7	7	7	7	7
		max MY	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		min MZ	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		max MZ	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		min VY	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		max VY	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		min L001	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		max L001	7	7	7	7	7	7	7	7	7	7	7	7	7	7
		min L002	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		max L002	7	7	7	7	7	7	6	6	6	6	6	6	6	6
		Max	8	8	8	8	8	8	7	7	7	7	7	7	7	7
ULS/SILS + Temp		Max	56	39	21	21	39	56	115	114	110	105	98	88	78	68
IMPERFECTION STRESS																
1st Transverse Buckling Mode																
Shear	7.8	MN														
	τ	Max	3	2	1	1	2	3	7	6	6	6	6	5	4	4
2nd Transverse Buckling Mode																
Shear	49.3	MN														
	τ	Max	17	10	3	3	10	17	42	41	40	38	35	31	27	23
Envelope of Imperfection Stress																
		Max	17	10	3	3	10	17	42	41	40	38	35	31	27	23
Total Stresses: IBDAS Forces + Temp + Imperfections																
		Max	73	49	25	25	49	73	156	155	150	143	133	120	105	91
CRITICAL STRESS (CAPACITY)			418	418	418	418	418	418	418	418	418	418	418	418	418	418
REDUCTION FACTOR			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UTILIZ. RATIO - Shear for Von Mises			**0.17**	**0.12**	**0.06**	**0.06**	**0.12**	**0.17**	**0.37**	**0.37**	**0.36**	**0.34**	**0.32**	**0.29**	**0.25**	**0.22**
UTILIZ. RATIO - Shear Only			**0.30**	**0.20**	**0.10**	**0.10**	**0.20**	**0.30**	**0.65**	**0.64**	**0.62**	**0.59**	**0.55**	**0.50**	**0.44**	**0.38**

			Longit. Stiffener Stress Points													
Stress point			LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8	LS13	LS14	LS15	LS16	LS17	LS18
			-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate ID			OW1	OW1	OW1	OW1	OW1	OW1	OW1	OW1	TF	TF	TF	TF	TF	TF
STRESS	Y	(mm)	0	-1461	-2817	-4063	-5273	-6631	-7803	-8833	-9860.5	-9860.5	-9860.5	-9860.5	-9860.5	-9860.5
POINT COOR.	Z	(mm)	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	3100.00	1900.00	633.34	-633.32	-1899.98	-3099.98
PLATE TYPE			Web	Web	Web	Web	Web	Web	Web	Web	Flange	Flange	Flange	Flange	Flange	Flange
Plate thick			40	40	40	40	40	40	40	40	35	35	35	35	35	35
ordinate for verical shear stress distrib			84	83	81	77	71	64	56	48	34	21	7	7	21	34
IBDAS ULS/SILS SECTION FORCES *(use actual parabolic shear distribution)*	τ (MPa)	min NS	100	99	95	91	84	75	66	56	41	26	9	9	26	41
		max NS	3	3	3	3	2	2	2	2	1	1	1	1	1	1
		min MY	93	92	89	85	79	70	62	53	42	28	12	12	28	42
		max MY	0	0	0	0	0	0	0	0	3	3	3	3	3	3
		min MZ	108	107	103	98	91	81	71	61	48	31	13	13	31	48
		max MZ	1	1	1	1	1	1	1	1	3	3	3	3	3	3
		min VY	108	107	103	98	91	81	71	61	48	31	13	13	31	48
		max VY	1	1	1	1	1	1	1	1	3	3	3	3	3	3
		min L001	0	0	0	0	0	0	0	0	3	3	3	3	3	3
		max L001	107	106	102	97	91	81	71	60	48	31	13	13	31	48
		min L002	1	1	1	1	1	1	1	1	3	3	3	3	3	3
		max L002	108	107	103	98	91	81	71	61	48	31	13	13	31	48
		MAX	108	107	103	98	91	81	71	61	48	31	13	13	31	48
	GOVERNING CASE		min VY	min VY	min VY	min VY	min VY	min VY	min VY	min VY	max L002	max L002	max L001	max L001	max L002	max L002
Torsion Stresses *(use avg stress distribution)*	τ (MPa)	min NS	0	0	0	0	0	0	0	0	0	0	0	0	0	0
		max NS	1	1	1	1	1	1	1	1	1	1	1	1	1	1
		min MY	7	7	7	7	7	7	7	7	8	8	8	8	8	8
		max MY	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		min MZ	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		max MZ	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		min VY	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		max VY	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		min L001	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		max L001	7	7	7	7	7	7	7	7	7	7	7	7	7	7
		min L002	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		max L002	6	6	6	6	6	6	6	6	7	7	7	7	7	7
		Max	7	7	7	7	7	7	7	7	8	8	8	8	8	8
ULS/SILS + Temp		Max	115	114	110	105	98	88	78	68	56	39	21	21	39	56
IMPERFECTION STRESS																
1st Transverse Buckling Mode																
Shear	7.8	MN														
	τ	Max	7	6	6	6	6	5	4	4	3	2	1	1	2	3
2nd Transverse Buckling Mode																
Shear	49.3	MN														
	τ	Max	42	41	40	38	35	31	27	23	17	10	3	3	10	17
Envelope of Imperfection Stress																
		Max	42	41	40	38	35	31	27	23	17	10	3	3	10	17
Total Stresses: IBDAS Forces + Temp + Imperfections																
		Max	156	155	150	143	133	120	105	91	73	49	25	25	49	73
CRITICAL STRESS (CAPACITY)			418	418	418	418	418	418	418	418	418	418	418	418	418	418
REDUCTION FACTOR			1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
UTILIZ. RATIO - Shear for Von Mises			**0.37**	**0.37**	**0.36**	**0.34**	**0.32**	**0.29**	**0.25**	**0.22**	**0.17**	**0.12**	**0.06**	**0.06**	**0.12**	**0.17**
UTILIZ. RATIO - Shear Only			**0.65**	**0.64**	**0.62**	**0.59**	**0.55**	**0.50**	**0.44**	**0.38**	**0.30**	**0.20**	**0.10**	**0.10**	**0.20**	**0.30**

			Longit. Stiffener Stress Points							
Stress point			LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
			-	-	-	-	-	-	-	-
Plate ID			OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2
STRESS	Y	(mm)	0	-1461	-2817	-4063	-5273	-6631	-7803	-8833
POINT COOR.	Z	(mm)	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00
PLATE TYPE			Web	Web	Web	Web	Web	Web	Web	Web
Plate thick			40	40	40	40	40	40	40	40
ordinate for verical shear stress distrib			84	83	81	77	71	64	56	48

IBDAS ULS/SILS SECTION FORCES *(use actual parabolic shear distribution)*	τ (MPa)	min NS	100	99	95	91	84	75	66	56
		max NS	3	3	3	3	2	2	2	2
		min MY	93	92	89	85	79	70	62	53
		max MY	0	0	0	0	0	0	0	0
		min MZ	108	107	103	98	91	81	71	61
		max MZ	1	1	1	1	1	1	1	1
		min VY	108	107	103	98	91	81	71	61
		max VY	1	1	1	1	1	1	1	1
		min L001	0	0	0	0	0	0	0	0
		max L001	107	106	102	97	91	81	71	60
		min L002	1	1	1	1	1	1	1	1
		max L002	108	107	103	98	91	81	71	61
		MAX	108	107	103	98	91	81	71	61
		GOVERNING CASE	min VY	min VY	min VY	min VY	min VY	min VY	min VY	min VY

Torsion Stresses *(use avg stress distribution)*	τ (MPa)	min NS	0	0	0	0	0	0	0	0
		max NS	1	1	1	1	1	1	1	1
		min MY	7	7	7	7	7	7	7	7
		max MY	6	6	6	6	6	6	6	6
		min MZ	6	6	6	6	6	6	6	6
		max MZ	6	6	6	6	6	6	6	6
		min VY	6	6	6	6	6	6	6	6
		max VY	6	6	6	6	6	6	6	6
		min L001	6	6	6	6	6	6	6	6
		max L001	7	7	7	7	7	7	7	7
		min L002	6	6	6	6	6	6	6	6
		max L002	6	6	6	6	6	6	6	6
		Max	7	7	7	7	7	7	7	7

ULS/SILS + Temp	Max	115	114	110	105	98	88	78	68

IMPERFECTION STRESS

1st Transverse Buckling Mode

Shear 7.8 MN

τ	Max	7	6	6	6	6	5	4	4

2nd Transverse Buckling Mode

Shear 49.3 MN

τ	Max	42	41	40	38	35	31	27	23

Envelope of Imperfection Stress

	Max	42	41	40	38	35	31	27	23

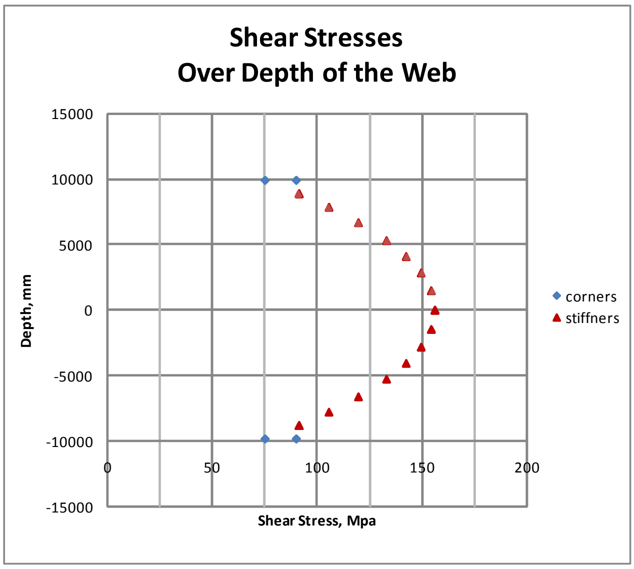
Total Stresses: IBDAS Forces + Temp + Imperfections

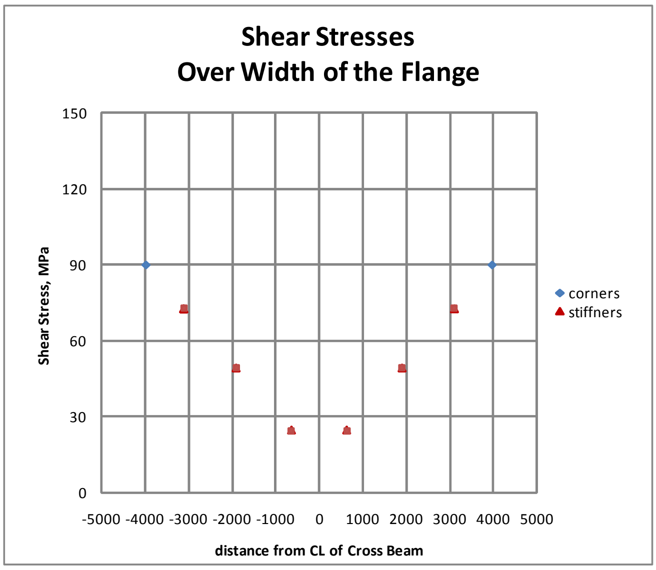
	Max	156	155	150	143	133	120	105	91

CRITICAL STRESS (CAPACITY)	418	418	418	418	418	418	418	418
REDUCTION FACTOR	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

UTILIZ. RATIO - Shear for Von Mises	**0.37**	**0.37**	**0.36**	**0.34**	**0.32**	**0.29**	**0.25**	**0.22**
UTILIZ. RATIO - Shear Only	**0.65**	**0.64**	**0.62**	**0.59**	**0.55**	**0.50**	**0.44**	**0.38**

As discussed previously, the shear stresses were calculated by determining the shear flow around the cross section. To further illustrate, the shear stress provided in the above tables are plotted over the depth and width of the cross section.





5.1.9 Calculation of Von Mises Utilization Ratios

Using the utilization ratios previously calculated for both longitudinal compressive stresses and shear, the utilization ratios for von Mises stresses were then determined. The von Mises equation is based on EN 1993-1-5 Section 10 (eq 10.5) as follows:

$$\left(\frac{\sigma_{x,Ed}}{\rho_x f_y / \gamma_{M1}}\right)^2 + \left(\frac{\sigma_{z,Ed}}{\rho_z f_y / \gamma_{M1}}\right)^2 - \left(\frac{\sigma_{x,Ed}}{\rho_x f_y / \gamma_{M1}}\right)\left(\frac{\sigma_{z,Ed}}{\rho z f_y / \gamma_{M1}}\right) + 3\left(\frac{\tau_{Ed}}{\chi_w f_y / \gamma_{M1}}\right)^2 \leq 1.0$$

Regarding the utilization ratio calculated using this equation, it should be noted that the equation is valid for identifying von Mises stresses that exceed the yield criterion. However, for utilization ratios below 1.0, the result of the equation is not always representative of the true utilization ratio for von Mises stresses. This can be most clearly seen by means of an example. For a section that has only longitudinal compressive stresses and no shear stresses, such that:

$$\left(\frac{\sigma_{x,Ed}}{\rho_x f_y / \gamma_{M1}} \right) = 0.95 \quad \text{and} \quad \left(\frac{\tau_{Ed}}{\chi_w f_y / \gamma_{M1}} \right) = 0$$

The actual utilization ratio is clearly 0.95. However, the von Mises equation shown above would result in:

$$(0.95)^2 + (0)^2 - (0.95)(0) + 3(0)^2 = 0.9025$$

As mentioned, the shown von Mises equation does indeed correctly identify stresses that exceed the yield criterion and furthermore, the form of the equation is necessary in order correctly account for different capacities for the each of the stress components. However, it is still important to consider also the utilization ratios for each of the individual stress components.

The following tables show the calculated von Mises utilization ratios for each stress point on the cross section. The values provided are for cross beam #2 at the face of the tower leg under ULS wind loading transverse to the bridge.

	PLATE STRESS POINTS								Long. Stiffener Stress Points							
Stress point	SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8
side of cross section									+	+	+	+	+	+	+	+
Plate ID	OW1	OW2	OW1	OW2	TF	TF	TF	TF	OW1	OW1	OW1	OW1	OW1	OW1	OW1	OW1
Stress Point Location Y (mm)	9860.5	9860.5	-9860.5	-9860.5	9860.5	9860.5	-9860.5	-9860.5	0	1461	2817	4063	5273	6631	7803	8833
Z (mm)	3979.999	-3980	3979.999	-3980	3979.999	-3980	3979.999	-3980	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00
Stiff Type									T3	T3	T3	T2	T2	T1	T1	T1
Longitudinal Stress, x, UR	0.740	0.718	0.727	0.750	0.740	0.718	0.727	0.750	0.03	0.23	0.40	0.40	0.53	0.57	0.65	0.73
red. Factor	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91
Shear Stress UR	0.179	0.179	0.179	0.179	0.215	0.215	0.215	0.215	0.37	0.37	0.36	0.34	0.32	0.29	0.25	0.22
red. Factor	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Von Mises UR	**0.644**	**0.612**	**0.626**	**0.659**	**0.686**	**0.654**	**0.668**	**0.701**	**0.42**	**0.46**	**0.54**	**0.51**	**0.59**	**0.58**	**0.61**	**0.68**

	Long. Stiffener Stress Points													
Stress point	LS13	LS14	LS15	LS16	LS17	LS18	LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
side of cross section	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Plate ID	TF	TF	TF	TF	TF	TF	OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2
Stress Point Location Y (mm)	9860.5	9860.5	9860.5	9860.5	9860.5	9860.5	0	1461	2817	4063	5273	6631	7803	8833
Z (mm)	3100.00	1900.00	633.34	-633.32	-1899.98	-3099.98	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00
Stiff Type	T1	T1	T1	T1	T1	T1	T3	T3	T3	T2	T2	T1	T1	T1
Longitudinal Stress, x, UR	0.83	0.86	0.87	0.87	0.85	0.81	0.04	0.18	0.36	0.37	0.50	0.55	0.63	0.71
red. Factor	0.89	0.85	0.84	0.84	0.85	0.89	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91
Shear Stress UR	0.17	0.12	0.06	0.06	0.12	0.17	0.37	0.37	0.36	0.34	0.32	0.29	0.25	0.22
red. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Von Mises UR	**0.78**	**0.79**	**0.77**	**0.76**	**0.77**	**0.75**	**0.42**	**0.44**	**0.51**	**0.49**	**0.56**	**0.55**	**0.58**	**0.64**

	Long. Stiffener Stress Points													
Stress point	LS1	LS2	LS3	LS4	LS5	LS6	LS7	LS8	LS13	LS14	LS15	LS16	LS17	LS18
side of cross section	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Plate ID	OW1	OW1	OW1	OW1	OW1	OW1	OW1	OW1	TF	TF	TF	TF	TF	TF
Stress Point Y (mm)	0	-1461	-2817	-4063	-5273	-6631	-7803	-8833	-9860.5	-9860.5	-9860.5	-9860.5	-9860.5	-9860.5
Location Z (mm)	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	4000.00	3100.00	1900.00	633.34	-633.32	-1899.98	-3099.98
Stiff Type	T3	T3	T3	T2	T2	T1	T1	T1	T1	T1	T1	T1	T1	T1
Longitudinal Stress, x, UR	0.03	0.21	0.37	0.39	0.52	0.56	0.64	0.72	0.82	0.86	0.88	0.88	0.88	0.84
red. Factor	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91	0.89	0.85	0.84	0.84	0.85	0.89
Shear Stress UR	0.37	0.37	0.36	0.34	0.32	0.29	0.25	0.22	0.17	0.12	0.06	0.06	0.12	0.17
red. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Von Mises UR	**0.42**	**0.45**	**0.52**	**0.50**	**0.57**	**0.56**	**0.60**	**0.65**	**0.77**	**0.79**	**0.78**	**0.79**	**0.81**	**0.80**

	Long. Stiffener Stress Points							
Stress point	LS23	LS24	LS25	LS26	LS27	LS28	LS29	LS30
side of cross section	-	-	-	-	-	-	-	-
Plate ID	OW2	OW2	OW2	OW2	OW2	OW2	OW2	OW2
Stress Point Y (mm)	0	-1461	-2817	-4063	-5273	-6631	-7803	-8833
Location Z (mm)	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00	-4000.00
Stiff Type	T3	T3	T3	T2	T2	T1	T1	T1
Longitudinal Stress, x, UR	0.04	0.25	0.42	0.42	0.55	0.59	0.66	0.74
red. Factor	0.50	0.52	0.55	0.77	0.75	0.87	0.90	0.91
Shear Stress UR	0.37	0.37	0.36	0.34	0.32	0.29	0.25	0.22
red. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Von Mises UR	**0.42**	**0.47**	**0.56**	**0.52**	**0.60**	**0.59**	**0.63**	**0.69**

From the above tables, the maximum von Mises utilization ratios for both the unstiffened corners and longitudinal stiffeners are:

Information about governing corner stress point

Max UR	**0.701**
Governing Stress Point	SP8
Long UR	0.750
Red	1.000
Shear UR	0.215
Red	1

Information about governing longit. stiffener stress point

Max UR	**0.808**
Governing Stress Point	LS17
side	-
Long UR	0.852
Red	0.850
Shear UR	0.118
Red	1.000

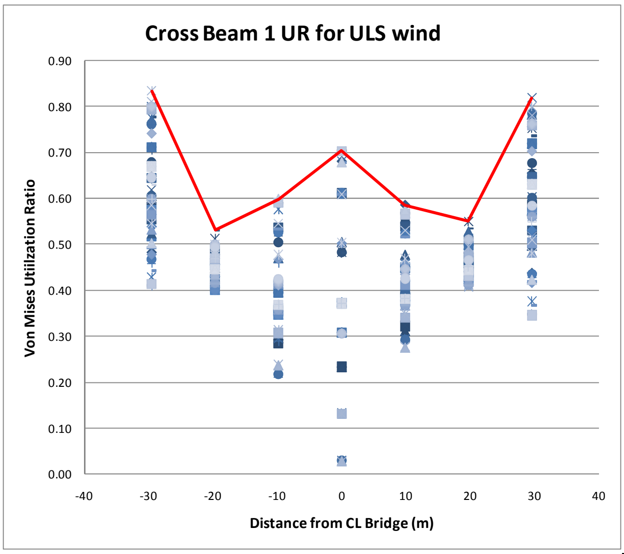
5.1.10 Overall Verification for all Three Cross Beams for Single Load Combination

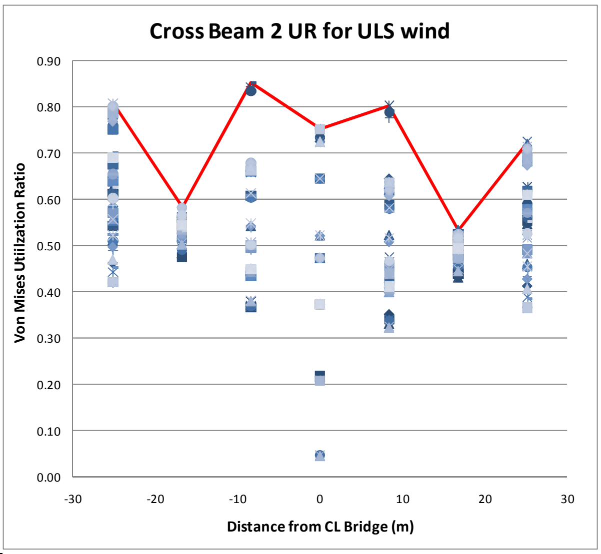
Using the same procedure as shown in the previous sections, the stresses and utilization ratios were then calculated for all sections within the three cross beams. The calculations for each section over the length of the cross beams were done using the same methods as shown above for the example section. The following tables show the resulting utilization ratios for all stiffeners and corner stress points on the cross section. Once again this verification of the three cross beams is shown for ULS Wind transverse to the bridge.

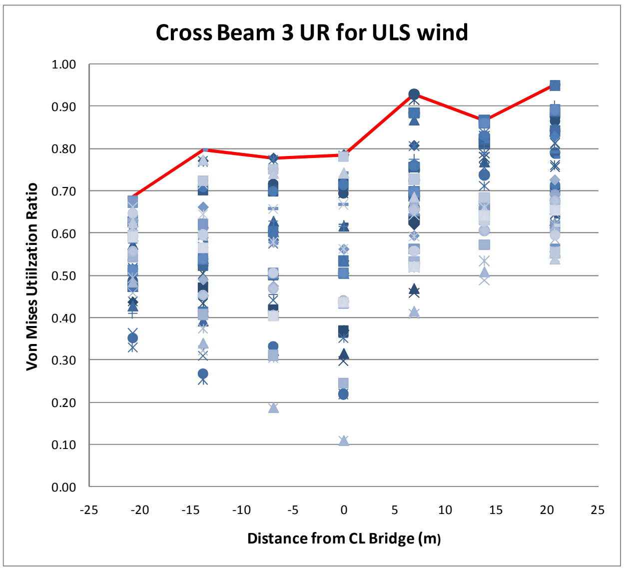
For reference, the same values presented in the previous tables for the end of cross beam 2 can be found in the following tables under column with the heading analysis section 8, cross beam 2.

				Cross Beam #1							Cross Beam #2							Cross Beam #3						
General	Analysis Section			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	S-coordinate			-29.531	-19.685	-9.842	0	9.842	19.685	29.531	-25.136	-16.755	-8.378	0	8.378	16.755	25.136	-20.742	-13.826	-6.913	0	6.913	13.826	20.742
	Cross Section Number			1	2	3	4	3	2	1	5	6	7	8	7	6	5	9	10	11	12	11	10	9
	Cross Beam Number			1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3
Input Summary	Plate sizes	OW1	mm	30	30	35	35	35	30	30	40	40	45	45	45	40	40	35	35	40	40	40	35	35
		TF	mm	25	25	25	25	25	25	25	35	35	25	25	25	35	35	40	40	30	30	30	40	40
		OW2	mm	30	30	35	35	35	30	30	40	40	45	45	45	40	40	35	35	40	40	40	35	35
		Depth	mm	21793	17234	12738	11500	12738	17234	21793	19721	15785	12317	11500	12317	15785	19721	17649	14338	11984	11500	11984	14338	17649
Section		A	(mm^2)	2.44E+06	2.28E+06	2.05E+06	1.88E+06	2.05E+06	2.28E+06	2.44E+06	2.84E+06	2.67E+06	2.29E+06	2.11E+06	2.29E+06	2.67E+06	2.84E+06	2.57E+06	2.39E+06	2.22E+06	2.07E+06	2.22E+06	2.39E+06	2.57E+06
		Y	(mm)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		Z	(mm)	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0
		a	(rad)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Properties		I_{1_Y}	(mm^4)	3.07E+13	2.75E+13	2.39E+13	2.12E+13	2.39E+13	2.75E+13	3.07E+13	3.54E+13	3.18E+13	2.74E+13	2.47E+13	2.74E+13	3.18E+13	3.54E+13	3.03E+13	2.68E+13	2.54E+13	2.34E+13	2.54E+13	2.68E+13	3.03E+13
		I_{2_Z}	(mm^4)	1.50E+14	9.29E+13	4.77E+13	3.61E+13	4.77E+13	9.29E+13	1.5E+14	1.43E+14	9.13E+13	4.77E+13	3.86E+13	4.77E+13	9.13E+13	1.43E+14	1.09E+14	7.37E+13	4.6E+13	3.99E+13	4.6E+13	7.37E+13	1.09E+14
VERIFICATION - UTILIZATION RATIOS - Von Mises																								
1	Plate Stress	SP1		0.65	0.44	0.29	0.23	0.33	0.48	0.65	0.64	0.49	0.37	0.22	0.35	0.46	0.59	0.44	0.45	0.41	0.37	0.62	0.82	0.83
2	Points (corners)	SP2		0.58	0.41	0.28	0.23	0.32	0.45	0.59	0.61	0.48	0.37	0.22	0.34	0.44	0.56	0.48	0.47	0.42	0.37	0.63	0.87	0.88
3		SP3		0.61	0.43	0.29	0.23	0.31	0.43	0.57	0.63	0.48	0.37	0.22	0.33	0.43	0.55	0.59	0.54	0.32	0.31	0.47	0.67	0.69
4		SP4		0.67	0.46	0.30	0.23	0.32	0.47	0.64	0.66	0.50	0.38	0.22	0.34	0.45	0.58	0.55	0.50	0.32	0.30	0.46	0.63	0.65
5		SP5		0.75	0.51	0.52	0.48	0.56	0.55	0.75	0.69	0.55	0.84	0.73	0.80	0.51	0.63	0.44	0.43	0.71	0.69	0.92	0.78	0.81
6		SP6		0.68	0.48	0.50	0.48	0.55	0.51	0.68	0.65	0.53	0.83	0.73	0.79	0.49	0.59	0.48	0.45	0.72	0.69	0.93	0.82	0.86
7		SP7		0.70	0.50	0.52	0.48	0.53	0.50	0.66	0.67	0.54	0.84	0.73	0.78	0.49	0.58	0.59	0.52	0.62	0.62	0.76	0.64	0.68
8		SP8		0.78	0.53	0.53	0.48	0.55	0.53	0.74	0.70	0.56	0.85	0.73	0.79	0.51	0.62	0.55	0.48	0.61	0.62	0.75	0.60	0.64
	Max Von Mises UR			**0.78**	**0.53**	**0.53**	**0.48**	**0.56**	**0.55**	**0.75**	**0.70**	**0.56**	**0.85**	**0.73**	**0.80**	**0.51**	**0.63**	**0.59**	**0.54**	**0.72**	**0.69**	**0.93**	**0.87**	**0.88**
	Governing Stress Point			**SP8**	**SP8**	**SP8**	**SP5**	**SP5**	**SP5**	**SP5**	**SP8**	**SP8**	**SP8**	**SP6**	**SP5**	**SP5**	**SP5**	**SP3**	**SP3**	**SP6**	**SP5**	**SP6**	**SP2**	**SP2**
	Longit UR			**0.81**	**0.59**	**0.42**	**0.07**	**0.47**	**0.62**	**0.80**	**0.75**	**0.60**	**0.52**	**0.05**	**0.49**	**0.57**	**0.71**	**0.65**	**0.54**	**0.43**	**0.32**	**0.65**	**0.80**	**0.85**
	Longit Red. Factor			**0.88**	**0.88**	**0.88**	**0.88**	**0.88**	**0.88**	**0.88**	**1.00**	**1.00**	**0.88**	**0.88**	**0.88**	**1.00**	**1.00**	**0.97**	**0.96**	**0.98**	**0.98**	**0.98**	**0.96**	**0.97**
	Shear UR			**0.20**	**0.25**	**0.34**	**0.40**	**0.34**	**0.24**	**0**	**0.21**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Shear Red.			**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**	**1**
9	Longitudinal	LS1	+	0.41	0.47	0.59	0.70	0.57	0.43	0.35	0.42	0.54	0.66	0.75	0.64	0.50	0.37	0.59	0.72	0.75	0.78	0.72	0.68	0.54
	Stiffener as	LS2	+	0.48	0.48	0.59	0.68	0.59	0.45	0.44	0.46	0.55	0.66	0.72	0.64	0.51	0.41	0.61	0.77	0.78	0.78	0.81	0.83	0.62
	effective column	LS3	+	0.55	0.49	0.54	0.61	0.54	0.47	0.53	0.54	0.56	0.61	0.65	0.59	0.53	0.49	0.63	0.70	0.70	0.72	0.76	0.81	0.70
		LS4	+	0.52	0.47	0.47	0.50	0.48	0.45	0.50	0.51	0.55	0.54	0.52	0.52	0.51	0.46	0.57	0.62	0.63	0.62	0.70	0.77	0.66
		LS5	+	0.62	0.48	0.41	0.37	0.43	0.48	0.60	0.59	0.56	0.49	0.37	0.47	0.52	0.53	0.57	0.57	0.57	0.51	0.69	0.79	0.76
		LS6	+	0.58	0.46	0.36	0.37	0.39	0.46	0.56	0.58	0.53	0.44	0.37	0.42	0.50	0.52	0.52	0.53	0.50	0.51	0.69	0.83	0.76
		LS7	+	0.61	0.43	0.36	0.37	0.39	0.45	0.60	0.61	0.53	0.44	0.37	0.42	0.49	0.56	0.49	0.52	0.50	0.51	0.69	0.82	0.79
		LS8	+	0.64	0.43	0.36	0.37	0.39	0.46	0.65	0.68	0.54	0.44	0.37	0.42	0.50	0.62	0.47	0.52	0.50	0.51	0.69	0.82	0.84
		LS13	+	0.77	0.48	0.40	0.31	0.46	0.53	0.78	0.78	0.57	0.67	0.47	0.63	0.53	0.72	0.43	0.39	0.59	0.53	0.87	0.82	0.89
		LS14	+	0.80	0.45	0.30	0.13	0.37	0.51	0.82	0.79	0.53	0.50	0.21	0.46	0.50	0.73	0.36	0.31	0.44	0.35	0.75	0.75	0.84
		LS15	+	0.78	0.42	0.22	0.03	0.29	0.48	0.80	0.77	0.49	0.37	0.05	0.34	0.46	0.71	0.33	0.25	0.33	0.22	0.65	0.71	0.81
		LS16	+	0.76	0.41	0.22	0.03	0.29	0.47	0.78	0.76	0.49	0.37	0.05	0.34	0.46	0.70	0.35	0.27	0.33	0.22	0.66	0.74	0.85
		LS17	+	0.76	0.44	0.29	0.13	0.36	0.49	0.78	0.77	0.52	0.49	0.21	0.45	0.48	0.70	0.41	0.33	0.45	0.35	0.77	0.80	0.90
		LS18	+	0.71	0.45	0.39	0.31	0.45	0.50	0.72	0.75	0.55	0.66	0.47	0.62	0.51	0.68	0.47	0.41	0.60	0.53	0.88	0.87	0.95
		LS23	+	0.41	0.47	0.59	0.70	0.57	0.43	0.35	0.42	0.54	0.66	0.75	0.64	0.50	0.37	0.59	0.72	0.75	0.78	0.73	0.68	0.55
		LS24	+	0.43	0.46	0.58	0.68	0.57	0.43	0.38	0.44	0.54	0.66	0.72	0.64	0.50	0.39	0.61	0.77	0.77	0.78	0.81	0.84	0.62
		LS25	+	0.47	0.47	0.53	0.61	0.52	0.44	0.44	0.51	0.55	0.60	0.65	0.58	0.51	0.45	0.63	0.71	0.70	0.71	0.76	0.83	0.71
		LS26	+	0.46	0.45	0.46	0.50	0.46	0.43	0.43	0.49	0.54	0.54	0.52	0.52	0.50	0.43	0.58	0.63	0.63	0.62	0.71	0.79	0.67
		LS27	+	0.54	0.45	0.40	0.37	0.42	0.45	0.52	0.56	0.55	0.49	0.37	0.47	0.51	0.50	0.58	0.58	0.58	0.51	0.70	0.82	0.78
		LS28	+	0.51	0.43	0.35	0.37	0.38	0.43	0.49	0.55	0.52	0.44	0.37	0.41	0.48	0.49	0.54	0.54	0.50	0.51	0.70	0.87	0.79
		LS29	+	0.54	0.41	0.35	0.37	0.38	0.42	0.53	0.58	0.51	0.44	0.37	0.41	0.47	0.52	0.52	0.54	0.50	0.51	0.70	0.86	0.83
		LS30	+	0.57	0.40	0.35	0.37	0.38	0.42	0.57	0.64	0.52	0.44	0.37	0.41	0.48	0.58	0.51	0.54	0.50	0.51	0.70	0.86	0.89
		LS1	-	0.41	0.47	0.59	0.70	0.57	0.43	0.35	0.42	0.54	0.66	0.75	0.64	0.50	0.37	0.59	0.72	0.75	0.78	0.72	0.68	0.54
		LS2	-	0.44	0.47	0.58	0.68	0.56	0.43	0.37	0.45	0.55	0.66	0.73	0.63	0.50	0.39	0.64	0.80	0.75	0.74	0.69	0.67	0.54
		LS3	-	0.49	0.48	0.53	0.61	0.52	0.44	0.42	0.52	0.56	0.61	0.65	0.57	0.51	0.45	0.68	0.73	0.66	0.67	0.64	0.67	0.57
		LS4	-	0.48	0.46	0.47	0.50	0.46	0.42	0.42	0.50	0.54	0.54	0.52	0.51	0.49	0.43	0.63	0.66	0.58	0.56	0.59	0.64	0.56
		LS5	-	0.56	0.47	0.41	0.37	0.41	0.44	0.50	0.57	0.55	0.50	0.37	0.46	0.50	0.49	0.67	0.62	0.51	0.43	0.56	0.65	0.62
		LS6	-	0.53	0.44	0.36	0.37	0.37	0.42	0.48	0.56	0.53	0.44	0.37	0.40	0.47	0.48	0.64	0.60	0.41	0.43	0.53	0.67	0.62
		LS7	-	0.56	0.42	0.36	0.37	0.37	0.41	0.52	0.60	0.52	0.44	0.37	0.40	0.47	0.52	0.62	0.60	0.41	0.43	0.53	0.67	0.65
		LS8	-	0.60	0.42	0.36	0.37	0.37	0.41	0.56	0.65	0.53	0.44	0.37	0.40	0.47	0.57	0.63	0.60	0.41	0.43	0.53	0.67	0.69
		LS13	-	0.74	0.47	0.41	0.31	0.43	0.48	0.70	0.77	0.56	0.67	0.47	0.61	0.50	0.67	0.61	0.49	0.47	0.44	0.67	0.65	0.73
		LS14	-	0.79	0.46	0.31	0.13	0.34	0.48	0.76	0.79	0.53	0.50	0.21	0.44	0.47	0.69	0.54	0.41	0.31	0.25	0.53	0.57	0.67
		LS15	-	0.80	0.43	0.24	0.03	0.27	0.45	0.77	0.78	0.50	0.38	0.05	0.32	0.44	0.69	0.48	0.34	0.19	0.11	0.42	0.51	0.61
		LS16	-	0.81	0.44	0.24	0.03	0.28	0.46	0.78	0.79	0.51	0.38	0.05	0.33	0.45	0.69	0.46	0.32	0.19	0.11	0.41	0.49	0.59
		LS17	-	0.83	0.48	0.31	0.13	0.35	0.49	0.80	0.81	0.55	0.51	0.21	0.45	0.49	0.71	0.49	0.37	0.30	0.25	0.52	0.53	0.62
		LS18	-	0.80	0.50	0.42	0.31	0.45	0.51	0.76	0.80	0.58	0.68	0.47	0.62	0.52	0.71	0.56	0.45	0.47	0.44	0.66	0.61	0.68
		LS23	-	0.41	0.47	0.59	0.70	0.57	0.43	0.35	0.42	0.54	0.66	0.75	0.64	0.50	0.37	0.59	0.72	0.75	0.78	0.73	0.68	0.55
		LS24	-	0.50	0.48	0.60	0.68	0.57	0.44	0.42	0.47	0.55	0.67	0.72	0.64	0.51	0.41	0.63	0.77	0.74	0.74	0.68	0.66	0.54
		LS25	-	0.59	0.50	0.55	0.61	0.53	0.46	0.51	0.56	0.57	0.61	0.64	0.58	0.52	0.48	0.66	0.72	0.66	0.67	0.64	0.66	0.56
		LS26	-	0.54	0.48	0.48	0.50	0.47	0.44	0.48	0.52	0.55	0.55	0.52	0.52	0.50	0.45	0.61	0.64	0.58	0.56	0.59	0.63	0.54
		LS27	-	0.65	0.49	0.42	0.37	0.43	0.47	0.58	0.60	0.57	0.50	0.37	0.47	0.52	0.53	0.65	0.60	0.51	0.44	0.56	0.63	0.60
		LS28	-	0.60	0.47	0.37	0.37	0.38	0.45	0.55	0.59	0.54	0.45	0.37	0.41	0.49	0.52	0.61	0.57	0.40	0.44	0.52	0.64	0.60
		LS29	-	0.63	0.45	0.37	0.37	0.38	0.44	0.59	0.63	0.53	0.45	0.37	0.41	0.49	0.55	0.59	0.56	0.40	0.44	0.52	0.64	0.62
		LS30	-	0.67	0.45	0.37	0.37	0.38	0.44	0.63	0.69	0.55	0.45	0.37	0.41	0.49	0.61	0.59	0.56	0.40	0.44	0.52	0.64	0.65
	Max UR			**0.83**	**0.50**	**0.60**	**0.70**	**0.59**	**0.53**	**0.82**	**0.81**	**0.58**	**0.68**	**0.75**	**0.64**	**0.53**	**0.73**	**0.68**	**0.80**	**0.78**	**0.78**	**0.88**	**0.87**	**0.95**
	Governing Stiffener			**LS17**	**LS25**	**LS24**	**LS1**	**LS2**	**LS13**	**LS14**	**LS17**	**LS18**	**LS18**	**LS1**	**LS2**	**LS13**	**LS14**	**LS3**	**LS2**	**LS2**	**LS2**	**LS18**	**LS18**	**LS18**
	side			**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**	**+**
	Longit UR			**0.85**	**0.18**	**0.12**	**0.05**	**0.21**	**0.65**	**0.89**	**0.85**	**0.65**	**0.53**	**0.03**	**0.19**	**0.64**	**0.83**	**0.33**	**0.34**	**0.29**	**0.22**	**0.73**	**0.84**	**0.91**
	Longit Red. Factor			**0.78**	**0.62**	**0.53**	**0.59**	**0.53**	**0.83**	**0.78**	**0.85**	**0.89**	**0.83**	**0.58**	**0.54**	**0.89**	**0.85**	**0.61**	**0.50**	**0.55**	**0.59**	**0.87**	**0.90**	**0.90**
	Shear UR			**0.11**	**0.38**	**0.43**	**0.48**	**0.42**	**0.19**	**0.10**	**0.12**	**0.21**	**0.36**	**0.50**	**0.45**	**0.20**	**0.11**	**0.42**	**0.47**	**0.48**	**0.50**	**0.34**	**0.23**	**0.20**
	Shear Red. Factor			**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**	**1.00**
Summary	**Corners**	**UR**		**0.78**	**0.53**	**0.53**	**0.48**	**0.56**	**0.55**	**0.75**	**0.70**	**0.56**	**0.85**	**0.73**	**0.80**	**0.51**	**0.63**	**0.59**	**0.54**	**0.72**	**0.69**	**0.93**	**0.87**	**0.88**
	Stiffeners	**UR**		**0.83**	**0.50**	**0.60**	**0.70**	**0.59**	**0.53**	**0.82**	**0.81**	**0.58**	**0.68**	**0.75**	**0.64**	**0.53**	**0.73**	**0.68**	**0.80**	**0.78**	**0.78**	**0.88**	**0.87**	**0.95**
		Max UR		**0.83**	**0.53**	**0.60**	**0.70**	**0.59**	**0.55**	**0.82**	**0.81**	**0.58**	**0.85**	**0.75**	**0.80**	**0.53**	**0.73**	**0.68**	**0.80**	**0.78**	**0.78**	**0.93**	**0.87**	**0.95**

The following figures show a plot of the von Mises utilization ratios for all stress points on each of the three cross beams. From the plot it is clear that for the ULS wind load combination being considered, all utilization ratios are below 1.0 for each of the three cross beams.





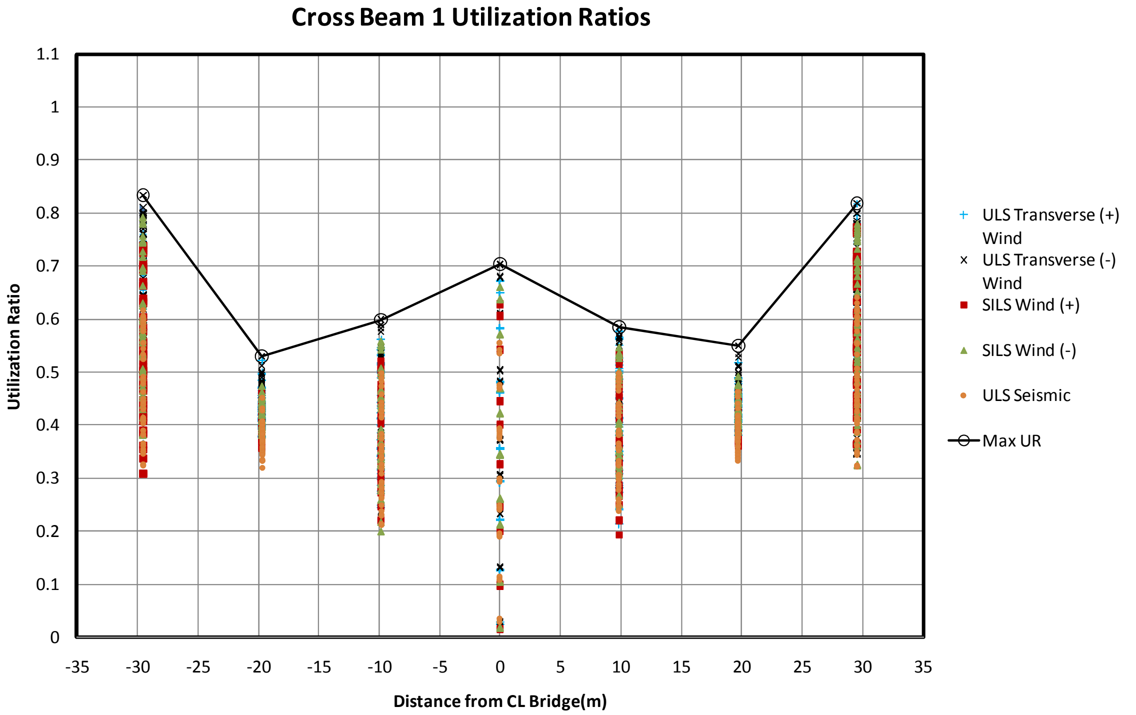


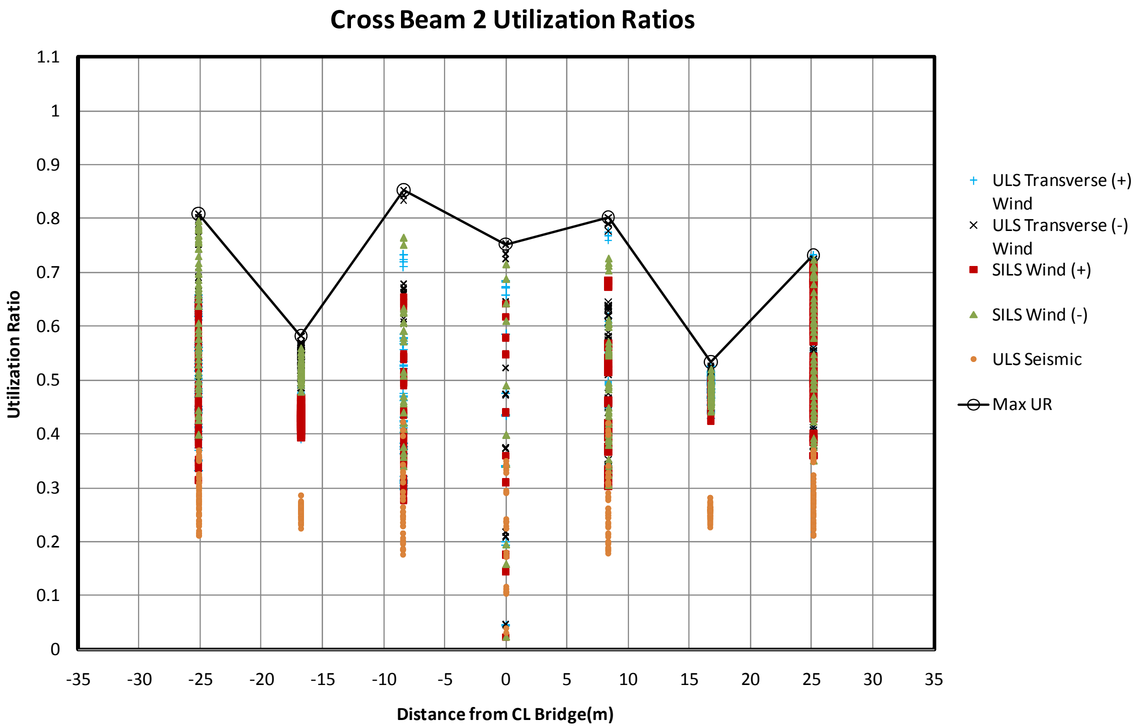
5.1.11 Verification for All Load Combinations

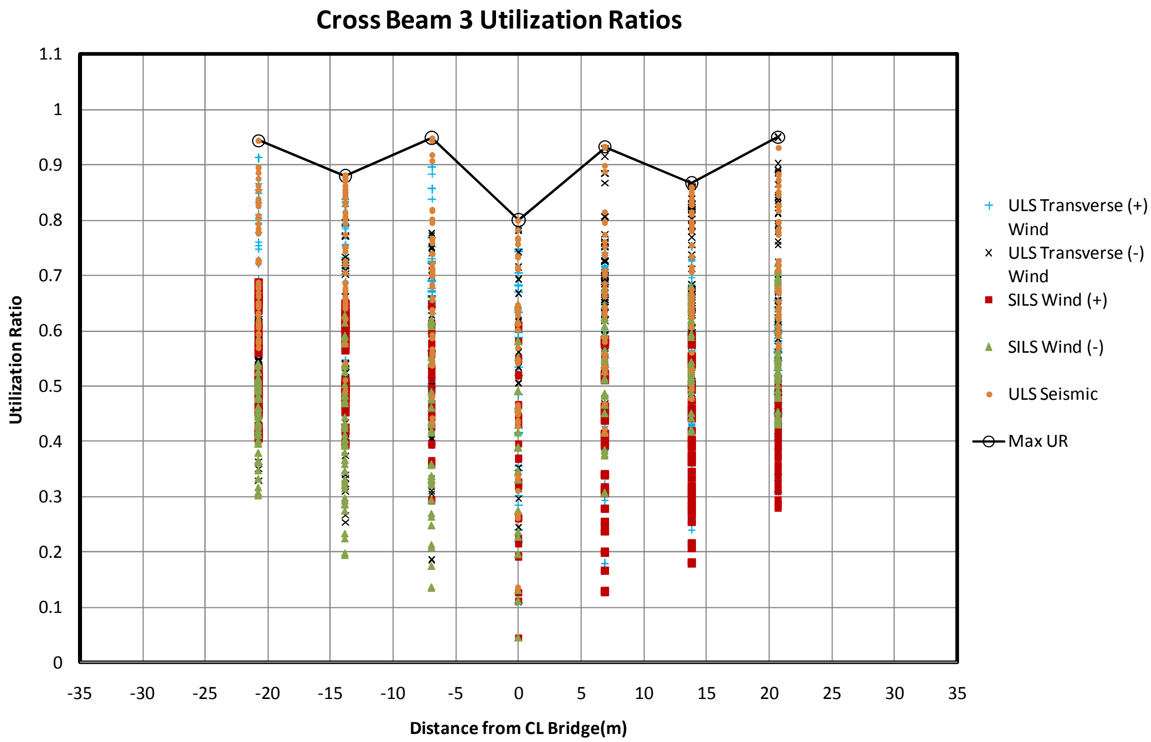
Using the same procedures as illustrated in the calculations above, all relevant load combinations were checked for all three cross beams. Due to the size of the data produced by these calculations, only the governing utilization ratios are provided here. The following plot shows the governing utilization ratio of all load combinations for each of the three cross beams.

Analysis Section	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
S-coordinate	-29.531	-19.685	-9.842	0	9.842	19.685	29.531	-25.136	-16.755	-8.378	0	8.378	16.755	25.136	-20.742	-13.826	-6.913	0	6.913	13.826	20.742
	Governing Utilization Ratios																				
Description	Cross Beam 1							Cross Beam 2							Cross Beam 3						
ULS 3 & 7 SEISMIC	0.62	0.45	0.50	0.56	0.50	0.46	0.64	0.37	0.29	0.42	0.35	0.42	0.28	0.37	0.94	0.88	0.95	0.80	0.93	0.86	0.93
SILS 2 SEISMIC	0.46	0.32	0.37	0.42	0.37	0.33	0.48	0.27	0.20	0.27	0.23	0.27	0.20	0.27	0.62	0.60	0.61	0.55	0.60	0.58	0.61
ULS 2 & 6: WIND, NORTH	0.78	0.52	0.56	0.67	0.58	0.52	0.82	0.66	0.49	0.73	0.68	0.78	0.53	0.73	0.91	0.84	0.90	0.75	0.74	0.75	0.65
ULS 2 & 6: WIND, WEST	0.17	0.13	0.13	0.14	0.13	0.13	0.17	0.14	0.11	0.17	0.14	0.17	0.11	0.14	0.36	0.35	0.41	0.30	0.41	0.35	0.36
ULS 2 & 6: WIND, SOUTH	0.83	0.53	0.60	0.70	0.59	0.55	0.82	0.81	0.58	0.85	0.75	0.80	0.53	0.73	0.68	0.80	0.78	0.78	0.93	0.87	0.95
ULS 2 & 6: WIND, EAST	0.18	0.14	0.15	0.14	0.15	0.15	0.18	0.14	0.11	0.18	0.14	0.17	0.11	0.14	0.35	0.33	0.39	0.30	0.39	0.33	0.35
ULS 2 & 6: WIND, 45 DEG (+,+)	0.53	0.37	0.39	0.46	0.40	0.36	0.55	0.42	0.32	0.49	0.45	0.52	0.35	0.47	0.68	0.63	0.69	0.53	0.56	0.55	0.46
ULS 2 & 6: WIND, 45 DEG (+,-)	0.57	0.37	0.42	0.48	0.40	0.38	0.56	0.52	0.39	0.57	0.49	0.54	0.35	0.46	0.48	0.58	0.58	0.55	0.71	0.65	0.71
ULS 2 & 6: WIND, 45 DEG (-,+)	0.52	0.37	0.39	0.46	0.40	0.36	0.56	0.42	0.31	0.48	0.44	0.53	0.35	0.48	0.67	0.63	0.69	0.53	0.55	0.55	0.46
ULS 2 & 6: WIND, 45 DEG (-,-)	0.57	0.37	0.41	0.48	0.41	0.38	0.55	0.52	0.38	0.58	0.49	0.52	0.34	0.45	0.48	0.58	0.58	0.55	0.72	0.65	0.70
SILS 1: WIND, NORTH	0.74	0.46	0.52	0.63	0.54	0.46	0.77	0.65	0.47	0.65	0.64	0.69	0.50	0.71	0.69	0.65	0.65	0.61	0.59	0.59	0.51
SILS 1: WIND, WEST	0.11	0.08	0.08	0.08	0.08	0.08	0.11	0.09	0.07	0.09	0.07	0.09	0.07	0.09	0.18	0.18	0.21	0.14	0.21	0.18	0.18
SILS 1: WIND, SOUTH	0.79	0.47	0.56	0.66	0.55	0.49	0.78	0.79	0.56	0.76	0.71	0.73	0.52	0.72	0.54	0.63	0.62	0.65	0.68	0.68	0.72
SILS 1: WIND, EAST	0.11	0.09	0.08	0.08	0.08	0.09	0.11	0.09	0.07	0.10	0.07	0.10	0.07	0.09	0.18	0.18	0.20	0.14	0.20	0.18	0.18
SILS 1: WIND, 45 DEG (+,+)	0.47	0.30	0.33	0.40	0.35	0.30	0.49	0.39	0.28	0.41	0.38	0.42	0.31	0.43	0.47	0.45	0.46	0.38	0.39	0.38	0.33
SILS 1: WIND, 45 DEG (+,-)	0.51	0.31	0.36	0.42	0.35	0.32	0.49	0.48	0.34	0.47	0.43	0.45	0.31	0.43	0.35	0.41	0.41	0.41	0.48	0.47	0.49
SILS 1: WIND, 45 DEG (-,+)	0.47	0.30	0.34	0.40	0.34	0.30	0.49	0.39	0.28	0.39	0.38	0.44	0.32	0.44	0.47	0.46	0.46	0.38	0.39	0.38	0.33
SILS 1: WIND, 45 DEG (-,-)	0.51	0.31	0.36	0.42	0.35	0.32	0.49	0.48	0.35	0.48	0.42	0.43	0.31	0.43	0.35	0.40	0.42	0.41	0.48	0.48	0.49
ULS5: DEAD & LIVE	0.14	0.12	0.12	0.11	0.12	0.12	0.14	0.11	0.09	0.15	0.13	0.14	0.09	0.11	0.36	0.35	0.42	0.33	0.42	0.35	0.36
Max UR of all Load Combinations	**0.83**	**0.53**	**0.60**	**0.70**	**0.59**	**0.55**	**0.82**	**0.81**	**0.58**	**0.85**	**0.75**	**0.80**	**0.53**	**0.73**	**0.94**	**0.88**	**0.95**	**0.80**	**0.93**	**0.87**	**0.95**

From the above table it can be seen that the highest utilization ratios in cross beams are produced by ULS and SILS wind acting transverse to bridge and ULS seismic. The utilization ratio for the ULS wind is typically approximately the same as for SILS wind. This is because the partial safety factor is 1.0 for ULS and 1.1 for SILS combinations. The following plots show the UR for all stress points for the critical load combinations of ULS and SILS wind and ULS Seismic.


Cross Beam 1 Utilization Ratios
Utilization Ratio
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Distance from CL Bridge(m)
ULS Transverse (+) Wind
ULS Transverse (-) Wind
SILS Wind (+)
SILS Wind (-)
ULS Seismic
Max UR


Cross Beam 2 Utilization Ratios
Utilization Ratio
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-35
-30
-25
-20
-15
-10
-5
0
5
10
15
20
25
30
35
Distance from CL Bridge(m)
ULS Transverse (+) Wind
ULS Transverse (-) Wind
SILS Wind (+)
SILS Wind (-)
ULS Seismic
Max UR



Furthermore, the verification shown above is for the three cross beams within the Sicilia tower. As the cross beams are controlled by transverse loads, the cross beam forces for the Calabria tower will be nearly identical and the verification and design will be valid for the cross beams in both towers. To confirm this, the maximum bending moments under transverse wind from the south and ULS seismic were compared for the Sicilia and Calabria cross beams.

ULS wind from South

	Maximum Strong Axis Moment (MNm)	
	Sicilia Tower	Calabria Tower
Cross Beam 1	2703	2647
Cross Beam 2	3221	3152
Cross Beam 3	2585	2534

SILS wind from South

	Maximum Strong Axis Moment (MNm)	
	Sicilia Tower	Calabria Tower
Cross Beam 1	3226	3157
Cross Beam 2	3786	3705
Cross Beam 3	2843	2783

ULS Seismic

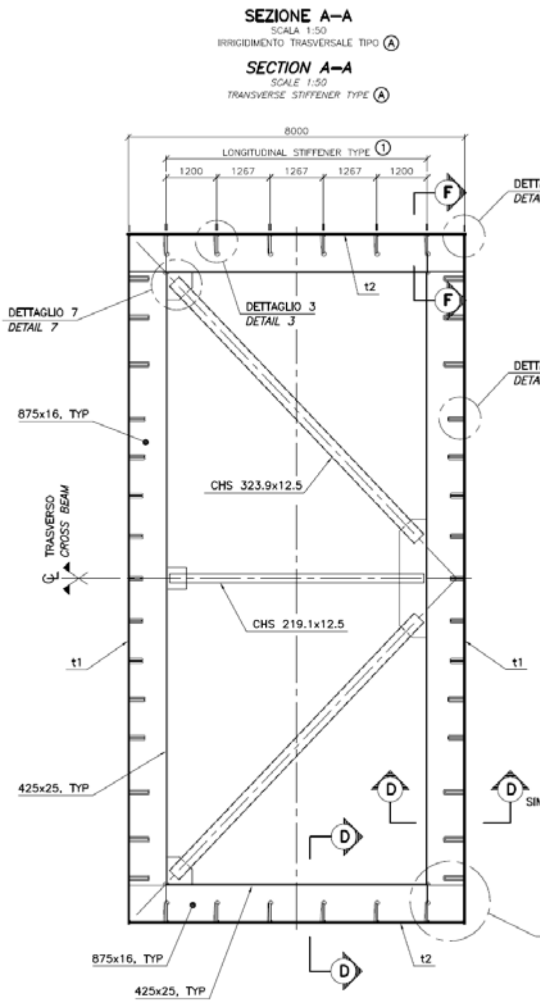
	Maximum Strong Axis Moment (MNm)	
	Sicilia Tower	Calabria Tower
Cross Beam 1	1932	1427
Cross Beam 2	1572	1528
Cross Beam 3	2342	1792

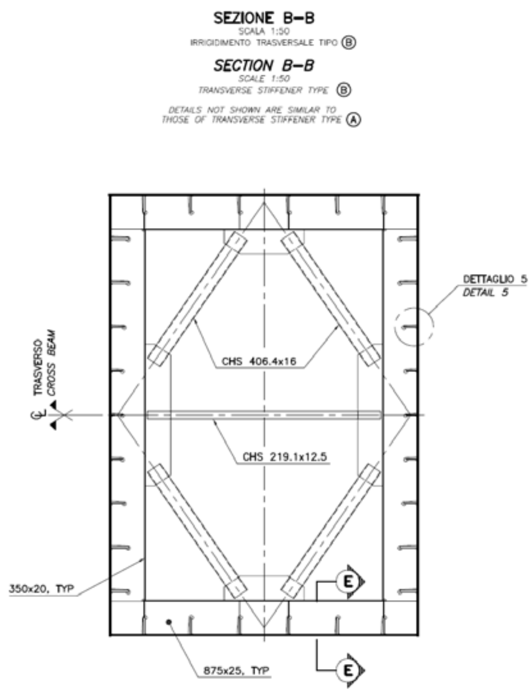
Therefore, it can be concluded that repeating the verification for the Calabria tower is not necessary.

5.2 Transverse Elements

The verification of the transverse elements in the cross beams was done in accordance with the design procedure presented in the CG.10.00-P-RG-D-P-SV-T4-00-00-00-00-01 “General Design Principles.”

The verification was done for the two types of transverse stiffeners, type A and type B, shown in the following figures.





Due to the minimal quantities associated with the cross beam transverse stiffeners, a slightly conservative approach was taken by using the maximum cross beam depth within each type of stiffener as well as the maximum main plate thickness for a given stiffener type. Therefore, the transverse stiffener plate dimensions are constant for all type A or type B transverse stiffeners.

For each stiffener type, the flange and web stiffeners are considered separately as each are responsible for resisting different forces. Furthermore, the transverse stiffeners in the flange must carry the axial load due to the shear reaction from the transverse stiffener on the web and vice-versa. Therefore, the verification is a slightly iterative procedure because the design of the flange stiffener is dependent of the design of the web stiffener and vice-versa. To avoid this, the axial load placed on each stiffener due to the reaction from the adjacent stiffener was taken as a moderately higher value than the actual reaction to avoid cycles of iterations. The same approach was used to for any additional forces that arise in the transverse stiffeners due to the bracing system.

The following sections show the verification for each unique transverse stiffener that was considered.

5.2.1 Transverse Stiffener Type A – Flange Stiffeners

Design of Transverse Stiffeners on Flanges - Diaphragm Type A

Panel Geometry

panel width

b	8000	(flange width)

spacing of diaphragms, a (use maximum of either side)

a1	4000
a2	4000

initial imperfection, w0. use s/300 where s is the minimum of a, b1 or b2.

w0	13.33

maximum additional deflection (use b/300)

w1, stiff	26.67	(max additional deflection for stiffeness considerations)

gamma,m1	1.1

Panel Loading

direct compressive stresses in panel (due to global bending)

max longitudinal stress at edge 1	350	consevative upper bound to longitudinal stress in cross beam
max longitudinal stress at edge 2	350	

mkleymann:
Includes 350 kN from web stiffener reaction and 725 kN from brace frame design

Nl	170432500	N

direct axial load in stiffener (due to reaction from adjacent panels at 90 degrees)

Na	1075000	N	(determine from design of web stiffener) (include additional compression due to braced frame forces)

direct applied out of plane loading (due to inclined flange, or ganty loads)

Equivalent Fd from Gantry Loads	52	N/mm	(see hand calcs)
Fd	52	N/mm	ganty load + kick force from curved flanges

Stiffener Dimension

web depth	875	mm	
web thickness	16	mm	
Flange width	425	mm	
Flange thickness	25	mm	
Stiffener yield	460	Mpa	
Main Plate thickness	40	mm	(max of flange thickness with type A stiff)
Area of Main Stiff.	166950	mm2	(6- 525x53 stiff)
Main Plate yield	460	mpa	

cut-out dimension

depth	545
width	100

E	200000	MPa

Stiffener Section Properties

Effective Stiffener properties

Since actual stress distribution is unknown, conservatively assume full compression

Local Buckling of Stiffener Web

b_{pl}		[mm]	875
t_{pl}	5)	[mm]	16.0
ψ_{pl}	5: Table 4.1	[-]	1
$K_{s,pl}$	5: Table 4.1	[-]	4
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,pl}$_hat	5: (4.3)	[-]	1.35
ρ_{pl}	5: (4.2)	[-]	**0.62**
beff,total		[mm]	543.48
beff,top			271.7
Remaining Web above cut-out			330
Web depth used in design			271.7

Local Buckling of Stiffener Flange

h		[mm]	212.5
t_{stif}	5)	[mm]	25
$K_{s,stif}$	1), 5: Table 4.2	[-]	0.43
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,stif}$_hat	5: (4.3)	[-]	0.64
ρ_{stif}	5: (4.3)	[-]	1.00
beff		[mm]	212.50
Beff, total		mm	425

Main Plate effective width

For the main plate, the effective width of 2 x 15εt will govern over local buckling

e	0.71
effective width	858

Section Properties

	b	t	Area	y	Ay	Ad^2	I'x
Main Plate	858	40	34308	20	686161	2366424984	4574408.97
Stiffener web	271.7	16	4348	779.1302	3387529	1071784973	26754555.5
Stiffener flange	425	25	10625	927.5	9854688	4418451583	553385.417
		Area	49281	ybar	282.6324		I,stiff 7888543890

e1 283
e2 657

Summary of Stiffener Section Properties

Area	49281
I,x	7.89E+09
ybar	283
emax	657

Check Minimum Stiffness

determine minimum stiffener to limit additional deflection to w1

Imin, stiffness 3.82E+09 ok

Check Strength Requirements

Max Flange Stress account for torsional buckling of flange

It	3408208	
yf	887.5	
Iflange	159928385.4	
Ipolar = Ix + Iy		
Ix	11941764323	
Iy	159928385.4	
Ipolar = Ix + Iy	12101692708	
G	76000	
sigma_cr	358.5	seems reasonable compared to flange as strut

considering simple case of flange as a strut

Area (using ha	17625
sigma_cr	293.9
lamda	1.13
emax_z	106.25
i	95.3
alpha	0.49
alpha_e	0.590
Φ	1.42
X	0.44

Maximum stress in flange considering stability

sigma,br 202.8

Stress due to axial only

sigma,a 21.8

Therefore, maximum stress allowed in stiffener due to bending only

sigma, bmax 162.6

Determine max additional deflection that causes yielding of stiffener

w1, strength 8.0
recall that w1, stiffness 26.7
Therefore, stiffener is govened by Strength

Determine min I such that the additional deflection w1 does not exceed w1,strength

Imin, strength 7.42E+09 OK

Summary

Stiffner Size

web	**875 x 16**			
flange	**425 x 25**			
Istiff	**7.89E+09**		D/C	
Imin, stiffness	**3.82E+09**	OK	0.48	
Imin, strength	**7.42E+09**	OK	0.94	
Net Section, Shear D/C	0.517			
Gross Section D/C	0.208			

Find equivalent UDL due to destabalizing effects

Find actual w1 caused by various loading

applied Fd	52	N/mm
Q due to NL and Na	10.82	N/mm
w1, actual	7.35	mm

controlling w1 for capacity

8.0 strength criteria

Equivalent Forces at midspan

	at capacity	actual applied	
y	4000	4000	
Fd	300.84	275.74	N/mm
Vd	0.0	0.0	N
Md	1950802363	1788037628	

check to see if Md produces stress equal to sigma, bmax

162.6 OK

Equivalent Forces at end

	at capacity	actual applied	
y	0	0	
Fd	0.00	0.00	N/mm
Vd	**766078**	**702161**	N
Md	0	0	

Equivalent Forces at cut-out

	at capacity at cutout	actual applied	
y	900	900	
Fd	104.13	95.44	N/mm
Vd	**718728**	**658761**	N
Md	675205972.6	618870321.9	

mkleymann:
Apply as axial load to Web Transverse Stiffener - use 800 kn to avoid iteration

Check Shear Capacity

At end (with full web section)

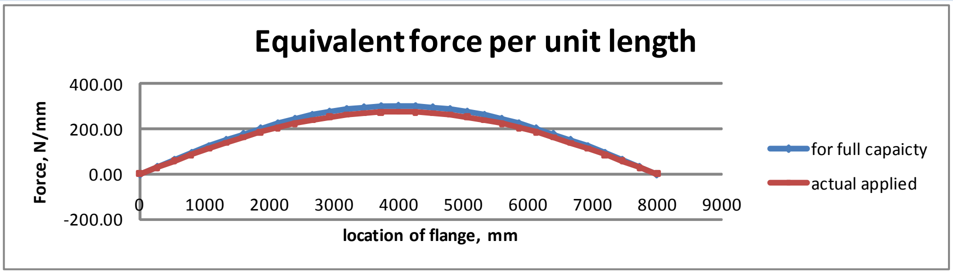
Shear Demand at end	702161	
Gross Shear Area	14000	
h/w	54.6875	need to check shear buckling
capacity	3380123	
D/C	0.208	OK

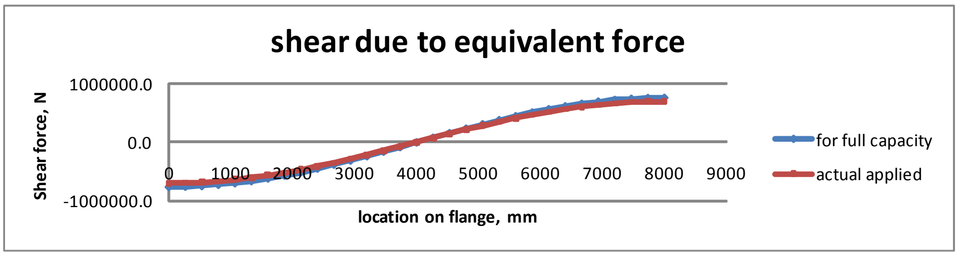
Shear Demand at cut-out	658761	
Cut out shear Area	5280	
capacity	1274789	
	0.517	OK

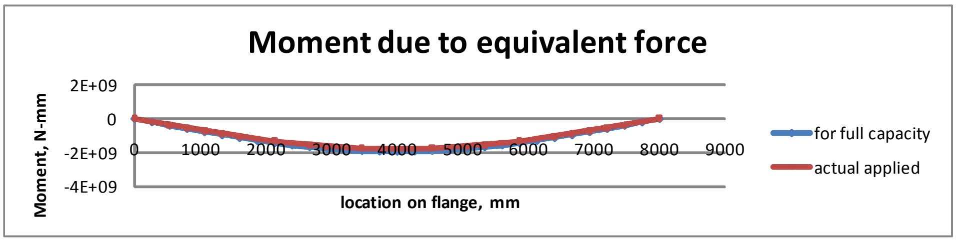
Check minimum stiffness for shear (as per 9.3.3 (3)

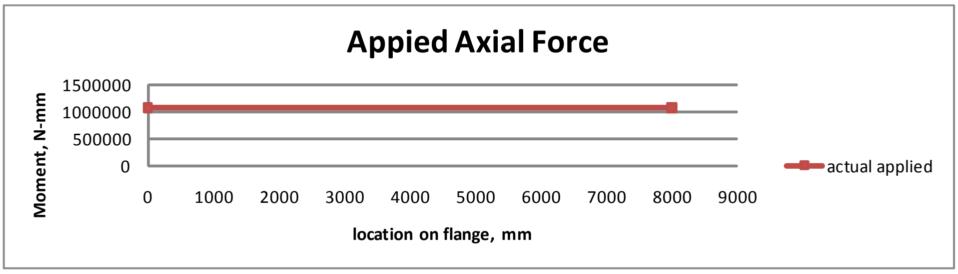
Ist, min	3.07E+09	
I, stiff	7.89E+09	ok

Plot forces on Stiffener









The following are the hand calculations used to determine the equivalent loading due to the inspection gantry for the transverse stiffeners on the cross beam flanges.

2388

COWI

Memo	Messina Strait Bridge, Progetto Definitivo, A9055 MEM-7-014
Title	Travelling gantry for tower cross beam - Wheel design loads
Date	16 August 2010
To	COWI: JEJE, CHSX
Copy	KPL
From	LFJ

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Denmark

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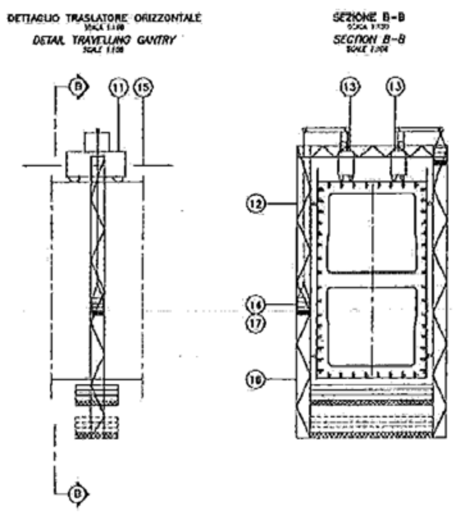
1 Introduction

This memo is prepared in order to evaluate the wheel design loads acting on the tower cross beams due to the travelling gantries.

2 Travelling gantry wheel design loads

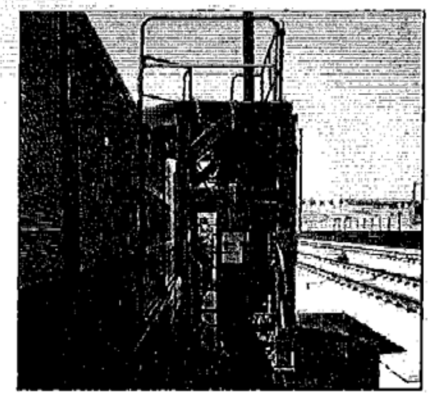
The travelling gantries for inspection of the tower cross beams are expected to be supported by two motorized "trains" running on rails located on the top of the cross beams. These trains can be working independently all along the cross beam or linked together as shown on the sketch below.



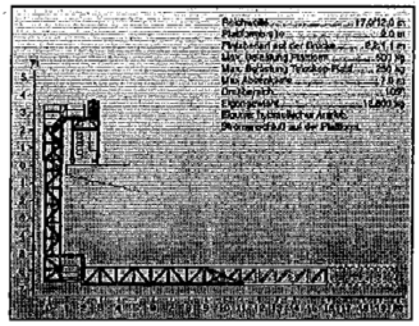
2 / 2

The wheel design loads for one supporting train can be estimated by choosing a standard travelling gantry like MBS 170-2, which could be modified to reach one half of the tower cross beam (WxH = 8x11.3 m to approx. 20 m), see sketch below.

MBS 170-2/ MBS 120-2 DB



Geräte für die kostengünstige Langzeitsanierung. Platzbedarf auf der Brücke ab Geländer beim MBS 170-2 = 2,2 m und beim MBS 120-2 Deutsche Bundesbahn = 1,1 m. Komplette Stromversorgung 220 und 380 Volt. Lärmschutzwandübergreifung 2,45 m. Hydrostatischer Fahrantrieb. Aufbau mit Autokran.

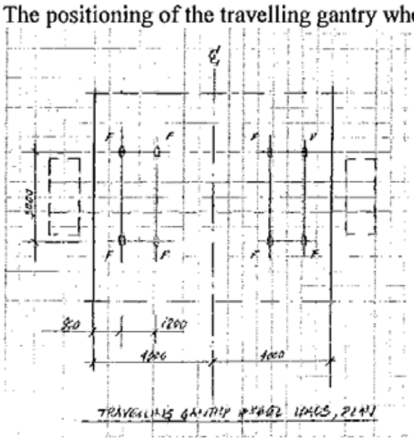


The wheel design loads for the travelling gantries are:

Permanent load:	F_G = 128/4 ± 50 % = 32 ± 16 kN.
Variable live load:	F_Q = 8/4 ± 50 % = 2 ± 1 kN (Personnel 2 kN + painting equipment 2 kN + mobile hoist & wire ropes 3 kN + concentrated load 1 kN = 8 kN).

Variable wind, seismic and thermal loads are not estimated at present.

The positioning of the travelling gantry wheel loads are:

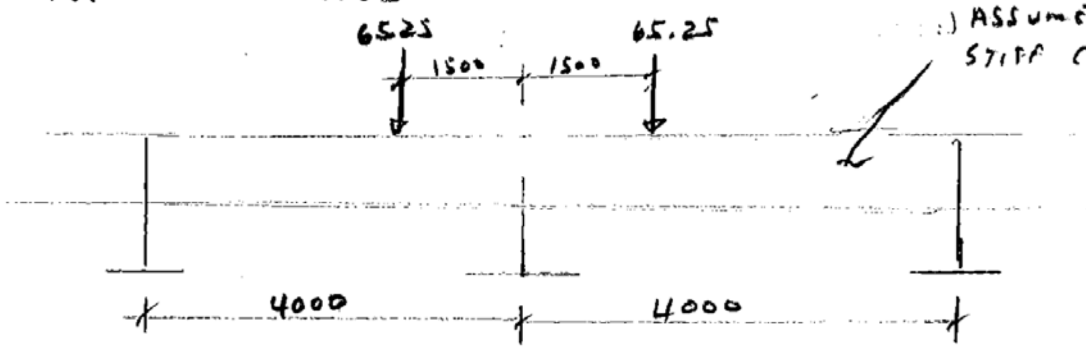


DETERMINE MAXIMUM REACTION ON TRANSVERSE STIFFENER DUE TO GANTRY LOADS

MAX FACTORED WHEEL LOAD
= 65.25 kN

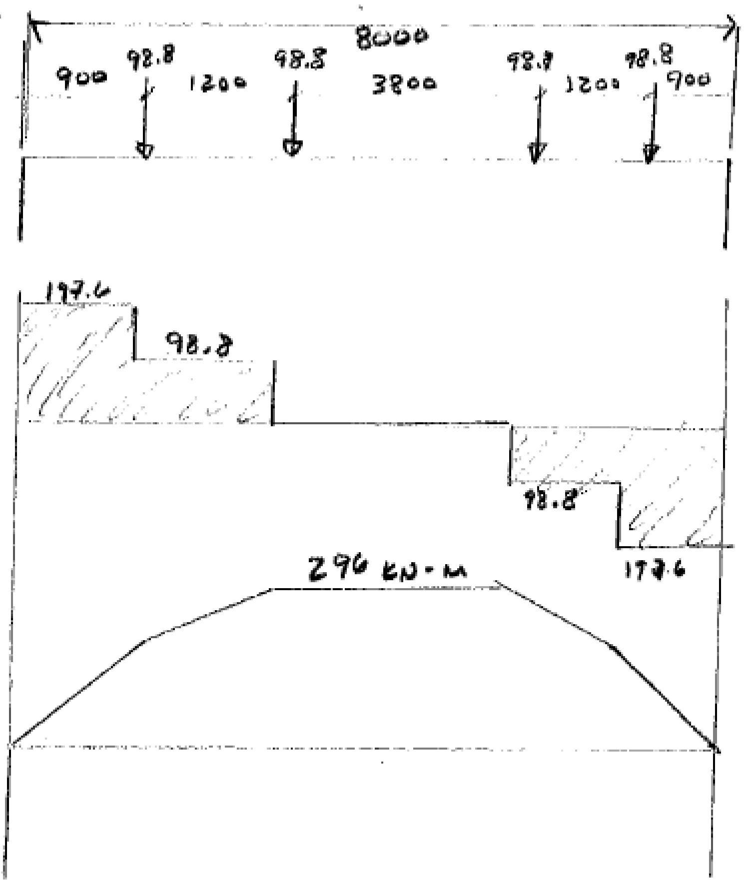
MAX REACTION ON TRANSVERSE STIFF DUE TO 1 LINE OF WHEELS

ASSUME LONGIT. STIFF CONTINUOUS



65.25 kN × .757 × 2 = 98.8 kN

DETERMINE MOMENTS & SHEARS IN TRANSVERSE STIFFENER



$\therefore$ SHEAR AT ENDS = 197.6 KN

MOMENT AT MIDSPAN = 296 KN-M

$$\Delta_1 = \frac{(98.3 \times 10^3)(900)(4000)}{(6)(200000)(7.3 \times 10^9)(8000)}\left(4000^2 + 900^2 - (2 \cdot 8000 \cdot 4000)\right)$$

(2100) (2100)

$= -.238$ m

$\Delta_2 = -.514$

$\Delta_{TOTAL} = 2(\Delta_1 + \Delta_2) = 1.5$ mm

EQUIVALENT UDL

$$F_d > \frac{\pi^2}{b^2} M_{LOAD} = \frac{\pi^2}{8^2} 296 = 45.6 \text{ kN/m}$$

$$F_d > \frac{\pi^4}{b^4} EI\, \delta_{LOAD} = \frac{\pi^4}{8000^4} \times (200000 \times 7.3 \times 10^9) \times 1.5 = \underline{\underline{52 \text{ kN/m}}}$$

$\therefore$ EQUIVALENT F_d' FOR GANTRY LOADS
$= 52$ kN/m

5.2.2 Transverse Stiffener Type A – Web Stiffeners

Design of Transverse Stiffeners on Webs - Diaphragm Type A

Panel Geometry

panel width (take as half depth of - cross beam 1) total depth of section
b 10178 20356

spacing of diaphragms, a (use maximum of either side)
a1 4000
a2 4000
initial imperfection, w0. use s/300 where s is the minimum of a, b1 or b2.
w0 13.33

maximum additional deflection (use b/300)
w1, stiff 33.93 (max additional deflection for stiffeness considerations)

gamma,m 1.1

Check of Symmetric Deformations for 3-celled transverse stiffeners

Panel Loading

direct compressive stresses in panel (due to global bending)
max longitudinal stress at top of panel 350 consevative upper bound to longitudinal stress in cross beam

max longitudinal stress at edge 2 0

Nl 96179125 N

direct axial load in stiffener (due to reaction from adjacent panels at 90 degrees). Include kick force, inclined flanges and gantry loa
Na 1800000 N (determine from design of flange stiffener)
(include additional compression due to braced frame forces)

mkleymann:
inclues 800kn reaction from flange stiffener and 1000kn from brace frame design

directly applied load (none for webs)
Fd 0 N/mm

Stiffener Dimension

web depth	875	mm
web thickness	16	mm
Flange width	425	mm
Flange thickness	25	mm
Stiffener yield	460	Mpa
Main Plate thicknes	40	mm
Area of Main Stiff.	142475	mm2
Main Plate yield	460	mpa

cut-out dimension
depth 545
width 100

E 200000 MPa

Stiffener Section Properties

Effective Stiffener properties

Since actual stress distribution is unknown, conservatively assume full compression

Local Buckling of Stiffener Web

b_{pl}		[mm]	875
t_{pl}	5)	[mm]	16.0
ψ_{pl}	5: Table 4	[-]	1
$K_{s,pl}$	5: Table 4	[-]	4
f_y	1: Table 3	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,pl}$_hat	5: (4.3)	[-]	1.35
ρ_{pl}	5: (4.2)	[-]	**0.62**
beff,total		[mm]	543.48
beff,top			271.7
Remaining Web above cut-out			330
Web depth used in design			271.7

Local Buckling of Stiffener Flange

h		[mm]	212.5
t_{stif}	5)	[mm]	25
$K_{s,stif}$	1), 5: Table 4.	[-]	0.43
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,stif}$_hat	5: (4.3)	[-]	0.64
ρ_{stif}	5: (4.3)	[-]	1.00
beff		[mm]	212.50
Beff, total		mm	425

Main Plate effective width

For the main plate, the effective width of 2 x 15εt will govern over local buckling

e	0.71
effective width	858

Section Properties

	b	t	Area	y	Ay	Ad^2	I'x	
Main Plate	858	40	34308	20	686161	2366424984	4574408.97	
Stiffener web	271.7	16	4348	779.1302	3387529	1071784973	26754555.5	
Stiffener flange	425	25	10625	927.5	9854688	4418451583	553385.417	
		Area	49281	ybar	282.6324		I,stiff	7888543890
							e1	283
							e2	657

Summary of Stiffener Section Properties

Area	49281
I,x	7.89E+09
ybar	283
emax	657

Check Minimum Stiffness

determin minimum stiffener to limit additional deflection to w1

Imin, stiff 3.76E+09 ok

Check Strength Requirements

Max Flange Stress account for torsional buckling of flange

It	3408208
yf	887.5
Iflange	159928385.4
Ipolar = Ix + Iy	
Ix	11941764323
Iy	159928385.4
Ipolar = Ix	12101692708
G	76000
sigma_cr	229.7

seems reasonable compared to flange as strut

considering simple case of flange as a strut

Area (usir	17625
sigma_cr	181.5
lamda	1.42
emax_z	106.25
i	95.3
alpha	0.49
alpha_e	0.590
Φ	1.86
X	0.33

Maximum stress in flange considering stability

sigma,br 150.0

Stress due to axial only

sigma,a 36.5

Therefore, maximum stress allowed in stiffener due to bending only

sigma, bmax 99.8

Determine max additional deflection that causes yielding of stiffener

w1, strength 8.0

recall that w1, stiffness 33.9

herefore, stiffener is govened by Strength

Determine min I such that the additional deflection w1 does not exceed w1,strength

Imin, strength 7.21E+09 OK

Summary

Stiffner Size

web	**875 x 16**		
flange	**425 x 25**		
Istiff	**7.89E+09**		
Imin, stiffne	**3.76E+09**	OK	4.76E-01
Imin, streng	**7.21E+09**	OK	9.14E-01
t Section, Shear D/C	0.242		
Gross Section D/C	0.095		

Find equivalent UDL due to destabalizing effects

Find actual w1 caused by various loading

applied Fd	0	N/mm
Q due to NL and Na	4.90	N/mm
w1, actual	6.93	mm

controlling w1 for capacity

8.0 strength criteria

Equivalent Forces at midspan

	at capacity	actual applied	
y	5089	5089	
Fd	114.11	99.20	N/mm
Vd	0.0	0.0	N
Md	1197686479	1.04E+09	

check to see if Md produces stress equal to sigma, bmax

99.8 OK

Equivalent Forces at end

	at capacity	actual applied	
y	0	0	
Fd	0.00	0.00	N/mm
Vd	**369684**	**321388**	N
Md	0	0	

mkleymann:
apply as axial load to flange transverse stiffener - use 350kn to avoid iteration

Equivalent Forces at cut-out

	at capacity at cutout	actual applied	
y	900	900	
Fd	31.29	27.20	N/mm
Vd	**355511**	**309067**	N
Md	328452631.1	2.86E+08	

Check Shear Capacity

At end

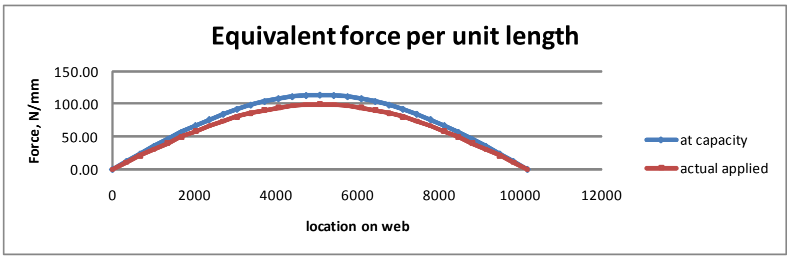
Shear Demand at er	321388	
Gross Shear Area	14000	
h/w	54.6875	need to check shear buckling
capacity	3380123	
D/C	0.095	OK

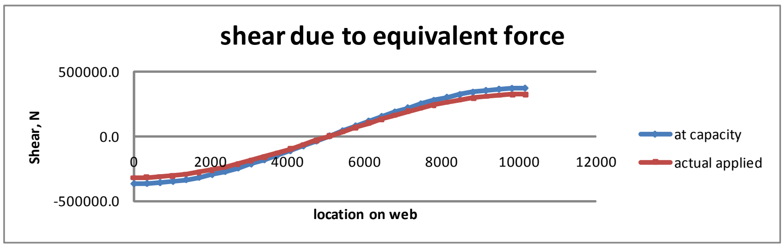
Shear Demand at cu	309067	
Cut out shear Area	5280	
capacity	1274789	
	0.242	OK

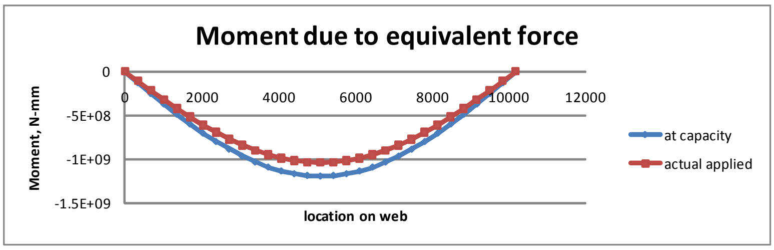
Check minimum stiffness for shear (as per 9.3.3 (3)

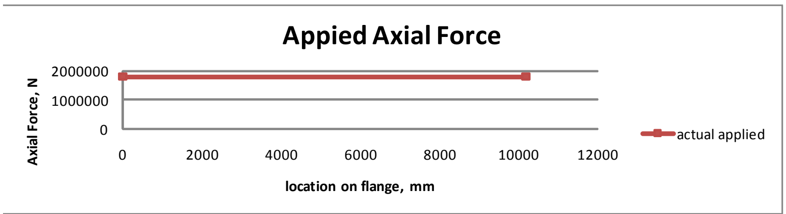
Ist, min	6.33E+09	
I, stiff	7.89E+09	ok

Plot forces on Stiffener





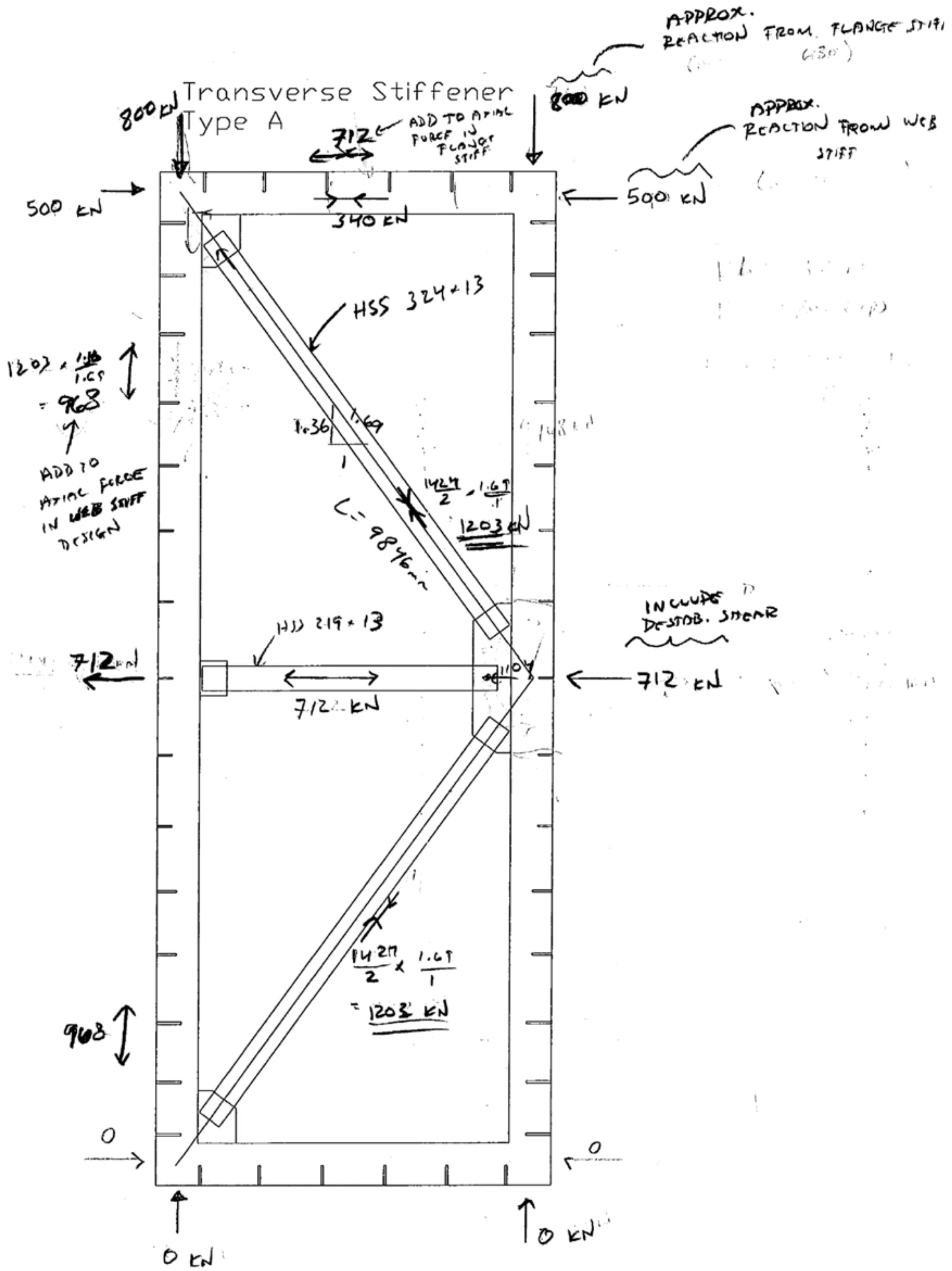




5.2.3 Design of Braced Frames – Type A Stiffeners

Using the forces and reactions from the design of the type A transverse stiffeners shown above, the braced frames were verified. The loads placed on the braced frames were taken as approximate and conservative values from the reactions calculated above to avoid excess iteration cycles.

	Diagonal Brace	Horizontal Brace
Section	323.9 x 12.5	219.1 x12.5
Outside Diameter	323.9	219.1
Inside Diameter	298.9	194.1
Thickness	12.5	12.5
Area	12229	8113
I	148465296	43445795
r	110	73
L	9800	6000
fy	355	355
Local Buckling		
d/t	26	18
Limit	39	39
	ok	ok
Determine Compressive Capacity		
lamda, 1	76.399	76.399
Lamda, bar	1.164	1.073
imperfection factor	0.21	0.21
Phi	1.28	1.17
chi	0.33	0.36
Nb,rd (kN)	1312	951


Transverse Stiffener
Type A
800 kN
712
ADD TO AXIAL FORCE IN FLANGE STIFF
800 kN
APPROX. REACTION FROM FLANGE STIFF
APPROX. REACTION FROM WEB STIFF
500 kN
340 kN
500 kN
HSS 324×13
1203 × 1.10/1.65
= 968
ADD TO AXIAL FORCE IN WEB STIFF DESIGN
1.36
1.69
1
1424/2 × 1.69/1
1203 kN
L = 9846mm
HSS 219×13
712 kN
712 kN
INCLUDE DESTAB. SHEAR
712 kN
1427/2 × 1.69/1
= 1203 kN
968
0
0
0 kN
0 kN

5.2.4 Transverse Stiffener Type B – Flange Stiffeners

Design of Transverse Stiffeners on Flanges - Diaphragm Type B

Panel Geometry

panel width (take as depth of cells)

b	4000	(1/2 flange width)

spacing of diaphragms, a (use maximum of either side)

a1	4000
a2	4000

initial imperfection, w0. use s/300 where s is the minimum of a, b1 or b2.

w0	13.33

maximum additional deflection (use b/300)

w1, stiff	13.33	(max additional deflection for stiffeness considerations)

gamma,m1	1.1

Check of Symmetric Deformations for 3-celled transverse stiffeners

Panel Loading

direct compressive stresses in panel (due to global bending)

max longitudinal stress at edge 1	350	consevative upper bound to longitudinal stress in cross beam
max longitudinal stress at edge 2	350	

mkleymann:
includes 250kn from reaction of web stiffener and 500 kn from design of brace frame

Nl	100432500	N

direct axial load in stiffener (due to reaction from adjacent panels at 90 degrees)

Na	750000	N	(determine from design of web stiffener) (include forces from braced frame)

direct applied out of plane loading (due to inclined flange, or ganty loads)

flange angle 1	12		
flange angle 2	7	degrees	
unbalanced vertical component	0.090		9016.026
UDL	1127	N/mm	
Moment	2254006617	N-mm	
equivalent sinosodal Fd	1390	N/mm	
Deflection	2.80	mm	
equivalent sinosodal Fd	1429	N/mm	
Max equivalent sinosodal FD	1429		

Equivalent Fd from Gantry Loads	52	N/mm	(see hand calcs)
Fd	1481	N/mm	(choose max of flange "kick" force and gantry load as they can't occur in the same direction

Stiffener Dimension

web depth	875	mm	
web thickness	25	mm	
Flange width	425	mm	
Flange thickness	25	mm	
Stiffener yield	460	Mpa	
Main Plate thickness	30	mm	(max of flange thickness with type A stiff)
Area of Main Stiff.	166950	mm2	(6- 525x53 stiff)
Main Plate yield	460	mpa	

cut-out dimension

depth	545
width	100

E	200000	MPa

Stiffener Section Properties

Effective Stiffener properties

Since actual stress distribution is unknown, conservatively assume full compression

Local Buckling of Stiffener Web

b_{pl}		[mm]	875
t_{pl}	5)	[mm]	25.0
ψ_{pl}	5: Table 4.1	[-]	1
$K_{s,pl}$	5: Table 4.1	[-]	4
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,pl}$_hat	5: (4.3)	[-]	0.86
ρ_{pl}	5: (4.2)	[-]	**0.86**
beff,total		[mm]	755.95
beff,top			378.0
Remaining Web above cut-out			330
Web depth used in design			330.0

Local Buckling of Stiffener Flange

h		[mm]	212.5
t_{stif}	5)	[mm]	25
$K_{s,stif}$	1), 5: Table 4.2	[-]	0.43
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,stif}$_hat	5: (4.3)	[-]	0.64
ρ_{stif}	5: (4.3)	[-]	1.00
beff		[mm]	212.50
Beff, total		mm	425

Main Plate effective width

For the main plate, the effective width
of 2 x 15εt will govern over local buckling

e	0.71
effective width	643

Section Properties

	b	t	Area	y	Ay	Ad^2	I'x	
Main Plate	643	30	19298	15	289474	3210659899	1447371.59	
Stiffener web	330.0	25	8250	740	6105000	829635730	74868750	
Stiffener flange	425	25	10625	917.5	9748438	2599342207	553385.417	
		Area	38173	ybar	422.885		I,stiff	6716507343
							e1	423
							e2	507

Summary of Stiffener Section Properties

Area	38173
I,x	6.72E+09
ybar	423
emax	507

Check Minimum Stiffness

determin minimum stiffener to limit additional deflection to w1

Imin, stiffnes	**1.80E+09**	**ok**

Check Strength Requirements

Max Flange Stress account for torsional buckling of flange

It	6770833	
yf	887.5	
Iflange	159928385.4	
Ipolar = Ix + Iy		
Ix	13951529948	
Iy	159928385.4	
Ipolar = Ix + Iy	14111458333	
G	76000	
sigma_cr	1192.8	seems reasonable compared to flange as strut

considering simple case of flange as a strut

Area (using ha	21562.5
sigma_cr	960.8

lamda	0.62
emax_z	106.25
i	86.1
alpha	0.49
alpha_e	0.601
Φ	0.82
X	0.74

Maximum stress in flange considering stability

sigma,br 339.8

Stress due to axial only

sigma,a 19.6

Therefore, maximum stress allowed in stiffener due to bending only

sigma, bmax 289.2

Determine max additional deflection that causes yielding of stiffener

w1, strength	4.6
recall that w1, stiffness	13.3

Therefore, stiffener is govened by Strength

Determine min I such that the additional deflection w1 does not exceed w1,strength

Imin, strength	**4.87E+09**	**OK**

Summary

Stiffner Size

web	**875 x 25**		
flange	**425 x 25**		
Istiff	**6.72E+09**		
Imin, stiffness	**1.80E+09**	OK	2.68E-01
Imin, strength	**4.87E+09**	OK	7.26E-01
Net Section, Shear D/C	0.825		
Gross Section D/C	0.409		

Find equivalent UDL due to destabalizing effects

Find actual w1 caused by various loading

applied Fd	1481.431873	N/mm
Q due to NL and Na	13.02	N/mm
w1, actual	3.32	mm

controlling w1 for capacity

4.6 strength criteria

Equivalent Forces at midspan

	at capacity	actual applied	
y	4000	4000	
Fd	0.00	0.00	N/mm
Vd	-3008765.7	-2162261.1	N
Md	4.6934E-07	3.3729E-07	

check to see if Md produces stress equal to sigma, bmax

0.0 NG

Equivalent Forces at end

	at capacity	actual applied	
y	0	0	
Fd	0.00	0.00	N/mm
Vd	**3008766**	**2162261**	N
Md	0	0	

mkleymann:
add to axial compression in web stiffener

Equivalent Forces at cut-out

	at capacity at cutout	actual applied	
y	900	900	
Fd	1534.70	1102.92	N/mm
Vd	**2287883**	**1644196**	N
Md	2487957166	1787980019	

Check Shear Capacity

At end

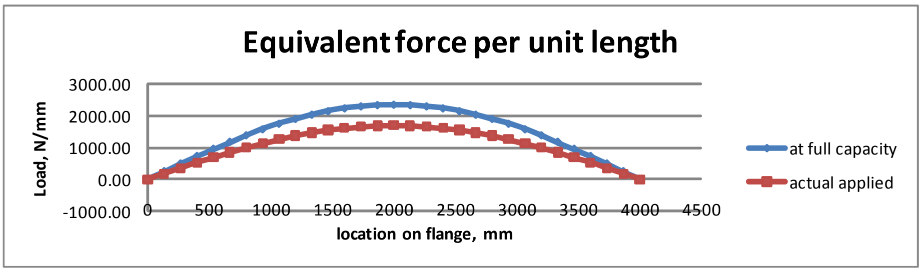
Shear Demand at end	2162261	
Gross Shear Area	21875	
h/w	35	OK, no shear buckling
capacity	5281443	
D/C	0.409	OK

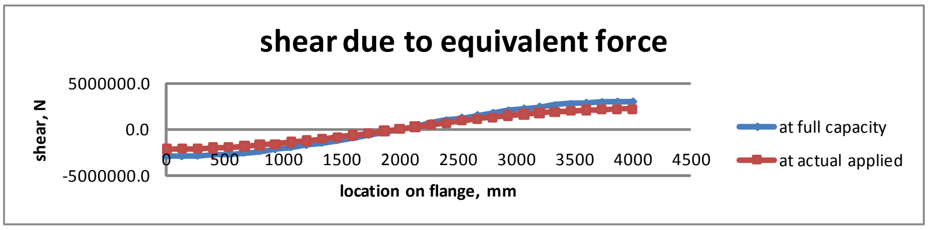
Shear Demand at cut-ou	1644196	
Cut out shear Area	8250	
capacity	1991858	
	0.825	OK

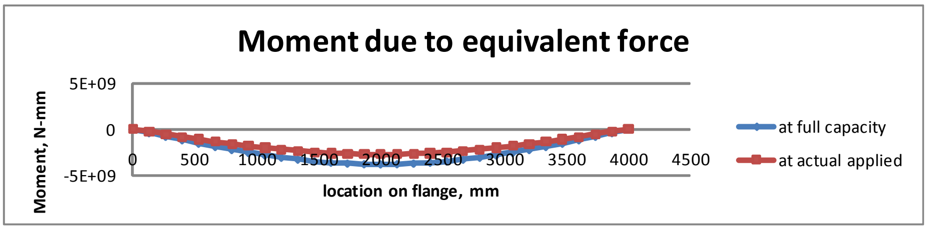
Check minimum stiffness for shear (as per 9.3.3 (3)

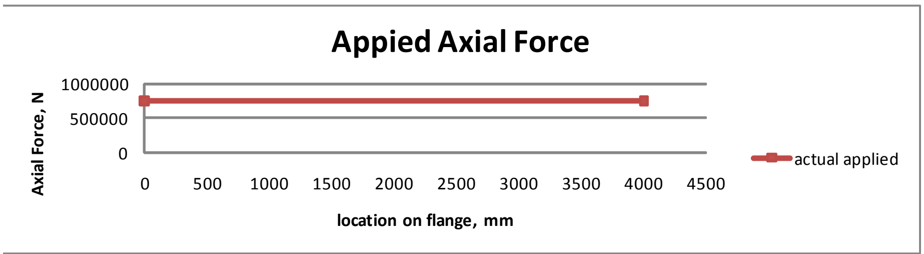
Ist, min	1.62E+08	
I, stiff	6.72E+09	ok

Plot forces on Stiffener









5.2.5 Transverse Stiffener Type B – Web Stiffeners

Design of Transverse Stiffeners on Webs - Diaphragm Type B

Panel Geometry

panel width (take as depth of cells) — total depth of section

b 7211.5 (max depth) — 14423

spacing of diaphragms, a (use maximum of either side)

a1 4000

a2 4000

initial imperfection, w0. use s/300 where s is the minimum of a, b1 or b2.

w0 13.33

maximum additional deflection (use b/300)

w1, stiff 24.04 (max additional deflection for stiffeness considerations)

gamma,m1 1.1

Check of Symmetric Deformations for 3-celled transverse stiffeners

Panel Loading

direct compressive stresses in panel (due to global bending)

max longitudinal stress at top of panel 325 consevative upper bound to longitudinal stress in cross beam

max longitudinal stress at edge 2 0

Nl 75886281 N

direct axial load in stiffener (due to reaction from adjacent panels at 90 degrees). Include kick force, inclined flanges and gan

Na 5000000 N (determine from design of flange stiffener)
(also account for forces from braced frame)

directly applied load (none for webs)

Fd 0 N/mm

Stiffener Dimension

web depth	875	mm	
web thickness	16	mm	
Flange width	350	mm	
Flange thickness	20	mm	
Stiffener yield	460	Mpa	
Main Plate thickness	45	mm	(max web thickness
Area of Main Stiff.	142475	mm2	(area of stiff on half web)
Main Plate yield	460	mpa	

cut-out dimension

depth	545	
width	100	
E	200000	MPa

Stiffener Section Properties

Effective Stiffener properties

Since actual stress distribution is unknown, conservatively assume full compression

Local Buckling of Stiffener Web

b_{pl}		[mm]	875
t_{pl}	5)	[mm]	16.0
ψ_{pl}	5: Table 4.1	[-]	1
$K_{s,pl}$	5: Table 4.1	[-]	4
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,pl}$_hat	5: (4.3)	[-]	1.35
ρ_{pl}	5: (4.2)	[-]	**0.62**
beff,total		[mm]	543.48
beff,top			271.7
Remaining Web above cut-out			330
Web depth used in design			271.7

Local Buckling of Stiffener Flange

h		[mm]	175
t_{stif}	5)	[mm]	20
$K_{s,stif}$	1), 5: Table 4.2	[-]	0.43
f_y	1: Table 3.1	[MPa]	460
e	5: (4.3)	[-]	0.71
$\lambda_{p,stif}$_hat	5: (4.3)	[-]	0.66
ρ_{stif}	5: (4.3)	[-]	1.00
beff		[mm]	175.00
Beff, total		mm	350

Main Plate effective width

For the main plate, the effective width of 2 x 15εt will govern over local buckling

e	0.71
effective width	965

Section Properties

	b	t	Area	y	Ay	Ad^2	I'x		
Main Plate	965	45	43421	22.5	976976	1351887567	7327318.66		
Stiffener web	271.7	16	4348	784.1302	3409268	1488858479	26754555.5		
Stiffener flange	350	20	7000	930	6510000	3741047136	233333.333		
		Area	54769	ybar	198.9492		I,stiff		6616108389
							e1		199
							e2		741

Summary of Stiffener Section Properties

Area	54769
I,x	6.62E+09
ybar	199
emax	741

Check Minimum Stiffness

determin minimum stiffener to limit additional deflection to w1

Imin, stiffness 1.34E+09 ok

Check Strength Requirements

Max Flange Stress account for torsional buckling of flange

It	2128000	
yf	885	
Iflange	71458333.33	
Ipolar = Ix + Iy		
Ix	9055491667	
Iy	71458333.33	
Ipolar = Ix -	9126950000	
G	76000	
sigma_cr	262.1	seems reasonable compared to flange as strut

considering simple case of flange as a strut

Area (using	14000
sigma_cr	203.4
lamda	1.32
emax_z	87.5
i	71.4
alpha	0.49
alpha_e	0.600
Φ	1.72
X	0.36

Maximum stress in flange considering stability

sigma,br 164.0

Stress due to axial only

sigma,a 91.3

Therefore, maximum stress allowed in stiffener due to bending only

sigma, bmax 57.8

Determine max additional deflection that causes yielding of stiffener

w1, strength 2.1

recall that w1, stiffness 24.0

Therefore, stiffener is govened by Strength

Determine min I such that the additional deflection w1 does not exceed w1,strength

Imin, strength 6.45E+09 OK

Summary

Stiffner Size

web	**875 x 16**		
flange	**350 x 20**		
Istiff	**6.62E+09**		
Imin, stiffne:	**1.34E+09**	OK	2.03E-01
Imin, strengt	**6.45E+09**	OK	9.75E-01
et Section, Shear D/C	0.155		
Gross Section D/C	0.065		

Find equivalent UDL due to destabalizing effects

Find actual w1 caused by various loading

applied Fd	0	N/mm
Q due to NL and Na	6.21	N/mm
w1, actual	2.00	mm

controlling w1 for capacity

2.1 strength criteria

Equivalent Forces at midspan

	at capacity	actual applied	
y	3605.75	3605.75	
Fd	97.98	95.21	N/mm
Vd	0.0	0.0	N
Md	516307103.7	501700960	

check to see if Md produces stress equal to sigma, bmax

57.8 OK

Equivalent Forces at end

	at capacity	actual applied	
y	0	0	
Fd	0.00	0.00	N/mm
Vd	**224922**	**218559**	N
Md	0	0	

mkleymann:
add to axial compression in falnge stiffener.
Conservatively use 250 kN

Equivalent Forces at cut-out

	at capacity at cutout	actual applied	
y	1000	1000	
Fd	41.35	40.18	N/mm
Vd	**203915**	**198146**	N
Md	217875166.1	211711555	

Check Shear Capacity

At end

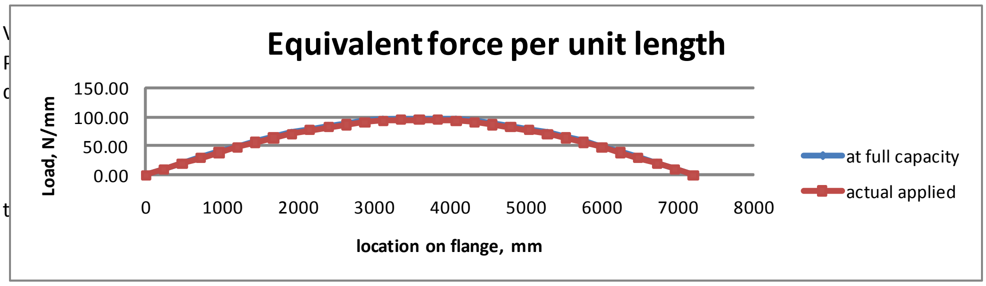
Shear Demand at enc	218559	
Gross Shear Area	14000	
h/w	54.6875	need to check shear buckling
capacity	3380123	
D/C	0.065	OK

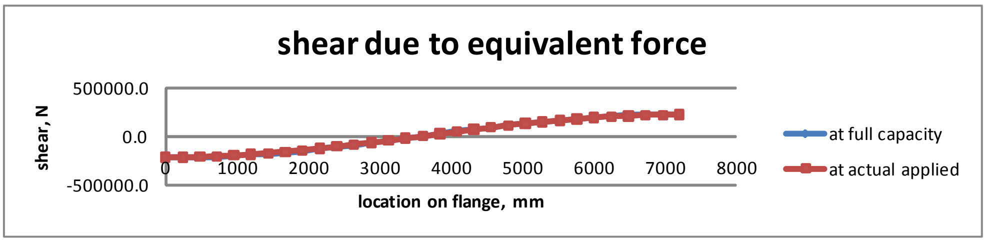
Shear Demand at cut	198146	
Cut out shear Area	5280	
capacity	1274789	
	0.155	OK

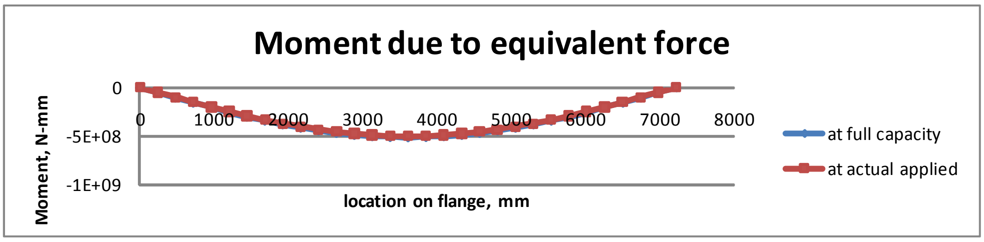
Check minimum stiffness for shear (as per 9.3.3 (3)

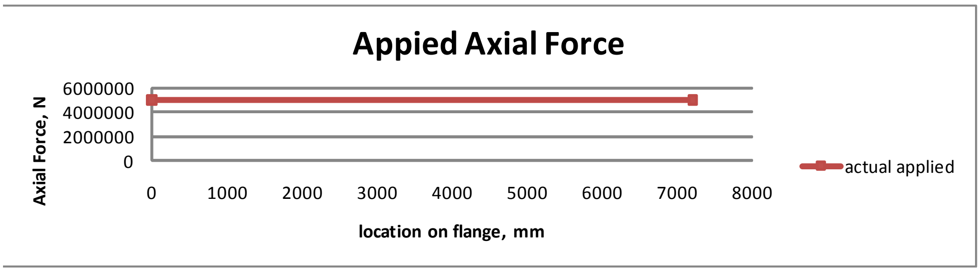
Ist, min	3.20E+09	
I, stiff	6.62E+09	ok

Plot forces on Stiffener





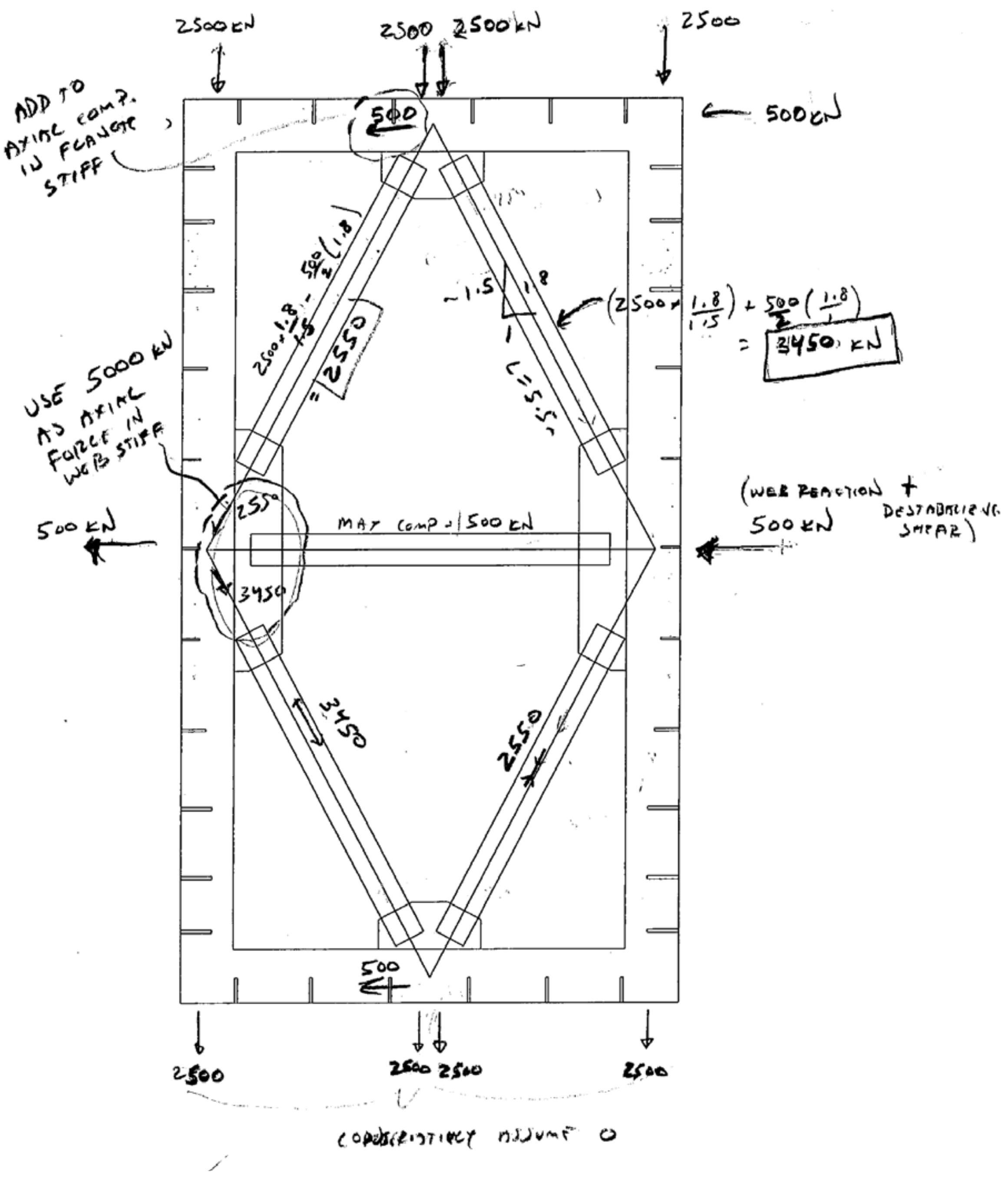




5.2.6 Design of Braced Frames – Type B Stiffeners

	Diagonal Brace	Horizontal Brace
Section	406.4 x16	219.1 x12.5
Outside Diameter	406.4	219.1
Inside Diameter	374.4	194.1
Thickness	16	12.5
Area	19623.64435	8113.163028
I	374488209	43445795
r	138	73
L	5500	6000
fy	355	355
Local Buckling		
d/t	25.4	17.528
Limit	39.2	39.2
	ok	ok
Determine Compressive Capacity		
lamda, 1	76.399	76.399
Lamda, bar	0.521	1.073
imperfection factor	0.21	0.21
Phi	0.67	1.17
chi	0.66	0.36
Nb,rd (kN)	4172.18	950.92

Transverse Stiffener
Type B



5.3 Fatigue

The cross beams are not subjected to direct stresses from live load on the bridge deck and so wind loads were considered to be the only reasonable source of fatigue loading. The cross beams are assessed for fatigue caused by regularly occurring wind loads using a simplified and conservative procedure. The frequency and cumulative frequency distributions of all wind speeds occurring at deck level of the Calabria tower are presented in Figure 5-1, with frequency plotted on the vertical axis and wind speed plotted on the horizontal axis. Wind speeds below 1 m/s, which represent 19% of the cumulative frequency, are not represented in the frequency distribution plot. The directional distribution of the winds is given by the wind rose in Figure 5-2, in which the vertical axis with the labels corresponds to North. The wind speed data is based on measurements taken at the Reggio Calabria airport and transformed to the bridge site considering the terrain between the two locations.

The regularly occurring winds are considerably smaller than the design wind speeds specified in the design basis. The design of the tower cross beams is governed by the SILS wind loads, which correspond to a wind speed of 60 m/s at 70 m above sea level. The root mean square structural response to time-varying winds is approximately proportional to $V^{2.8}$, where V is the wind speed. The cumulative wind speed distribution shows that 95% of all wind speeds occurring at the Calabria tower are less than 15 m/s. If it is assumed, very conservatively that:

- 15 m/s winds occur at the bridge site frequently enough that they represent an appropriate fatigue loading;
- all cross beam elements are stressed to the design yield stress, f_y/γ_{M0}, under the governing SILS wind load combination;
- the wind always blows in the most critical direction; and
- the entire stress on all elements is attributable to the wind load,

then the maximum fatigue stress caused by the 15 m/s winds would be: $\left(\frac{15}{60}\right)^{2.8} \times \frac{f_y}{\gamma_{M0}} = 9\ \text{MPa}$

An axial stress of 9 MPa is well below the constant amplitude stress threshold for even the worst of fatigue details, confirming that wind induced fatigue in the cross beams is not a concern.

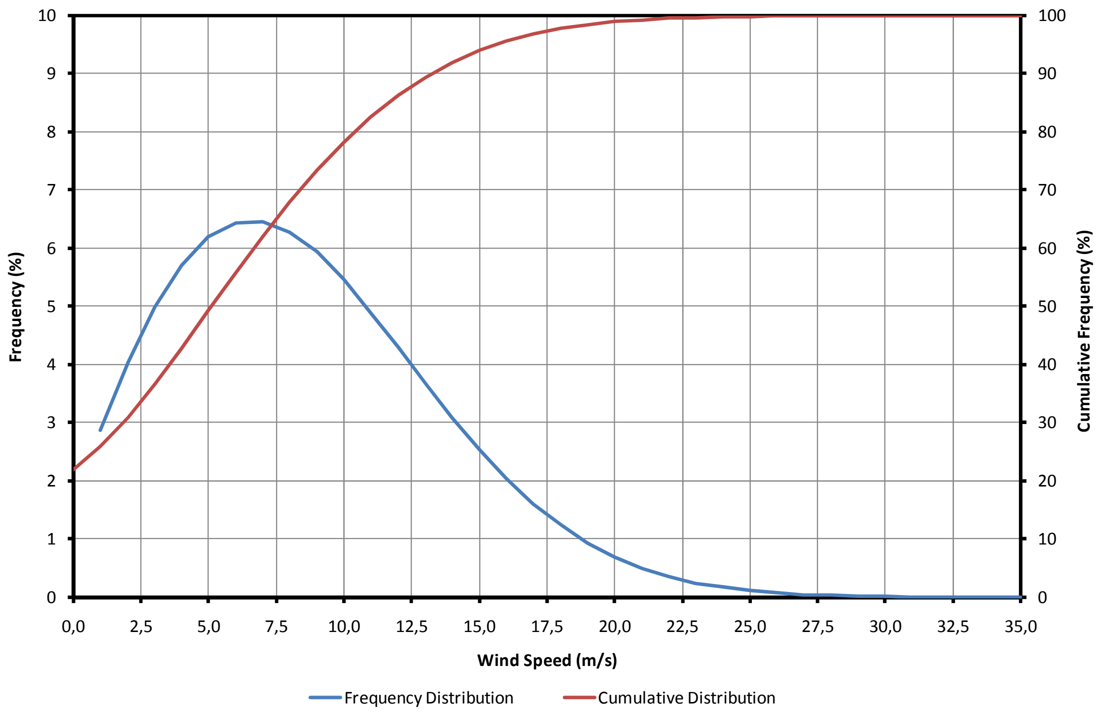


Figure 5-1: Frequency and cumulative frequency distributions of wind speeds at deck level of the Calabria Tower.

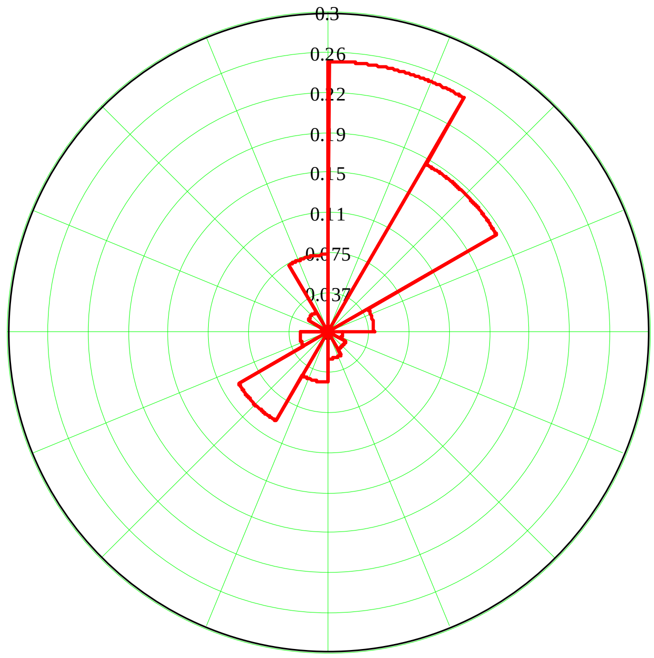


Figure 5-2: Wind rose for all wind speeds at deck level of the Calabria Tower.