Stretto di Messina

Concessionaria per la progettazione, realizzazione e gestione del collegamento stabile tra la Sicilia
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EurolinK

PONTE SULLO STRETTO DI MESSINA

PROGETTO DEFINITIVO

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INDICE

1 Introduction

This report describes the design of the following structural elements of the towers:

- Tower Saddles
- Splay Saddles

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

For some items it is found advantageous to introduce changes to the design and the following changes are introduced:

- The main cable strand arrangement has been altered from a matrix arrangement to a vertical staggered arrangement to improve stability of the cable prior to compaction and to improve constructability.
- The main cable wire diameter has been increased from 5.32 mm to 5.40 mm and the number of strands in main span is increased from 324 to 349. Both changes have been made to accommodate increases in deck weight. The number of additional strands in the side spans has increased from 8 and 6 in Sicilia and Calabria span respectively to 12 and 8.
- Saddle trough plate grooves have been changed from circular profile slots to square to suit the PPWS strand erection procedure and strand arrangements within the troughs have been revised to accommodate the new main cable arrangement.
- The main cable spacing has increased from 1750 to 2000 mm due to the revised strand arrangement at the saddles.
- The geometry of the splay saddle trough has been carefully optimised to minimise horizontal deviation forces and reduce the tendency for strand deformation and wire movement during strand erection. Control measures have been added to further mitigate the problem.

All the calculations are based on the Design Basis. The global IBDAS model version 3.3b was used for the applied load combinations.

Selected main results of the calculations are enclosed in Appendices.

2 Design References

2.1 Design Specifications

CG.10.00-P-RG-D-P-GE-00-00-00-00-00-02-B - "Design Basis, Structural, Annex

GCG.F.05.03 Design Development – Requirements and Guidelines

GCG.G.03.02 Structural Steel Works and Protective Coatings

GCG.G.03.03 Suspension system

2.2 Design Codes

"Norme tecniche per le costruzioni," 2008 (NTC08).

EN 1993-1-1	Design of Steel Structures – Part 1-1: General rules and rules for buildings
EN 1993-1-5	Design of Steel Structures – Part 1-5: Plated structural elements
EN 1993-1-8	Design of Steel Structures – Part 1-8: Design of joints
EN 1993-1-9	Design of Steel Structures – Part 1-9: Fatigue
EN 1993-1-10	Design of Steel Structures – Part 1-10: Selection of steel for fracture toughness and through thickness properties
EN 1993-1-11	Design of steel structures - Part 1-11: Design of structures with tension components
EN 1993-2	Design of Steel Structures – Part 2: Steel Bridges

2.3 Drawings

The saddle drawings relevant for this report are listed in Table 2-1.

Table 2-1 Cable system drawings relevant for this report

Drawing Title	Drawing Number
Tower Saddle - General Arrangement	CG1000-PAXDPSV-S7SL000000-01
Tower Saddle - Sections and Details	CG1000-PWXDPSV-S7SL000000-01
Tower Saddle - Additional Anchorages	CG1000-PWXDPSV-S7SL000000-02
Tower Saddle - Trough Plates	CG1000-PWXDPSV-S7SL000000-03
Tower Saddle - Trough Plates Sections and Details	CG1000-PWXDPSV-S7SL000000-04
Splay Saddle - General Arrangement	CG1000-PAXDPSV-S7SL000000-02
Splay Saddle - Trough Plates - Sicilia	CG1000-PWXDPSV-S7SL000000-05
Splay Saddle - Trough Plates - Calabria	CG1000-PWXDPSV-S7SL000000-06
Splay Saddle - Trough Plates Sections and Details	CG1000-PWXDPSV-S7SL000000-07

3 Nomenclature

Additional PPWS anchorages - the weldments that anchor the additional PPWS, found only in the side spans, at the tower tops.

Continuous tower section - the plates that are continuous throughout the length of the tower legs

Cross Beams – the transverse beams connecting the tower legs.

Diaphragms - horizontally disposed plates within the tower legs

Main Cables - each of the two main cables is made up of two individual cables of prefabricated steel wire strands grouped and compacted into two single cables of circular cross section.

PPWS - Preformed parallel wire strands that collectively make up the main cable.

PPWS socket - the end termination of the PPWS strand

Primary stiffeners - the large vertical plates that transfer the load applied by the tower saddle into the continuous tower section.

Secondary Stiffeners - the vertical plates that transfer the load applied by the tower saddle into the primary stiffeners.

Spacers - thin metal plates inserted between adjacent strands in a single slot or groove.

Splay Saddle - the manufactured assembly over which the cables pass that deviates the strands

Splay Saddle Central Part - the weldment that supports the splay saddle trough plates at the top and is connected to the rocker bearing at the bottom

Splay Saddle Rocker Bearing - the two-part bearing, the upper part being fixed tot he splay saddle central part and the lower part being fixed to the sloping concrete floor of the anchorage.

Tower Legs – the vertical elements of the bridge towers, extending from the tops of the concrete pedestals at elevation +18.00 to the undersides of the tower saddles at approximate elevation +396.50.

Tower saddle – the manufactured assembly over which the main cables pass and which applies the cable load to the top of the tower leg.

Tower saddle frame - the weldment comprising side plates and base plate that is located on top of the tower leg and which carries the additional PPWS anchorages.

Tower top plate - the uppermost plate that caps the tower legs and which directly the supports the tower saddle frame.

Tower top stiffeners - additional plates within the tower leg that are curtailed within or just below the tower leg transition zone.

Tower top transition section - the tapered and recessed section of the tower leg that extends from the top of the uppermost cross beam to the tower top plate.

Trough Plates - the curved steel castings, with machined grooves, that contain the PPWS strands as they are deviated over the saddle (these are found at both the tower saddle and the splay saddle).

4 Materials

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

4.1 Cast Steel

The trough plates of both tower and splay saddles, the top plate of the splay saddle central part and the upper and lower components of the rocker bearing are fabricated from cast steel as specified below:

Component	Material	Min Yield Stress (Rp0.2)	Min Tensile Strength (Rm)
Trough Plates	G24Mn6+QT2 (1.1118) to UNI EN 10340 (t<100mm)	500 MPa	650 MPa
Splay saddle central part top plate	G24Mn6+QT2 (1.1118) to UNI EN 10340 (t<300mm)	380 MPa	600 MPa
Splay saddle central part rocker bearing	G24Mn6+QT2 (1.1118) to UNI EN 10340 (t<500mm)	380 MPa	600 MPa

Table 4-1: Design parameters for trough plates

4.2 Structural Steel

Structural steelwork components are fabricated from hot rolled structural steels, produced in accordance with EN 10025-4 except where observed below. The grades of steel used are assumed to have the mechanical properties listed below. It is assumed that that the mechanical properties will not vary with material thickness for thicknesses up to 100 mm.

Grade	Min Yield Strength (Reh)	Min Tensile Strength (Rm)
S 420 ML (t<100mm)	420 MPa	520 MPa
S 420 ML (t<150mm)	365 MPa	460 MPa
S 460 ML (t<100mm)	460 MPa	540 MPa

S 460 ML (t<200mm)	385 MPa	490 MPa

Table 4-2: Structural steel mechanical properties for stated thicknesses

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

Mechanical Properties	Value
Elastic modulus: E (MPa)	210 000
Poisson's ratio: v	0.3
Shear modulus: G (MPa)	E / [2 (1 + v)]
Coefficient of thermal expansion: α ($°C^{-1}$)	12×10^{-6}
Density: (ρ kg/m^3)	7850

Table 4-3: Characteristics of structural steel

Structural steelwork is machined at bearing contact surfaces unless the load is transmitted through weld.

4.3 Structural Bolts

Structural bolts are grade 10.9 with class 10 nuts and washers in accordance with GCG.G.03.02 and NTC 08, section 11.

Bolt Grade	Proof strength	Tensile strength
10.9	900 MPa	1000 MPa

Table 4-4: Design parameters used for bolt design

4.4 Welding

Welding procedures and welder qualification shall be in accordance with GCG.G.03.02 and NTC 08, section 11. Weld design shall be in accordance with NTC 08, section 4, as summarised in table Table 4-5.

Steel grade	Yield Stress	Factors $\beta/\beta_1/\beta_2$	Partial Factor
S460ML	460 MPa	1.00/0.62/0.75	γ_{M2} = 1.25

Table 4-5: Design parameters used for weld design

The material partial factors (safety coefficients) used to verify the steel elements are in accordance with NTC08 Sections 4.2.4.1.1, 4.2.4.1.4, 4.2.8.1.1, 4.2.8.2 and are listed in below..

Verification	Partial Factor
Resistance of class 1, 2, 3 and 4 sections and castings	γ_{M0} = 1.05
Resistance to instability of members in road and rail bridges	γ_{M1} = 1.10
Resistance to fracture of sections and plates under tension (weakened by holes), bolts in shear and tension, connected plies in bearing and welds	γ_{M2} = 1.25
Fatigue resistance	γ_{M3} = 1.35

Table 4-6: Partial material factors for steel elements used in the saddles

5 Design Principles

The design principles are described in the Cable System, Specialist Technical Design Report CG1000-PRXDPSV-S7SS000000-01.

6 Tower Saddles, Design Verifications

6.1 Design Forces

Components subject to force applied by a single PPWS are designed to resist the ultimate tensile strength of the strand. A single PPWS strand consists of 127 No 5.40 mm dia. wires at grade 1860 MPa giving a UTS of:

UTS of a single PPWS:	5410	kN

Components subject to forces applied by groups of strands without being the complete cable are designed to resist the maximum forces in the strands at SILS or ULS that are allowed by the design basis.

Max force at SILS (UTS/1.4)	3864	kN
Max force at ULS (UTS/1.67)	3239	kN

The resolution of the maximum allowable forces into the tower yields the following vertical forces.

Axial load in tower due to max SILS force in strand	2042	MN
Axial load in tower due to max ULS force in strand	1712	MN

Components subject to forces applied by the complete cable are designed to resist the maximum design forces applied by the cable at the relevant limit state and the maximum tendency for the saddle to be sheared off the tower. The verifications are made at SILS or ULS.

The saddle and trough plate is generally governed by the load combination that maximises axial load in the tower. Moments and shears at the level of the saddle are small by comparison and do not have a significant effect on the design.

The only notable exception to this is consideration of slip of the trough plates, which is critical under a load combination that maximises resultant shear generated by a difference in cable tension between the two spans.

These forces are selected from the IBDAS model 3.3b results files for the tower at the node immediately below the saddle and are summarised below.

	Ns [MN]	My [MNm]	Mz [MNm]	Vy [MN]	Vz [MN]	Mt [MNm]
Design ULS case for maximum axial load in Tower						
IBDAS load cases 6517 plus temperature envelope 4510	-1753	-161	1.7	-66.3	-49.7	-6.1
Design ULS case for maximum moment in Tower						
IBDAS load cases 6902 plus temperature envelope 4510	-1450	448	0.9	-52.4	111.1	15.2
Design SILS case for maximum axial load in Tower						
IBDAS load cases 6812 plus temperature envelope 4510	-1528	-187	0.8	-58.3	-59.6	-6.99
Design SILS case for maximum moment in Tower						
IBDAS load cases 6930 plus temperature envelope 4510	-1336	54	39.5	-35.5	10.4	1.5
Design ULS case for saddle slippage						
IBDAS load cases 7513 plus temperature envelope 4510	931	412	1.4	33.7	120.7	14.8
Design SILS case for saddle slippage						
IBDAS load cases 6932 plus temperature envelope 4510	1137	454.9	1.3	41.6	130.0	16.2

Table 6-1: IBDAS 3.3b results used for tower saddle design

IBDAS load case 6517 is a load combination at ULS of the loading in the finished bridge (PP+PN+QA+VS_dyn+VT) with surfacing of 40mm.

Temperature envelope 4510 is a worst temperature loading envelope which is added to the governing limit state envelopes.

IBDAS load cases 6812 is a load combination at SILS of the loading in the finished bridge (PP+PN+QR+VS_dyn+VT with surfacing of 40mm

IBDAS load cases 7513 is a load combination at ULS of the loading in the finished bridge (PP+PN+VS_dyn+VT with surfacing of 15mm

IBDAS load cases 6932 is a load envelope at SILS of the loading in the finished bridge (envelope w. seismic) with surfacing of 15 and 40mm.

6.2 Trough Plates - Geometry

The grooves in the trough plates are detailed to accommodate the PPWS arranged in a rectangular section. Grooves wide enough for a single strand are 66mm wide. Grooves wide enough for a two strands incorporate a spacer and are 138mm wide.

In side elevation, the radius of the saddle has a single point of origin over the principle loaded length which is defined at the reference condition of the bridge with full dead load only. Radii of curvature, therefore, depend on the distance from that origin. Sections at the mouth of the saddle to the main span and side span sides are curved differently to allow vertical rotation of the cable downwards without permitting the tangent point of the cable to reach the edge of the saddle. The gap above the strands also permits upward rotation of the cable in order for the free cable profile to be accommodated without restricting the positioning of the trough plates above.

The grooves are straight on plan except in the regions close to the mouth of the trough plates at main span and side span sides where the spacers are tapered at suitable radii to permit the strands to deviate towards the cable clamp. Some widening therefore occurs in the grooves. The transverse arc of the side of the groove extends to the end of the trough plates in order to permit additional lateral rotation of the cable during service. The gap between the strand and the spacer to the other side will permit rotation in the opposite direction.

The maximum SLS inclinations at the tower tops that the main cable adopts are taken from the IBDAS model 3.3b results. The maximum net changes in cable angle that the saddle must accommodate are shown below.

CABLE INCLINATIONS AT SLS (Degrees)	REF CONDITION	MAX. ANGLE	NET CHANGE IN ANGLE
Sicily Side Span (angle to horizontal)	23.71	25.25	2.06
Sicily Tower (angle to vertical)	0.00	-0.52	
Main Span Side (angle to horizontal)	-20.79	-23.39	-2.08
Main Span Side (angle to horizontal)	20.79	23.30	2.01
Calabria Tower (angle to vertical)	0.00	0.50	
Calabria Side Span (angle to horizontal)	-22.63	-23.90	-1.77
		(COMB 6700)	

The saddle shall accommodate the free cable without impeding installation of the trough plates. At free cable condition the geometry at the towers is as follows:

CABLE INCLINATIONS AT SLS (Degrees)	REF CONDITION	FREE CABLE	NET CHANGE IN ANGLE
Sicily Side Span (angle to horizontal)	23.71	25.00	0.32 (lowers)
Sicily Tower (angle to vertical)	0.00	0.97	
Main Span Side (angle to horizontal)	-20.79	-19.80	0.02 (lifts)
Main Span Side (angle to horizontal)	20.79	19.80	-0.18 (lifts)
Calabria Tower (angle to vertical)	0.00	-0.81	
Calabria Side Span (angle to horizontal)	-22.63	-23.60	-0.16 (lowers)

The combined effect of the change in the cable angle and rotation of the tower saddle produces a net change in angle between the cable and the saddle. The greatest lift of the cable occurs at the main span side of the Calabria Tower. The worst case is the lowest trough plate since it is here that the strand tangent point is furthest from the edge of the trough plate. At the edge of the trough plates the resulting lift of the strands is 5mm which is accommodated by the available gap of 30mm.

The maximum SLS horizontal rotations that the cables adopt at the towers are taken from the IBDAS model 3.3b results.

CABLE INCLINATIONS AT SLS (Degrees)	HORIZONTAL DEVIATION
Sicily Side Span (angle to axis of bridge)	0.01
Main Span Side (angle to axis of bridge)	0.58
Main Span Side (angle to axis of bridge)	0.58
Calabria Side Span (angle to axis of bridge)	0.02

The cable may rotate in the saddle at the end region where the curvature of the spacer is provided.

6.3 Trough Plates

The spacers must resist the spreading force of the strand at free-cable profile. The free cable force in a strand was calculated in order to determine whether the strands in a groove could apply a significant spreading force to the spacers prior to the neighbouring grooves being occupied and providing support.

Stress in spacer	28	N/mm^2
Material yield	500	N/mm^2

By inspection, it can be seen that this is not a critical case.

At the limit states, the strands apply radial forces which accumulate towards the bottom trough plate. The lowest trough plate (A), however, is supported over its full soffit and therefore the bending of the base of the groove does not occur. The second trough plate (B) carries the forces from the trough plates above which combine with the bending of the base.

The total forces applied to the tower are the maximum allowable SILS and ULS tensions in the PPWS resolved vertically.

	SILS	ULS	
Vertical force into tower	2042	1712	MN

The critical locations in trough plates A and B are verified below.

Underside of trough plate B			**SILS**	**ULS**	
Equivalent direct stress			440	369	N/mm^2
Material yield	500	N/mm^2			
Gamma M			1.00	1.05	
UTILISATION			**0.88**	**0.77**	

Underside of trough plate A			**SILS**	**ULS**	
Accumulate bearing stress of	10	trough plates			
Equivalent direct stress			488	409	N/mm^2
Material yield	500	N/mm^2			
Gamma M			1.00	1.05	
UTILISATION			**0.98**	**0.86**	

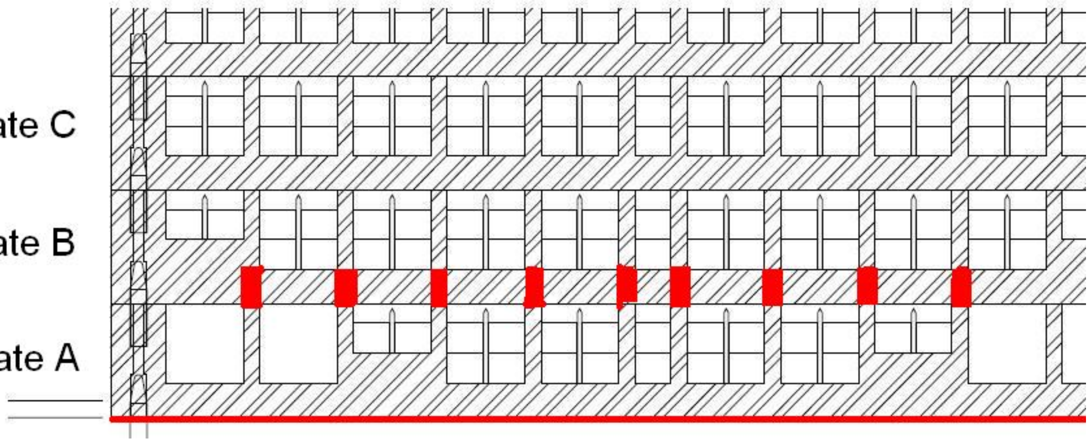

Figure 6-1 Cross section of tower trough plates showing critical locations at underside of A and through base of B

The complete cable applies the following maximum pressure to the tower.

	SILS	ULS	
Contact pressure	24	28	MN/m^2

Under the applied SILS and ULS loading, the individual bearing and bending stresses in trough plate B are as follows.

	SILS	ULS	
Bearing pressure	137	156	N/mm^2
Stress due flexure of base	23	19	N/mm^2
Shear stress	12	10	N/mm^2

To this effect is added that caused by the main cable transmitting tension to the trough plates as its own tension increases. This is of course limited by friction, but since the more onerous effect is experienced with a higher coefficient of friction the gamma value of 1/1.65 has been used at ULS.

		SILS	ULS	
Coefficient of friction	0.3			
Coeff * gamma M		0.3	0.495	
Max stress in trough plate due to cable tension		12	23	N/mm^2

At the mouth of the saddle, the trough plates accommodate the splay of the PPWS as they are gathered into the first cable clamp. The worst case is the outer column of grooves. The effect of the horizontal shear transmitted by the trough plates into the tower is added to this. Friction between the PPWS and the trough plate, reduced accordingly by gamma value, may be taken to aid in resisting this transverse force, but, the support of the spacer by friction with the trough plate above cannot be counted on in such a localised area. The spacers are also thinner at this point.

	SILS	ULS	
Flexural stress in spacer	234	219	N/mm^2
Shear stress	15	14	N/mm^2

The combined effects of these stresses follow.

			SILS	ULS	
Equivalent direct stress			373	378	N/mm^2
Material yield	500	N/mm^2			
Gamma M			1.00	1.05	
UTILISATION			**0.75**	**0.79**	

The saddle trough plates resist the SILS and ULS loading as detailed.

The overall stability of the trough plates on top of each other and the tower is maintained by friction. The dowels are for locating purposes only. The load case with a maximum value of resultant horizontal shear/axial load was selected from the IBDAS results (see section 6.1 above).

		SILS	ULS	
Min vertical compression Ns IBDAS		1137	931	MN
Resultant shear		137	125	MN
Trough plate friction coefficient	0.30			
Coeff / gamma M		0.30	0.18	
Frictional resistance		341	169	MN
UTILISATION		**0.40**	**0.74**	

The trough plates are stable against sliding at SILS and ULS.

In the event that the manufacturer finds advantageous the manufacture of all trough plates to a single radius with deformation occurring once installed the additional stresses caused by deforming the trough plates must be added to the service effects above. These stresses are factored with gamma M = 1.00.

Stress in deformed trough plate	99	N/mm^2	(either tension or compression at the tip of spacer)
	42	N/mm^2	(either tension or compression at the underside of trough plate)

			SILS	ULS	
Equivalent direct stress tip of spacer			389	396	N/mm^2
Equivalent direct stress underside of trough plate			377	383	N/mm^2
Material yield	500	N/mm^2			
Gamma M			1.00	1.05	
UTILISATION			**0.75**	**0.80**	

6.4 Additional Anchorages and Saddle Frame

The bearing plates which support individual PPWS and the local distribution of this force into the longitudinal stiffeners are designed to resist the UTS of the strand.

Contact pressure	361	N/mm^2		
Yield stress of steel (S460)	460	N/mm^2		
			SILS	**ULS**
gamma M			1.00	1.05
UTILISATION			**0.78**	**0.82**

The stiffened base plate and stiffeners are designed to resist the maximum allowable SILS or ULS tension in the strands applied eccentrically. The deflection of the plate and corresponding increase in eccentricity is taken into account.

	SILS	ULS	
Deflection in plate	24	19	mm

Stresses are checked at the stiffener tips and the combined stress from biaxial bending and shear in the base plate. At SILS, the material yield stress may be reached and plastic deformation permitted, whereas at ULS, the section remains elastic.

	SILS	ULS	
Stress at bottom tip of transverse stiffs	276	415	N/mm^2
Stress at tip of long. stiffs	255	427	N/mm^2
Equivalent direct stress in base plate	376	296	N/mm^2
Material factor	1.00	1.05	
MAXIMUM UTILISATION	**0.82**	**0.97**	

The front edge of the base plate is unstiffened transversely but is supported on the trough plates below at quarter points.

	SILS	ULS	
Equivalent direct stress	386	293	N/mm^2
Material factor	1.00	1.05	
UTILISATION	**0.84**	**0.67**	

Close to the supported edge the base plate is unstiffened.

	SILS	ULS	
Bending stress	355	293	N/mm^2
Vertical Shear stress	38	31	N/mm^2
Longitudinal shear stress	124	104	N/mm^2
Equivalent direct stress	420	347	N/mm^2
Material factor	1.00	1.05	
UTILISATION	**0.91**	**0.79**	

At the support the additional force from the handstrands is added to the base plate. These forces are applied unfactored.

Total force	4400	kN
Moment	4840	kN.m

The bolts experience shear and tension. The connections are symmetrical about the saddle side plate so no additional eccentricity is applied.

		SILS	ULS	
Choose number of bolts at each edge	50			
Longitudinal shear applied per bolt		971	821	kN
Tension applied per bolt		335	285	kN
Combine Ft and Fv (NTC08, eq 4.3.65)		0.856	0.906	

The saddle frame side plate transfers the forces applied by the bolted connection. The highest stress occurs at the base plate connection.

	SILS	ULS	
Compressive stress due bending	9	8	N/mm^2
Tensile stress due bending	27	23	N/mm^2
Shear stress	72	61	N/mm^2
Interaction	128	108	N/mm^2
gamma M1	1.00	1.10	
UTILISATION	**0.28**	**0.26**	

The base plate resists the forces applied to it because it is held in down by the trough plates. Local bending and shear stresses occur in the base plate.

	SILS	ULS	
Equivalent direct stress	306	258	N/mm^2
gamma M0	1.00	1.05	
UTILISATION	**0.67**	**0.59**	

6.5 Top Plate Bearing Pressures

The thick top plate is supported by a rectangular grillage at varying centres. The thickness of the plate is significant compare to the span, therefore much of the load applied to it is transferred by stiff bearing into the grillage plates. However, some variation in pressure will occur along the supported edges. A Lusas model was produced for part of the top plate and a unit load applied in order to assess the transmission of pressure into the grillage and particularly the distribution along the edges for varying panel dimensions. Relationships between the average pressure and the peak and corner pressures were identified and largest values chosen as a c onservative estimate of the pressure distribution along the edges.

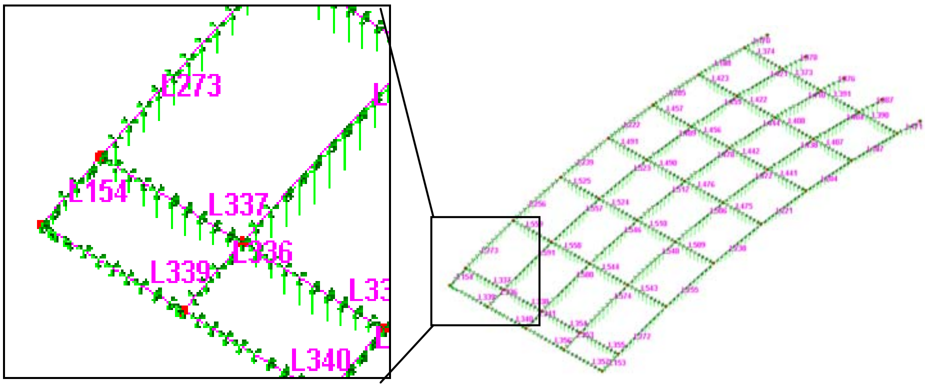

Figure 6-2: LUSAS FE model showing reactions at a selection of the supports of tower top plate.

Adjustment factor for peak pressure	Average x 1.30
Adjustment factor for pressure at panel corner	Average x 0.30

6.6 Transition Section

The design of the grillage plates for the transition section is governed by the highest applied pressure. The resistance is achieved by strength of the materials.

Forces applied to tower	Ns[MN]	My[MNm]	Mz[MNm]	Vy[MN]	Vz[MN]	Mt[MNm]
Design case SILS	-1528.41	-186.505	0.775	-58.272	-59.57	-6.939
Design case ULS	-1753.016	-161.253	1.727	-66.294	-49.691	-6.143

Since the ULS pressure is significantly greater than the SILS pressure and the material factors are 1.05 and 1.00 respectively, the SILS is non-critical and will no longer be considered.

The following discussion refers to the ULS case only.

The bending stresses, and accompanying shears, experienced by the top plate are due to biaxial bending.

Bending stress long way span	250	N/mm2
Bending stress short way span	215	N/mm2
Shear stress at short edge	31	N/mm2
Shear stress at long edge	43	N/mm2
equiv direct stresses	241	N/mm2
gamma m0	1.05	
UTILISATION	**0.73**	**For direct stress**
UTILISATION	**0.22**	**For shear stress**

Bearing pressures onto the grillage vary. The peak values are shown below. The bearing capacity of the grillage below the top plate, being of thinner plates, will be less critical and is not considered.

Peak bearing pressure on short edges	271	N/mm2
Peak bearing pressure on long edges	373	N/mm2
Limiting stress of bearing contact = 1.5 x fy/gamma M0 (EN 1993-1-8, table 3.10)		
Limiting stress of bearing contact	690	N/mm^2
UTILISATION	**0.54**	

The shortest secondary stiffeners develop bending and shear under the applied load. The combined stresses are checked at the edges, the centre of the span and the quarter points. The top edge of the plate is critical at the quarter point.

Shear stress at edge	230	N/mm^2
Bending in plt M	230	N/mm^2
Bending and bearing, no shear	326	N/mm^2
Adjustment to average for bearing stress at panel corners from Lusas model		
Min bearing/average	0.30	
Shear and 30% ave. bearing, no bending	407	N/mm^2
gamma M0	1.05	
UTILISATION	**0.93**	**For direct stress**
UTILISATION	**0.91**	**For shear stress**

The remaining secondary stiffeners support those discussed above. This plate is checked for shear buckling and found to yield before buckling. The same analysis as above is repeated.

Shear stress at edge	134	N/mm^2
Shear stress at quarter point	67	N/mm^2
Max Bending stress in plt M	107	N/mm^2
Bending stress at quarter point	89	N/mm^2
Shear,BM, bearing at top 1/4	266	N/mm^2
Shear and BM bottom of plt	255	N/mm^2
gamma M0	1.05	
UTILISATION	**0.24**	**For direct stress**
UTILISATION	**0.53**	**For shear stress**

The primary stiffeners run longitudinally and transversely. Longitudinal stiffeners within the outer tapering sections support a series of secondary stiffeners as well as direct bearing from the top plate. The maximum equivalent direct stress is found at the top edge mid-way between the vertical supporting edge and the first secondary stiffener.

Maximum equivalent direct stress	281	N/mm^2
gamma M0	1.05	
UTILISATION	**0.64**	**For direct stress**
UTILISATION	**0.56**	**For shear stress**

The primary stiffeners in the central part of the tower leg run longitudinally and transversely.

The longitudinal stiffeners, three in number carry a greater proportion of the load than do the two transverse stiffeners, although, the stiffnesses are so arranged to distribute the forces fairly evenly between all stiffeners.

Stresses in the longitudinal stiffeners

Shear stress at edge	145	N/mm^2
Shear stress at 1/4 point	73	N/mm^2
Max bending stress	116	N/mm^2
Bending stress at 1/4 point	87	N/mm^2
Interaction at top of plt		
Bearing, bending centre	163	N/mm^2
Shear,bearing, bending 1/4	205	N/mm^2

Interaction at bottom of plt		
Bending centre	116	N/mm^2
Shear, bending 1/4	153	N/mm^2
gamma M0	1.05	
UTILISATION	**0.47**	**For direct stress**
UTILISATION	**0.57**	**For shear stress**

Stresses in the transverse stiffeners

Shear stress at edge	147	N/mm^2
Shear stress at 1/4 point	74	N/mm^2
Max bending stress	104	N/mm^2
Bending stress at 1/4 point	78	N/mm^2
Slope of sides	19.98	degrees
Add'l compr force due slope	32	MN
Add'l compr stress due slope	54	N/mm^2
Interaction at top of plt		
Bearing, bending centre	148	N/mm^2
Shear,bearing, bending 1/4	185	N/mm^2
Interaction at bottom of plt		
Bending centre	51	N/mm^2
Shear, bending 1/4	130	N/mm^2
gamma M0	1	
UTILISATION	**0.42**	**For direct stress**
UTILISATION	**0.58**	**For shear stress**

The plate sizes designed for each type of stiffener are as follows.

Plates designed		t (mm)	D (mm)	Butt welds to edges (mm)
Secondary additional stiffeners		60	1000	60
Secondary transverse stiffeners		60	2500	38
Central Stiffener - Side section (width varies from 4 to 6m)		60	10000	40
Longitudinal central stiffener		60	10000	41
Longitudinal outer stiffener		60	10000	41
Transverse stiffeners	(inner)	60	10000	42
Transverse stiffeners	(outer)	60	10000	42

7 Splay Saddles, Design Verifications

7.1 Design Forces

Components subject to forces applied by groups of strands without being the complete cable are designed to resist the maximum forces in the strands at SILS or ULS that are allowed by the design basis.

Max force in strand at SILS (UTS/1.4)	3864	kN
Max force at ULS (UTS/1.67)	3239	kN

Max allowable cable tension (single cable) MN	**No PPWS**	**SILS**	**ULS**
Sicily side span cable	361	1395	1169
Calabria side span cable	357	1380	1157

The resolution of the maximum allowable forces into the strands at reference geometry yields the following reactions at the rocker bearing.

Max allowable resultant force into splay saddle (double cable) MN

	Angle of incidence (deg)	**SILS**	**ULS**
Sicily side span cable	7.98	387	325
Calabria side span cable	8.05	386	324

Components subject to forces applied by the complete cable are designed to resist the maximum design forces applied by the cable at the relevant limit state and the maximum tendency for the saddle to be sheared off the tower. The verifications are made at SILS or ULS.

The saddle and trough plate is governed by the maximum cable tension load combination that maximises the reaction at the rocker.

The possible 'unzipping' of the twin splaying cables due to slip of the trough plates is assessed by applying a reduction factor, γ_M, to the cable to trough plate friction.

These cable forces are selected from the IBDAS model 3.3b results files for the cable at the saddle.

	Ns[MN]
Max ULS cable tension (IBDAS load cases 6517 plus temperature envelope 4510)	**1108**
Max SILS cable tension (IBDAS load cases 6812 plus temperature envelope 4510)	**978**

IBDAS load case 6517 is a load combination at ULS of the loading in the finished bridge, PP+PN+QA+VS+VT with surfacing of 40mm.

Temperature envelope 4510 is a worst temperature loading envelope for uniform temperature.

IBDAS load cases 6812 is a load combination at SILS of the loading in the finished bridge PP+PN+QR+VS+VT with surfacing of 40mm

7.2 Trough Plates - Geometry

The cable run strands are parallel in the compacted cable. At the final cable band they splay apart and diverge towards the trough plates. The strands are grouped for entry into the trough plate grooves, the separation being controlled by the spacer thickness and the groove width. The greater splay of the cable within the splay saddle makes the forces on the spacers higher, and therefore they tend to be thicker than those at the tower saddles. As a result, the distance between the main cables increases from 2000mm to 2310mm at the entrance to the trough plates, and continues to increase as they diverge within the trough plates.

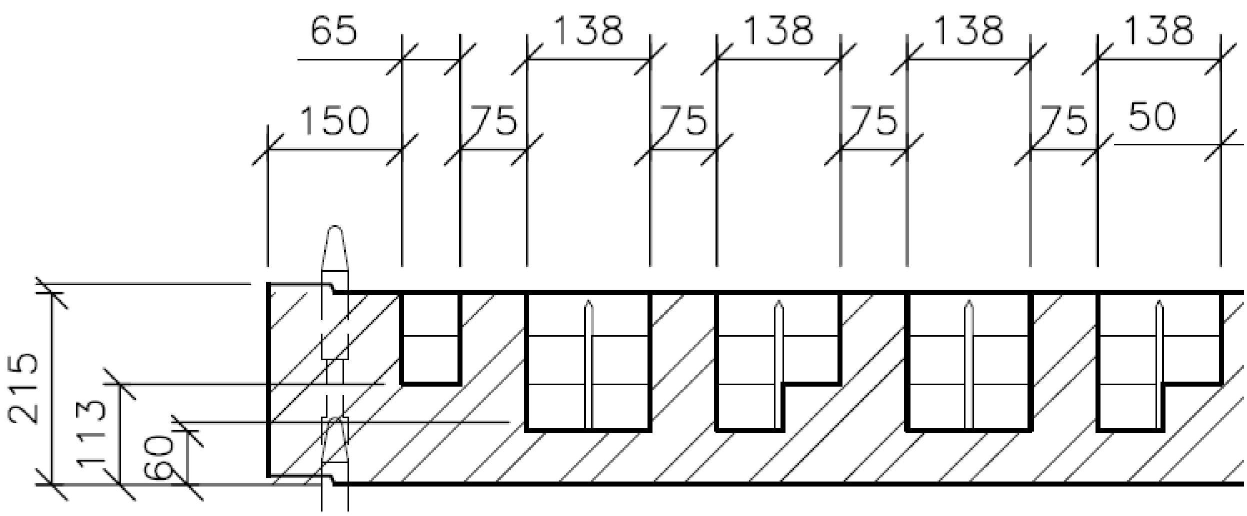

Figure 7-1 Partial section through splay saddle trough plate F

The spacers thicken as the horizontal splay of the strand groups increases the distance between them.

Each trough plate guides the strands through a different vertical arc in order to splay the strands vertically. The vertical curve of the trough plates is set out at a single origin in order to direct the forces through the rocker and each layer of strands leaves the respective arc tangentially after having passed through different angles of deviation. Between the entry and exit tangent points of the vertical arcs, the strands apply a radial pressure to the trough plates. Local flexure and shear of the base of the trough plate spread the forces to the spacers and thence to the trough plates below, accumulating towards the rocker. The radii of the vertical arcs are determined by the position of the rocker, the main cable axis in the side span, the theoretical main cable axis of the deviated cable and the trough plate thickness. There is no flexibility in adjustment of these tangent points since all parameters but the trough plate thickness are fixed.

The horizontal splay of each groove column is defined as the same for each trough plate. Guiding the strands through the same radius of arc ensures that the spacers are aligned to carry the radial pressures directly. Since the incoming cable angle is defined by the spacer thickness and the deviation angles defined by the anchor wall setting out points any appropriate radius of curvature may be chosen, provided that it is imposed on all strands in a particular column and that the spacers do not reduce in thickness. In order to distribute the horizontal splay forces over the greatest length of trough plate, the horizontal curvature is commenced as close as practically possible upon entering the trough plates and continues until as close as practically possible to the exit point.

Transverse splaying of the strands may cause lateral bunching of wires. The vertical curvature holds the wires in the closed-packed arrangement. If the horizontal component of force is sufficient to overcome the vertical correcting force, wires may move laterally, jumping over others and crossing. The close-packed formation is hexagonal, so, neglecting friction, when the horizontal force is greater than tan(30°) times the vertical force wire bunching may occur.

In order to distribute horizontal forces over a longer length of trough plate, the horizontal arc extends beyond the region with vertical curvature. In these areas, shown shaded on Figure 7-2 the wires have no correcting force and control measures must be taken. These will be designed by the contractor as part of the erection equipment, however, the system shown illustratively on the drawings comprises rectangular steel bars screwed to the trough plates over the strands, which hold the wires in place. Because the wire crossing requires increased space the wires the stiffness of the wires themselves will enable intermittent control blocks. They will be used in conjunction with similar controlling efforts immediately before and after the trough plates.

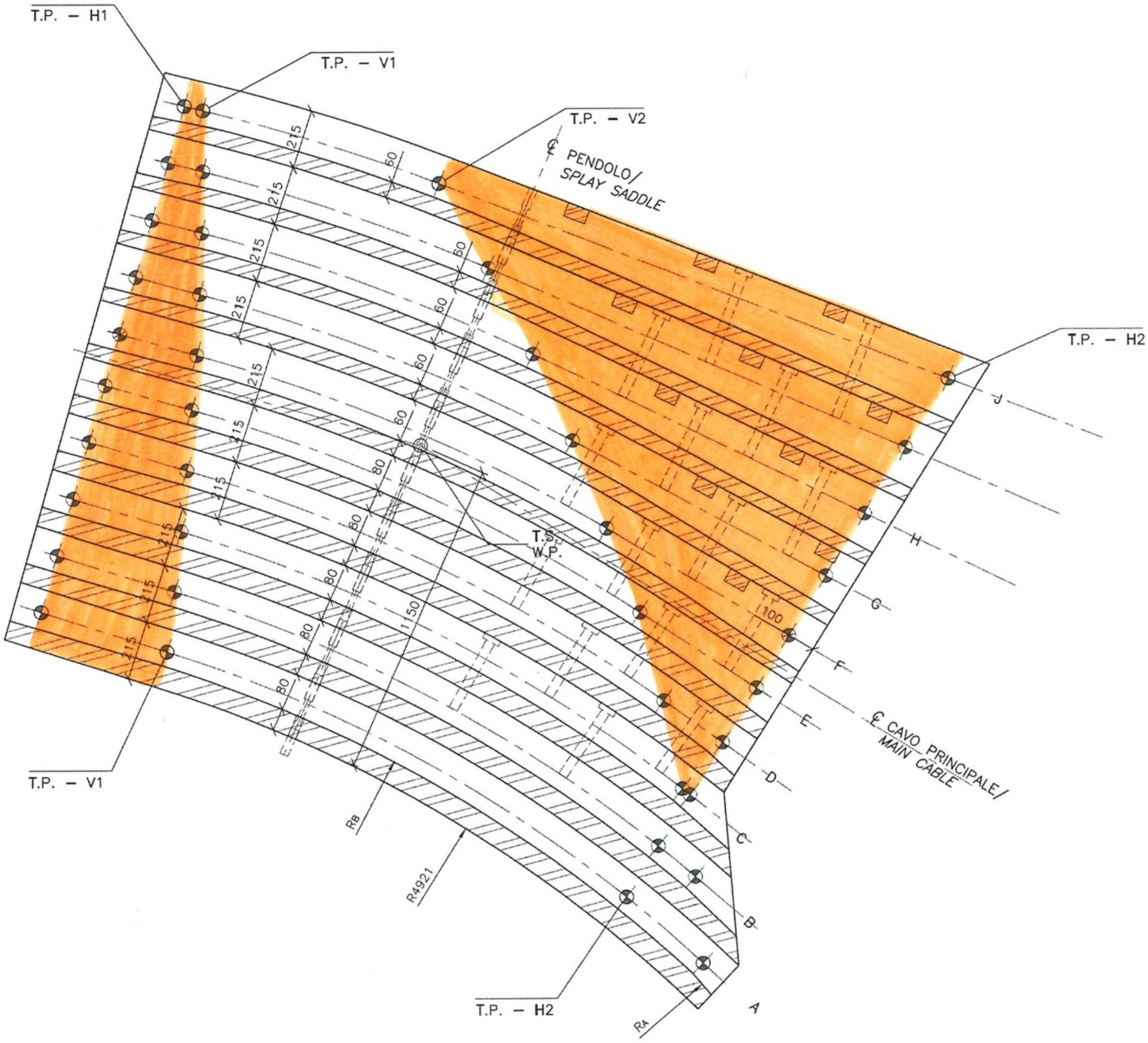

Figure 7-2 Section through splay saddle trough plates showing regions where horizontal splay occurs without vertical splay.

The horizontal radii do not have a common centre as in the case of the vertical arcs but equilibrium is maintained because the out-of-balance forces are reacted by equal and opposite forces from the other cable. The flexure of the spacers and the balancing tension in the trough plate bases, increasing towards the centre, adding transverse tensile stresses to the trough plate bases.

7.3 Trough Plates

The following stresses occur in the trough plates and the internal corners of the spacers:

STRESS	DIRECTION
Accumulated radial stress at spacer;	Radial compression
Flexure of the spacers due the horizontal spreading force of strand wires, and accompanying shear	Radial tension or compression Transverse shear
Flexure of trough plate base due to radial pressure of PPWS and accompanying shear	Transverse tension of compression Radial shear
Horizontal force on spacer due to the horizontal splay and accompanying shear	Radial tension or compression Transverse shear
Accumulated horizontal tension in the trough plate base	Transverse tension
Moment from spacer distributed into base	Transverse tension

The maxima of these stresses are tabulated below. They are not necessarily coincident in the same location.

MAXIMUM STRESSES (N/mm^2)	SILS	ULS
Accumulated radial stress at spacer;	286	240
Flexure of the spacers due the horizontal spreading force of strand wires	147	123
and accompanying shear	37	31
Flexure of trough plate base due to radial pressure of PPWS	50	42
and accompanying shear	21	18
Horizontal force on spacer due to the horizontal splay	56	47
and accompanying shear	18	15
Accumulated horizontal tension in the trough plate base	136	114
Moment from spacer distributed into base	143	120
Yield stress of cast steel	500	500

The equivalent direct stress is calculated for coincident stresses at the corners of all grooves.

Equivalent Direct Stress at critical location	477	400
Gamma M0	1.00	1.05
MAXIMUM UTILISATION	**0.95**	**0.84**

Unzipping of the cable may occur if there is insufficient friction between the strands and the trough plates. This is verified below:

	SILS	**ULS**	
Max allowable tension (single cable)	1395	1169	MN
Resultant splay force (single cable)	126	105	MN
Longitudinal component (unzip)	5.7	4.7	MN
Long'l unzip force (double cable)	11.3	9.5	MN
Transverse component (single cable)	126	105	MN
Reaction on base of grooves (double cable)	387	325	MN
Coeff. of friction - wires and grooves	0.20	0.20	
Gamma M friction at SILS	1.00	1.65	
Resistance to unzip force	128	65	MN
UTILISATION	**0.09**	**0.15**	

During construction of the main cable, the strands will be placed one-at-a-time and the transverse forces on the trough pates must, by definition, be out of balance. This is of concern where there is no radial force to hold the trough plates in position. Here no friction is developed with the trough plate below and it may be free to move. Dowels are provided for positioning the trough plates only. Shear keys are provided for resisting the maximum transverse forces but since it is impractical to use shears keys with an interference fit, the trough plates must be held onto them by holding down bolts. The solution shown on the drawings defines 6No M30 grade 10.9 bolts per trough plate and shear keys of 70 wide with side slopes at 1:2. It is verified below for the worst out-of-balance force due to a single four-strand groove.

Shear keys

Max transverse force per four strand group	2336	kN
Resistance of shear key	13605	kN
gamma M SLS	1.25	

UTILISATION	**0.17**	
Holding down bolts		
Tensile capacity M30	283	kN
Number of bolts provided per trough plate	6	
Side face of shear key at	26.5	degrees
Tension generated in bolts w/out friction	1165	kN
UTILISATION	**0.69**	

Clearly, this detail can be adjusted to suit the contractor's preferred erection scheme if, for instance, more out-of-balance forces are imposed on the trough plates during cable construction.

7.4 Central Part and Rocker Bearing

The central part is manufactured from cast steel and structural steel.

Cast steel, grade G24Mn6+QT2 (1.1118) to UNI EN 10340		
Material yield	370	N/mm^2
UTS	620	N/mm^2
Hot-rolled steel, S420ML to EN 10025-4 UP TO 100MM		
Material yield	420	N/mm^2
Hot-rolled steel, S420ML to EN 10025-4 OVER 100MM		
Material yield	360	N/mm^2

The radial force from the trough plates bears onto the top plate. The pressure is distributed through the stiffened fabrication and through the rocker bearing.

Stresses at critical cross-sections are verified.

	SILS	ULS	
Force in one saddle is for two cables	387	325	MN
Stress at critical sections			
Top of top casting	58	49	N/mm2
Underside of top casting	169	141	N/mm2
Underside of curtailed stiffs	249	209	N/mm2
Top of bearing casting	214	180	N/mm2
gamma M0	1.00	1.05	
MAXIMUM UTILISATION	**0.69**	**0.61**	

The rocker bearing is designed in accordance with EN 1337-6 -2004, 6.5.1.

Rocker bearing	SILS	ULS	
Applied loading	387	325	MN
Gamma M	1.00	1.10	
Design resistance (N'Rd)	1048	866	MN
Gamma M2	1.00	1.25	
UTILISATION	**0.37**	**0.47**	

The pressure applied to the concrete is verified in accordance with EN 1992-1-1,cl. 10.9.5.2(2) assuming the concrete class to be 45.

	SILS	ULS	
Bearing pressure on concrete	27	23	N/mm2
Estimate local pressure limit factor on fcd	1.00	0.85	
Limiting pressure	45	38.25	N/mm2
UTILISATION	**0.61**	**0.60**	

Appendix 1 - Tower Saddle - Design Calculations

TOWER SADDLES -TROUGH PLATE DESIGN

Slot dimensions				
No wires in strand	127			
Wire diamater (nominal)	5.4 mm			
Tolerance +	0.08 mm			
Tolerance -	-0.05 mm			
Max Dia	5.48 mm			
Min Dia	5.35 mm			
Single strand width	12 wires			
Single strand height	11 close packed rows			
Close packed angle	60 degrees			
Clearance for each strand	1 mm			
Material yield	500 N/mm^2			
Single strand slot				
Nominal slot width	65.8 mm	W	66.00 mm	
Max strand width	65.76 mm	d	53.00 mm	
Nominal strand height	52.17 mm			
Max strand height	52.94 mm			
Four strand slot				
Max spacer thickness	6 mm	W	138.00 mm	
Min spacer thickness	5.8 mm	d	106.00 mm	
Nominal slot width	137.6 mm			
Max strand width	137.52 mm			
Nominal strand height	104.33 mm			
Max strand height	105.88 mm			

Spreading force
Spreading force bends spacer only during cable construction - it is balanced by neighbouring strands in permanent condition

Friction angle	0.65		
(assume hydrostatic distribution)			
H (Free cable)	669462 kN	(estimated)	
Angle cable main span (free cable)	19.61228 degrees		698 strands
Angle cable side span (free cable)	24.39689 degrees		722 strands
Vertical force into tower	705 kN / strand		
Length of strand contact in saddle	15200 mm on plan		
Length of saddle	16000 mm		
Vertical force per 4-strand slot	186 N/mm run of slot		
Horizontal force in spacer	121 N/mm run of slot		
Lever arm	35 mm		
Moment in spacer	4256 N.mm/mm run		
Thickness of spacer	30 mm		
Stress in spacer	28 N/mm^2	(free cable)	
Material yield	500 N/mm^2		

By inspection, this is not a critical case

Permanent condition
Design trough plate grooves for max permissible ULS/SILS condition

			SILS	**ULS**
Number of PPWS in groove	4			
Number of strands in one cable	349			
Vertical force into tower			2042	1712 MN
Vertical force of 4 strands			23.40	19.62 MN
Spacer thickness	30 mm			
Width of saddle	16 m			
Vertical force of 4 strands			1463	1226 N/mm run
Bearing onto spacers (applied from trough plates above)			49	41 N/mm^2
Spacing between grooves	168 mm			
Thickness of base	60 mm			
Moment in base			20478.09	17167.26 N.mm/mm run
Shear in base			731	613 N/mm run
Stress due flexure of base			23	19 N/mm^2
Shear stress			12	10 N/mm^2

Underside of trough plate B			**SILS**	**ULS**
Accumulate bearing stress of	9 trough plates above			
Bearing stress			439	368 N/mm^2
Add flexure and shear in base of trough plt				
Stress due flexure of base		0	23	19 N/mm^2
Shear stress		0	12	10 N/mm^2

Equivalent direct stress		440	369 N/mm^2	
Material yield	500 N/mm^2			
Gamma m		1.00	1.05	
UTILISATION		**0.88**	**0.77**	OK

Underside of trough plate A		**SILS**	**ULS**	
Accumulate bearing stress of	10 trough plates above			
Bearing stress		488	409 N/mm^2	
Equivalent direct stress		488	409 N/mm^2	
Material yield	500 N/mm^2			
Gamma m		1.00	1.05	
UTILISATION		**0.98**	**0.86**	OK

Overall design of trough plates to IBDAS forces at SILS and ULS

Consider underside of trough plate A

Length	16 m					
Width	3.945 m					
	Ns[MN]	My[MNm]	Mz[MNm]	Vy[MN]	Vz[MN]	Mt[MNm]
IBDAS forces at SILS	-1528.41	-186.505	0.775	-58.272	-59.57	-6.939
IBDAS forces at ULS	-1753.016	-161.253	1.727	-66.294	-49.691	-6.143

		SILS	ULS	
Contact pressure		24	28 MN/m^2	N/mm^2

Consider root of spacer in trough plate A			
Reduction in area due to grooves			
Spacer thickness	30 mm		
Groove spacing	168 mm		
Factor of increase in stress	5.6		
Bearing pressure		137	156 N/mm^2

Consider contact location on underside of trough plate B			
Bearing pressure		137	156 N/mm^2
Additional stressflexure and shear in base of groove			
Stress due flexure of base		23	19 N/mm^2
Shear stress		12	10 N/mm^2

Additional stress due to change in tension in cable			
Maximum tension transmitted to trough plate governed by friction			
Number of piece per trough plate	5		
Length of trough plate piece	3.2 m		
Direct force on trough plate pile		306	351 MN
Coefficient of friction	0.3		
Coeff * gamma m		0.3	0.495
Assume 50% acts in each direction			
Max tensile force applied to trough plates		46	87 MN
Number of trough plates	10		
Area of all trough plates	3.844 m^2		
Max stress due to cable tension		12	23 N/mm^2

Flexural stress in spacer due to horiz forces and strand splay to cable clamp			
Horiz forces from splay to cable clamp			
Length of arc	400 mm		
Second from outermost groove bears on spacer			
Strand column in trough plt	C		
Transverse deviation angle	0.44 degrees		
Tension of strands in groove		15.46	12.96 MN
Horiz force on trough plts at this location		118	99 kN

PPWS from CL at saddle	635 mm
PPWS from CL at cable clamp	575 mm
Distance	11500 mm
Add lateral translation angle	0.14 degrees
Splay angle of outer PPWS	0.44 degrees

Transverse force applied to saddle			
Transverse shear Vy IBDAS		58	66 MN

Reduce by frictional resistance between strand and groove			
Friction coeff on groove floor	0.00	(neglect friction of spacer with trough plate above)	
Vertical force at splay arc		585	490 kN
Horizontal force resisted by friction		0	0 kN
Force on spacer		177	165 kN
Height of action	53 mm		
Thinnest point	20 mm		
Flexural stress in spacer		234	219 N/mm^2
Shear stress		15	14 N/mm^2

Combine stresses					
Bearing direct stress	Vert		137	156	
Flexural direct stress in spacer	Vert		234	219	
Coincident shear stress	Transv		15	14	
Longitudinal direct stress	Long		12	23	
Flexural direct stress in base	Transv		23	19	
Coincident shear stress	Vert		12	10	
Equivalent direct stress			373	378 N/mm^2	
Material yield		500 N/mm^2			
Gamma m			1.00	1.05	
UTILISATION			**0.75**	**0.79**	**OK**

Overall frictional capacity of saddle				
Min vertical compression Ns IBDAS		1137	931 MN	
Coincident shear Vy		42	34 MN	
Coincident shear Vz		130	121 MN	
Resultant shear		137	125 MN	
Trough plate friction coefficient	0.30			
Coeff / gamma m		0.30	0.18	
Frictional resistance		341	169 MN	
UTILISATION		**0.40**	**0.74**	**OK**

POSSIBLE MANUFACTURING OPTION

Consider: Manufacture all trough plates to the same radius. When installed and loaded they will deform to the correct radius.

Trough plate manufacturing radius		Base	
Depth of trough plate	200 mm	width	168 mm
Number of trough plates	10	base	60 mm
Radius a CL cable (R0)	19918 mm	Lever arm	30 mm
Radius at u/s trough plt 1 (R1)	18918 mm	Stalk	
Radius at t/s trough plt 10 (R10)	20918 mm	thickness	30 mm
Area of one slot + spacer	14280 mm^2	height	140 mm
x bar (neutral axis position)	59 mm	Lever arm	130 mm
Modulus of inertia (I)	39531059 mm^4		
Z min	281183.3 mm^3		

CALC PROOF	W=4fZ/L
deflection = $WL^3/48EI$	deflection=$4fZL^2/48EI$
M=WL/4	Z=I/y
f=M/Z	deflection=$4fL^2/48Ey$
f=WL/4Z	f=12.deflection.E.y/L^2

Width of saddle at R1	15600 mm				
Offset of centre of circle	547 mm				
Angle of saddle in side span	23.71 degrees				
Angle of saddle in main span	20.79 degrees				
Subtended angle of saddle	44.5 degrees				
Number of trough plate pieces	5 per level				
Trough plate subtended angle	8.9 degrees				
Length of trough plate arc (R0)	3094 mm	Max gap to chord	60 mm	Req'd deflection	0.0 mm
Length of trough plate arc (R1)	2939 mm		57 mm		-3.0 mm
Length of trough plate arc (R10)	3249 mm		63 mm		3.0 mm
Young's modulus (E)	205000 N/mm^2				
Stress in trough plate (f) (R10)	99 N/mm^2	(either tension or compression at the tip of spacer)			
	42 N/mm^2	(either tension or compression at the underside of trough plate)			

Stress at tip of spacer adds to bearing stress

Stress at underside of trough plate adds to bearing and bending stresses

Equivalent direct stress tip of spacer		389	396 N/mm^2	
Equivalent direct stress underside of trough plate		377	383 N/mm^2	
Material yield	500 N/mm^2			
Gamma m		1.00	1.05	
UTILISATION		**0.75**	**0.80**	**OK**

CHECK LIMITING COMPRESSIVE STRESS IN FREE EDGE AT TOP OF SPACER

c/t	-2.000	
alpha	1.00	
limiting value c.alpha / t .eta	-2.92	Class 1, Ok for full fy

General Note: Trough plate bearing onto saddle frame should be very good contact in order to directly transmit the load

TOWER TOP GRILLAGE STIFFENING IN TRANSITION ZONE EXTENDING FROM SADDLE BASE-PLATE TO PRISMATIC TOWER SECTION
Bearing pressure on top of stiffening plates in a grillage, transferred to continuous section by shear and bending

Forces applied to tower	Ns[MN]	My[MNm]	Mz[MNm]	Vy[MN]	Vz[MN]	Mt[MNm]
Design case SILS	-1528.41	-186.505	0.775	-58.272	-59.57	-6.939
Design case ULS	-1753.016	-161.253	1.727	-66.294	-49.691	-6.143

Pressure applied by saddle			SILS	ULS	
Base plate width	4.4	m			
Baseplate length	16	m (on plan)			
Maximum direct pressure			21.88	25.05	N/mm^2
By inspection SILS not critical					
Consider ULS only					

Steel yield strength	460	N/mm^2	
Steel UTS	590	N/mm^2	
Steel yield at 200 thick	360	N/mm^2	1.25
Steel UTS at 200 thick	490	N/mm^2	

Tower top plate - shown at tender as 200mm				
Plate thickness	200	mm		
Unrestrained rotation at supports, allows splicing				
Panel length	1600	mm	1334	mm
Panel width	1000	mm	1000	mm
Total force on panel	40.08	MN	33.42	MN
Reaction on short edge	6.26	MN	6.26	MN
Reaction on long edge	13.78	MN	10.45	MN
M long way	2.505	kN.m/mm		
M short way	2.153	kN.m/mm		
Bending stress long way span	250	N/mm2		
Bending stress short way span	215	N/mm2		
Shear stress at short edge	31	N/mm2		
Shear stress at long edge	43	N/mm2		
equiv direct stresses	241	N/mm2		
gamma m0	1.05			
UTILISATION	**0.73**	**For direct stress**		
UTILISATION	**0.22**	**For shear stress**		

Bearing onto grillage		
Force onto short edges	6262	N/mm
Force onto long edges	8611	N/mm
Bearing pressure from two panels		
Stiffener thickness	60	mm
Average bearing pressure on short edges	209	N/mm2
Ave. bearing pressure on long edges	287	N/mm2
Adjustment to average for peak bearing stress from Lusas model		
Peak/Ave	1.30	
Peak bearing pressure on short edges	271	N/mm2
Peak bearing pressure on long edges	373	N/mm2
Limiting stress of bearing contact = 1.5 x fy/gamma m0 (EN 1993-1-8, table 3.10)		
Limiting stress of bearing contact	690	N/mm^2
UTILISATION	**0.54**	

Secondary additional stiffeners		
Plt thick	**60**	mm
Length/span	1600	
Width of panel	1000	mm
Total MN bearing onto stiff	27.55	MN
End shear	13.78	MN
Depth of stiff	**1000**	mm
Shear stress at edge	230	N/mm^2
Bending in plt M	230	N/mm^2
Bending and bearing, no shear	326	N/mm^2
Adjustment to average for bearing stress at panel corners from Lusas model		
Min bearing/average	0.30	
Shear and 30% ave. bearing, no bending	407	N/mm^2
gamma m0	1.05	
UTILISATION	**0.93**	**For direct stress**
UTILISATION	**0.91**	**For shear stress**
gamma m2	1.25	
Weld Penetration reqd	65	**mm**
	Full Strength Butt Weld	

Secondary transverse stiffeners

Plt thick	**60**	mm	
Length	2000	mm	
Total MN bearing on plt = 2xload on short edge + 2xreaction from add stiffs			
Total load applied to plt	40.08	MN	
Adjustment to average for bearing stress at panel corners from Lusas model			
Min bearing/average	0.30		
Bearing stress at centre	63	N/mm^2	
Adjustment to average for peak bearing stress from Lusas model			
Peak/Ave	1.30		
Peak bearing stress	271	N/mm^2	
End shear	20.04	MN	
Depth of stiff	**2500**	mm	
Shear stress at edge	134	N/mm^2	
Shear stress at quarter point	67	N/mm^2	
Max bending moment	10020	kN.m	
Max Bending stress in plt M	107	N/mm^2	
BM at quarter point	8350	kN.m	
Bending stress at quarter point	89	N/mm^2	
Shear,BM, bearing at top 1/4	266	N/mm^2	
Shear and BM bottom of plt	255	N/mm^2	
Check that no shear buckling (EN 1993-1-5,5.2)			
a/hw	0.4000		
t/hw	0.0240		
k tor	37.375		
tor crit	4086	N/mm^2	ok, yields first
gamma m0	1.05		
UTILISATION	**0.24**	**For direct stress**	
UTILISATION	**0.53**	**For shear stress**	
gamma m2	1.25		
Weld Penetration reqd	38	mm	27 mm leg fillet weld each side

Central Stiffener - Side section (width varies from 4 to 6m)

			Lever arms	
Plt thick	60	mm		
Average bearing from top plt	7830	N/mm		
Ave. bearing stress	131	N/mm^2		
Peak bearing on plt	10179	N/mm		
Max Bearing Stress	170	N/mm^2		
Min bearing on plt	2349	N/mm		
Min Bearing Stress	39	N/mm^2		
No transv stiffs supported	4			
Direct bearing from panel 1334 x 1000: No	6		1333	mm
Support to long edge	10.45	MN	2666	mm
End reaction from trasnv stiffs	20.04	MN		
Total force applied	142.83	MN	4000	mm
End shear R2 (skin)	57.13	MN	5000	mm
End shear R1 (internal)	85.70	MN		mm
Max M		MN.m (occurs at central transv)		
Depth of stiff	10000	mm		
Shear stress	143	N/mm^2		
Angle of sloping side	10.30	degrees		
Internal compressiveforce due inclined support	10.39	MN		
Internal compressive stress due inclined support	17	N/mm^2		
Note: transferred into diaphragms				

Maximum stresses

Action (N/mm2 UNO)	chainage (n	0	0.6665	1.333	2	2.666	3.3325	4	5
Max/min Bearing stress		39	170	39	170	39	170	39	0
Average bearing stress		131	131	131	131	131	131	131	0
Bending moment MN.m		0	54	100	117	119	93	57	0
Bending stress		0	36	67	78	79	62	38	0
Additional compr stress		17	17	17	17	17	17	17	17
Shear MN		86	75	65	14	-36	-47	-57	-57
Shear stress		143	126	108	24	-61	-78	-95	-95
Peak total stress at top		251	281	209	199	148	231	178	165
Average total stress at top		280	259	243	167	193	204	217	165
Total stress at bottom		248	218	193	73	122	142	166	165

gamma m0	1.05		281	ok
UTILISATION	**0.64**	**For direct stress**		
UTILISATION	**0.56**	**For shear stress**		
gamma m2	1.25			
Weld Penetration reqd	40	mm	29 mm leg fillet weld each side	

Principal Stiffeners - Central section

Load from top plt is distributed through secondary stiffs into the principal stiffeners
The load is distributed from the bearing plt and secondary stiffeners
The longitudinal stiffeners are the central one and two sides
The transverse stiffeners are the two internal ones

Longitudinal span	8	m	
Depth of long'l stiffs	10	m (central)	10 m (side)
Transverse span min	4	m	
Transverse stiffs span max	12	m	
Height of transition section	13	m	
Transverse span at bottom	10.15	m	
Average transverse span	7.08	m	
Depth of transv stiffs	10	m	
Longitudinal central stiffener	1	off	
Thickness	60	mm	
Longitudinal outer stiffener	2	off	
Thickness	60	mm	
Transverse stiffeners	2	off	
Thickness	60	mm	

Load distribution according to relative stiffness Stiffness k = L^3/48EI

Although most load is applied to the longitudinal stiffeners, the transverse stiffeners will pick up some more load due their stiffness.

	I	k	Distribution ratio	k = W/δ
All longitudinal stiffs k1	1.5E+13	4.7E+17	0.60	(384/5)EI/L^3
All transverse stiffs k2	1.0E+13	3.2E+17	0.40	(53.9)EI/L^3
Total stiffness		7.9E+17		
Total load applied	877 MN		Total load calculated from top plt	

Total distributed to long'l stiffs	**523**	**MN**
Central longitudinal stiff	**174**	**MN**
Each outer longitudinal stiff	**174**	**MN**
Total distributed to transv stiffs	**353**	**MN**
Each transv stiff	**177**	**MN**

Longitudinal stiffeners	60	mm thick	10 m deep
Average bearing on plt	8611	N/mm run	8 m wide
Max bearing stress	187	N/mm^2	
Bearing stress at 1/4 point	187	N/mm^2	
Shear area	600000	mm2	
Z plastic	1.50E+09	mm3	
Shear in central long'l stiff	87	MN	
SF at 1/4 point	44	MN	
Max M in long'l stiff	174	MN.m	
BM at 1/4 point	131	MN.m	
Shear stress at edge	145	N/mm^2	
Shear stress at 1/4 point	73	N/mm^2	
Max bending stress	116	N/mm^2	
Bending stress at 1/4 point	87	N/mm^2	
Interaction at top of plt			
Bearing, bending centre	163	N/mm^2	
Shear,bearing, bending 1/4	205	N/mm^2	
Interaction at bottom of plt			
Bending centre	116	N/mm^2	
Shear, bending 1/4	153	N/mm^2	
gamma m0	1.05		
UTILISATION	**0.47**	**For direct stress**	
UTILISATION	**0.57**	**For shear stress**	
gamma m2	1.25		
Weld Penetration reqd	41	mm	30 mm leg fillet weld each side

Transverse stiffeners	60 mm thick	10 m deep	
Average bearing on plt	6262 N/mm run	7.08 m average width	
Max bearing stress	136 N/mm^2		
Bearing stress at 1/4 point	136 N/mm^2		
Shear area	600000 mm2		
Z plastic	1.50E+09 mm3		
Shear in transverse stiff	88 MN		
SF at 1/4 point	44 MN		
Max M in long'l stiff	156 MN.m		
BM at 1/4 point	117 MN.m		
Shear stress at edge	147 N/mm^2		
Shear stress at 1/4 point	74 N/mm^2		
Max bending stress	104 N/mm^2		
Bending stress at 1/4 point	78 N/mm^2		
Slope of sides	19.98 degrees		
Add'l compr force due slope	32 MN		
Add'l compr stress due slope	54 N/mm^2		
Interaction at top of plt			
Bearing, bending centre	148 N/mm^2		
Shear,bearing, bending 1/4	185 N/mm^2		
Interaction at bottom of plt			
Bending centre	51 N/mm^2		
Shear, bending 1/4	130 N/mm^2		
gamma m0	1		
UTILISATION	**0.42 For direct stress**		
UTILISATION	**0.58 For shear stress**		
gamma m2	1.25		
Weld Penetration reqd	42 mm	30 mm leg fillet weld each side	

General Note: approximate manual models so not recommended to utilise above 90% except in bearing, which is conservative in this model

density steel	7850	kg/m^3
Tee stiffs	b	t
stalk	550	55
table		
Wt/m	237.4625	kg/m

PRELIMINARY WEIGHT TAKE-OFF AND CHECK FOR STIFFENING OF STIFFENERS — **8845** kN

Use EN 1993-1-5 because NTC 08 does not cover plated fabrications — ***Total*** ***901587*** ***kg***

WEIGHT IN GRILLAGE FABRICATION **Plates designed**		t (mm)	D (mm)	B average (mm)	Number plts required	Wt 1 plt (kg)	Length T (mm)	Stiffs/plt	Wt plt + T (kg)	Total Wt (kg)	hw/t (1993:1:5:cl.5.1)	
Secondary additional stiffeners		60	1000	1000	32	471		0	471	15072	16.67	no stiffs
Secondary transverse stiffeners		60	2500	2000	22	2355	1500	0	2355	51810	41.67	no stiffs
Central Stiffener - Side section (width varies from 4 to 6m)		60	10000	0	2	0	7500	3.5	6233	12467	166.67	check stiffs
Longitudinal central stiffener		60	10000	8000	1	37680	7500	6	48366	48366	166.67	check stiffs
Longitudinal outer stiffener		60	10000	8000	2	37680	7500	6	48366	96732	166.67	check stiffs
Transverse stiffeners	(inner)	60	10000	4000	2	18840	9000	2	23114	46229	166.67	check stiffs
Transverse stiffeners	(outer)	60	10000	1538.462	4	7246	10000	1.5	10808	43232	166.67	check stiffs
Diaphragms for tee stiffs		12	18000	8000	4	13565	0	0	13565	54259		no stiffs
Skin		40	12250	4000	2	15386	10000	2	20135	40271	306.25	check stiffs
		45	12250	8000	2	34619	11000	5	47679	95358	272.22	check stiffs
Continuous plts		60	12250	18000	2	103856	9750	15	138584	277169	204.17	check stiffs
		50	12250	8000	2	38465	11500	8	60312	120623	245.00	check stiffs

STIFFENING OF STIFFENERS (cont) **Plates designed**		**a** **(stiffener spacing)**	**a/hw**	**k tor** **(A.3.(2))**	**tor cr** **(calc on full depth of plt, no account taken of diaphs)**	**I w bar** **(lambda)**	**Chi** **Xw**	**Vbw (kN)** **(gamma M1 =1.10)**	**V applied** **(kN)**	CHECK
Secondary additional stiffeners		1600	1.60	6.90	4721	0.24	1.0	14486.24	13777	ok
Secondary transverse stiffeners		2000	0.80	12.34	1351	0.44	1.0	36215.61	20040	ok
Central Stiffener - Side section (width varies from 4 to 6m)		1333	0.13	304.53	2083	0.36	1.0	144862.4	85699	ok
Longitudinal central stiffener		1600	0.16	212.59	1454	0.43	1.0	144862.4	87169	ok
Transverse stiffeners	(inner)	2000	0.20	137.50	941	0.53	1.0	144862.4	88374	ok
Transverse stiffeners	(outer)	1500	0.15	241.33	1651	0.40	1.0	144862.4	88374	ok
Diaphragms for tee stiffs	fit around stiffeners									
Skin	Not our scope of work - leave as on drawing with note that by others									
Continuous plts	Not our scope of work - leave as on drawing with note that by others									

(Ned = Vapp) — gamma M1 — 1.1

Stiffener size and rigidity check (EN 1993-1-5,9.2)	Single side, flat thickness (t)	eta = Outstand (B)	0.715 15.eta.T	Eff width of plt	Area	Ecc'ty	2nd mom A Ist	b	sigma m (b^2/a^2) . (Ned/b) . (2/a)	u	Ist (min)	Is 2nd mom A big enough?
Secondary additional stiffeners	55	550	643	1341.553	110743.2	113	8.81E+09	3500	23.54509	1.937594	301003581	ok
Secondary transverse stiffeners	55	550	643	1341.553	110743.2	113	8.81E+09	3500	0.01753	1.937594	224166	ok
Central Stiffener - Side section (width varies from 4	55	550	643	1333	110230	114	8.80E+09	3500	0.25327	1.936081	3227984	ok
Longitudinal central stiffener	55	550	643	1341.553	110743.2	113	8.81E+09	3500	0.14897	1.937594	1904451	ok
Transverse stiffeners	55	550	643	1341.553	110743.2	113	8.81E+09	3500	0.07733	1.937594	988562	ok
Transverse stiffeners	55	550	643	1341.553	110743.2	113	8.81E+09	3500	0.18329	1.937594	2343258	ok

TOWER SADDLES - ANCHORAGES FOR ADDITIONAL PPWS STRANDS

Additional strands are anchored to the saddle frame.
The force by-passes the saddle trough plates directly to the baseplate

Single PPWS components designed for UTS

UTS of PPWS	5410 kN			

Bearing plates and contact area of longitudinal stiffeners are designed for UTS
By inspection, critical section is bearing onto stiffeners

		SILS	ULS	
Contact height	300 mm			
Stiffener thickness	50 mm			
Contact pressure	361 N/mm^2			
Yield stress of steel (S460)	460 N/mm^2			
gamma m		1.00	1.05	
UTILISATION		**0.78**	**0.82**	

Stiffened plate at connectinos designed for max allowable SILS/ULS

Sicily tower

		SILS	ULS	
Clearance required for cable rotation	140 mm			
Eccentricity	70 mm			
Increase ecc'y by y/2 for P.delta effect	y =	24	19	mm
Number of add'l PPWS at lower ecc'y	12			
Ecc'y of socket above top of plt	45 mm			
Increased ecc'y		139	134	mm
Number of add'l PPWS at higher ecc'y	12 (increased 5-10-2010)			
Ecc'y of socket above top of plt	340 mm			
Increased ecc'y		434	429	mm
Total force applied to stiffened plate per strand		3864	3239	kN
Total force applied to stiffened plate		92742	77748	kN
Moment applied to stiffened plate		26571	21886	kN.m
Shear stress in longitudinal stiffs				
Length of long. stiffs	3750 mm			
Max. no off PPWS per cheek plt	2			
Max shear stress		41	35	N/mm^2

Check weld of cheek plates

Fillet weld strength (NTC08, 4.2.8.2.4) — This code defines fillet weld resistance in shear as UTS/root3/gamma M2

		SILS	ULS	
Shear applied to long. stiffs		2061	1728	N/mm
UTS S460	540 N/mm2 (EN 10025:4)			
Limiting stress to NTC08		SILS	ULS	
gamma m		1.00	1.25	
beta		1.00	1.00	
Limiting stress		540	432	N/mm^2
Throat of FW	14 mm	20 mm leg		
no beads of weld	2			
Resistance /mm		8730	6984	N/mm
UTILISATION		**0.24**	**0.25**	

Check local buckling of cheek plts under contact bearing pressure

Check as outstand compression element, EN 1993-1-5, table 4.2. Full utilisation if Rho not less than 1

Outstand of stiff	470	mm		
sigma2/sigma1	1			
k sigma	0.4300			
lamda p bar	0.7057			
rho	1.0000			

Check stresses in stiffened plt

Couple

Moment due to eccentric PPWS			26571	21886	kN.m
Length of stiffened plt	3750	mm			
Eff. width transverse beam	1875	mm wide			
Lever arm of couple	1875	mm			
Force on transverse "beam"			14171	11673	kN
Spans to side plates of saddle - bending in transverse stiffeners and base plt					
Span	4465	mm			
Max moment in transverse beam spanning to side plts			7909	6515	kN.m
Depth of stiffeners (d)	250	mm			
Thickness of stiffeners (t)	100	mm			
Number of stiffeners	6				
Thickness of base plt	100	mm			
Area of cross section	337500	mm2	Plastic	Elastic	
Centroid (y')			90	127.7778	mm
Ixx				3.48958E+09	mm4
Z top of base plt			28687500	27309783	mm3
Z bottom tip of transverse stiffs			28687500	15703125	mm3
Stress at top of base plt			276	239	N/mm^2
Stress at bottom tip of transverse stiffs			276	415	N/mm^2

Check distribution of moment longitudinally in order to develop the couple

Longitudinal stress: Bending in longitudinal stiffeners and base plate

Moment applied			26571	21886	kN.m
No longitudinal stiffs	13				
Area of cross section	752000	mm2	Plastic	Elastic	
Centroid			84	166	mm
Ixx				2.07293E+10	mm4
Z tip of long. stiffs			104191579	51282338	mm3
Z bottom base plt			104191579	125039971	mm3
Stress at tip of long. stiffs			255	427	N/mm^2
Stress at bottom of base plt			255	175	N/mm^2
Equivalent direct stress in base plate			376	296	N/mm^2

Combine long and transverse stresses in the base plt

Max. shear stress in base plate	124	104	N/mm^2
Equivalent direct stress	214	180	N/mm^2
Max stress in stiffened plate	376	427	N/mm^2
Material factor	1.00	1.05	
UTILISATION	**0.82**	**0.97**	

Front Edge - supported on trough plates				
Load applied over full width			14171	11673 kN
Number of supports	3			
Number of spans	4			
Span	1116	mm		
Load applied			3543	2918 kN
Moment (propped cantilever)			494	407 kN.m
No transverse stiffs here so base plate alone in bending				
Bending stress in base plate			105	87 N/mm^2
Combine with long. stress and shear in the base plt				
Equivalent direct stress			386	293 N/mm^2
Material factor			1.00	1.05
UTILISATION			**0.84**	**0.67**
Check deflection upwards of rear beam	Beam under udl: y = 5/384.W.L3/EI		E =	210000 N/mm2
increase to reduce P.delta effect while maintaining shorter plate length				
Load applied			14171	11673 kN
Span	4465	mm		
Inertia	3489583333	mm4	SILS	ULS
Deflection in plate			22	18 mm
Bending in base plate near support				
Lever arm	235	mm		
Vertical force applied to beam			14171	11673 kN
End shear			7086	5836 kN
Moment			1665	1372 kN.m
Bending stress			355	293 N/mm^2
Vertical Shear stress			38	31 N/mm^2
Longitudinal shear stress			124	104 N/mm^2
Equivalent direct stress			420	347 N/mm^2
Material factor			1.00	1.05
UTILISATION			**0.91**	**0.79**
Check bolts				
Size of bolt	60	mm dia.		
Tensile area	2360	mm2		
Dia. hole	66	mm		
UTS bolt (grade 10.9)	1000	N/mm2		
Bolts in single shear			SILS	ULS
gamma M2			1.00	1.25
Pv (NTC08, eq 4.2.58)			1414	1131 kN
Pt (NTC08, eq 4.2.63)			1416	1133 kN
Total force applied to stiffened plate			92742	77748 kN
Moment applied to stiffened plate			26571	21886 kN.m
Tension per handstrand	1100	kN		
No off	4			
Total force	4400	kN		
Height above bolt group	1.1	m		
Moment	4840	kN.m		

Choose number of bolts at each edge	50				
Longitudinal shear applied per bolt			971	821	kN
Tension applied per bolt			335	285	kN
Combine Ft and Fv (NTC08, eq 4.3.65)			0.856	0.906	
Min spacing (NTC08)	145	mm			
Min end dist	79	mm			
Use spacing	145	mm	check spacing!		
Edge dist	80	mm			
alpha min	0.150				
k min	1.69				
Thinnest ply	80	mm			
Bearing Pb	1220	kN	bearing not critical		

Saddle frame side plates

Number of PPWS attached	24				
Plt thick	80	mm			
No side plts	2				
Ave. height of PPWS above trough plates	650				
Average height above base plate	2650	mm			
Length of side plate utilised	7000	mm			

PPWS 1	PPWS 2
500	800

Consider as web in shear (1993-1-1, 5.5)

Shear at top of saddle frame	92742	77748	kN
Shear in single side plt	46371	38874	kN
Moment in single plt	122883	103016	kN.m

Check shear capacity of plate (EN 1993-1-5, cl 5.3 and App A.3)

side plt t	80	mm					
hw	8000	mm	(estimate length of plate utilised)				
a	2650	mm					
hw/a	3.019						
k tor	52.67						
tor crit	1001	N/mm^2					
lamda w bar	0.5153						
X chi	1.00		(table 5.1)		η	1.00	(N.A.2.4)
gamma M1				1.00	1.10		
V b,Rd				169972	154520	kN	
UTILISATION				**0.27**	**0.25**		

Check compression zone (EN 1993-1-5, cl 4.4, table 4.2)

Pure bending so sigma2/sigma1 = 0

b bar	4000	mm			
k sigma	7.81				
lamda p bar	0.8814				
rho	0.8926				

Calculate new bending section with reduced compression zone

Length removed	430	mm			
New centroid	2000	mm			
2nd mom area	2.6879E+13	mm^4			
Modulus compressive fibre	1.3440E+10	mm^3			
Modulus tensile fibre	4.4799E+09	mm^3			
Bending moment			122883	103016	kN.m
Compressive stress due bending			9	8	N/mm^2
Tensile stress due bending			27	23	N/mm^2
Shear stress			72	61	N/mm^2
Interaction			128	108	N/mm^2
gamma M1			1.00	1.10	
UTILISATION			**0.28**	**0.26**	

#1		#2
1785	mm	9785
1107	mm	5107

Weld of side plate to base plate (NTC08)

Weld size: 35 mm leg 24.749 mm throat

Shear stress in fillet weld	234	196	N/mm2
Direct stress in fillet weld	89	74	N/mm2
Combined (equivalent direct) stress	415	348	N/mm2
gamma M2	1.00	1.25	
UTILISATION	**0.90**	**0.95**	

Saddle frame base plate

Force in side plate is transferred into the base plate at an unrestrained point.
It must then be transferred back to the area beneath the trough plates where it will be restrained.
Take 1mm cantilever and check bending through lever arm.
Distance of side plate from edge of trough plate

Clearance: side plts & trough plts	220 mm			
Thickness of base plt	50 mm			
Max force applied by side plt		2194	1840	N per mm
M base plate cantilever		482765.64	404713.7108	N.mm/mm
Stress in base plt due side plate		302	253	N/mm2
Shear due side plt		27	23	N/mm2
Compressive stress due trough plates		24	28	N/mm2
Equivalent direct stress		306	258	N/mm^2
gamma m0		1.00	1.05	
UTILISATION		**0.67**	**0.59**	

Put nominal stiffs outside side plates for fabrication alignment control

Stresses in continuous plates

Area of tower leg at continuous section (section above splice)

Plate	No Off	Width (mm)	Thickness (mm)	Area (mm^2)
A	2	4500	55	495000
B	4	2650	40	424000
C	4	2650	40	424000
D	2	8000	50	800000
E	4	3500	50	700000
F	4	2500	50	500000
G	2	4000	60	480000
H	4	4000	60	960000
				4783000 mm^2

Forces from Tower

N -1753.02 MN

Uniform stress in tower leg

fs -366.51 N/mm2

Appendix 2 - Splay Saddle - Design Calculations

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SICILY SPLAY SADDLE						
SETTING OUT OF TROUGH BASES (DIMENSIONS IN MM)						
TROUGH PLATE	Dim A	Radius R_A	Dim B	Radius R_B	Dim C	Radius R_C
J	2003.4	200685.6	816.3	6916.1	209.3	2195.3
I	1684.0	141797.8	1010.4	6701.1	268.5	3609.6
H	1382.4	95556.5	1194.1	6486.1	324.8	5279.8
G	1097.2	60197.4	1366.5	6271.1	376.6	7096.4
F	831.0	34533.1	1537.4	6056.1	425.1	9040.5
E	574.3	16496.0	1696.9	5861.1	460.1	10589.6
D	338.1	5720.6	1833.9	5646.1	503.3	12670.5
C	257.2	3312.6	1958.4	5431.1	542.3	14709.5
B	271.3	3685.2	2070.0	5216.1	577.9	16703.4
A	100.2	507.0	2206.0	5001.1	598.8	17933.1

SETTING OUT OF TROUGH SIDES (DIMENSIONS IN MM)						
STRAND COLUMN	Dim D	Radius R_D	Dim E	Radius R_E	Dim F	Radius R_F
1,23	148.1	2195.9	2397.5	11508.4	81.5	666.7
2,22	144.3	2084.7	2616.5	12533.6	79.8	639.3
3,21	132.9	1768.7	2618.6	13590.2	80.5	650.5
4,20	120.5	1454.5	2645.3	15006.6	81.2	661.8
5,19	110.5	1223.5	2623.3	16379.9	81.9	673.3
6,18	101.4	1030.7	2625.9	18672.2	82.5	683.1
7,17	93.6	878.6	2628.4	21721.2	83.1	693.1
8,16	87.2	762.9	2630.3	25021.2	83.8	704.7
9,15	82.0	674.9	2632.1	29481.6	84.5	716.5
10,14	77.7	606.2	2633.9	36562.7	85.2	728.4
11,13	74.5	557.5	2635.6	48720.9	85.8	738.7
12.0	72.1	522.3	2638.9	92399.2	85.0	725.0

CALABRIA SPLAY SADDLE						
SETTING OUT OF TROUGH BASES (DIMENSIONS IN MM)						
TROUGH PLATE	Dim A	Radius R_A	Dim B	Radius R_B	Dim C	Radius R_C
J	2039.8	208051.2	881.9	6916.1	170.1	1451.0
I	1718.2	147619.7	1075.5	6701.1	230.1	2653.3
H	1415.0	100117.5	1258.2	6486.1	285.4	4077.3
G	1128.3	63658.0	1429.7	6271.1	337.2	5689.5
F	860.6	37040.7	1589.5	6056.1	385.5	7435.7
E	602.7	18165.0	1758.3	5861.1	420.5	8846.0
D	365.2	6673.5	1894.3	5646.1	462.3	10689.6
C	268.1	3598.7	2017.6	5431.1	500.7	12538.4
B	253.5	3218.9	2128.1	5216.1	535.7	14353.2
A	100.6	511.1	2224.9	5001.1	568.3	16150.9

SETTING OUT OF TROUGH SIDES (DIMENSIONS IN MM)						
STRAND COLUMN	Dim D	Radius R_D	Dim E	Radius R_E	Dim F	Radius R_F
1,23	130.5	1705.5	2634.5	11615.4	83.9	706.4
2,22	119.6	1432.9	2634.8	12665.6	83.8	704.7
3,21	110.5	1223.5	2634.8	13722.5	83.8	704.7
4,20	102.5	1053.1	2635.0	14986.7	83.7	703.1
5,19	95.4	912.6	2635.3	16500.4	83.7	703.1
6,18	88.9	792.8	2636.1	18802.7	83.7	703.1
7,17	83.9	706.4	2637.0	21853.5	83.7	703.1
8,16	79.2	629.8	2637.6	25146.4	83.7	703.1
9,15	73.7	545.7	2638.4	29609.2	83.7	703.1
10,14	73.1	536.9	2639.3	36648.9	83.7	703.1
11,13	71.4	512.3	2640.3	48735.1	83.7	703.1
12.0	70.7	502.3	2641.1	92432.3	83.7	703.1

SICILY SPLAY SADDLE - SILS CHECK ON TROUGH PLATES

Trough Plate Design	Cast steel, grade		
Material yield	500	N/mm^2	
Gamma M0 at SILS	1.00		
Limiting stress	500	N/mm^2	
Max allowable SILS tension (single cable)	1395	MN	
Resultant SILS axial force in splay saddle	387	MN	(double cable)
Number of strands in this cable	361		

Trough plate dimensions

Min spacer thickness	25	mm
4-PPWS slot height	105	mm
4-PPWS slot width	138	mm
Total width of grooves	1510	mm
Gap over strand with wire control	50	mm - Specified by YY as overall trough plt height
Gap over strand without wire control	30	mm
2-PPWS slot width	65	mm
Max gap under PPWS at exit	10	mm
Lever arm of action on spacer above base	73	mm

	INNER COLUMN									OUTER COLUMN			
Strand Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	WIDTH
Spacer thickness	25	60	65	75	75	50	50	75	75	75	75	150	2360

Trough plate	Base thickness (mm)	Trough plate thickness (mm)
#10	60	215
#9	60	215
#8	60	215
#7	60	215
#6	60	215
#5	80	215
#4	80	215
#3	80	215
#2	80	215
#1	80	215
	Total	2150

Force applied by PPWS = (2 x PPWS tension x sin [half of deviation angle])

No. PPWS in a slot

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Total PPWS
Trough plate	Table is not automatically updated if strand arrangement changes												
#10	0	0	2	3	4	3	3	4	3	2	0	0	24
#9	0	3	4	4	4	3	3	4	4	4	3	0	36
#8	2	4	4	4	4	3	3	4	4	4	4	2	42
#7	2	4	4	4	4	3	3	4	4	4	4	2	42
#6	1	4	3	4	3	3	3	3	4	3	4	1	36
#5	2	3	4	3	4	2	3	4	3	4	3	2	37
#4	2	4	4	4	4	3	3	4	4	4	4	2	42
#3	2	4	4	4	4	3	3	4	4	4	4	2	42
#2	1	3	4	4	4	3	3	4	4	4	3	1	38
#1	0	0	1	3	4	3	3	4	3	1	0	0	22
													361

Width of slot at lowest point (mm)

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Trough plate	Table is not automatically updated if strand arrangement changes											
#10	65	138	138	138	138	65	138	138	65	138	138	65
#9	65	65	138	138	138	138	65	138	138	138	65	65
#8	65	138	138	138	138	65	138	138	138	138	138	65
#7	65	138	138	138	138	138	65	138	138	138	138	65
#6	65	138	65	138	65	65	138	65	138	65	138	65
#5	65	65	138	65	138	65	65	138	65	138	65	65
#4	65	138	138	138	138	138	65	138	138	138	138	65
#3	65	138	138	138	138	65	138	138	138	138	138	65
#2	65	65	138	138	138	138	65	138	138	138	65	65
#1	65	138	65	65	138	65	138	138	65	65	138	65

CHECK STRESSES AT THE ROOT OF THE SPACERS

1. Vertical deviation causes a radial pressure on trough plates spacers.

Radial bearing of each trough plate (kN)

Trough plate	Column #1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Vert. angle (degrees)
#10	0	0	912	1367	1823	1367	1367	1823	1367	912	0	0	6.76
#9	0	1746	2328	2328	2328	1746	1746	2328	2328	2328	1746	0	8.64
#8	1421	2842	2842	2842	2842	2131	2131	2842	2842	2842	2842	1421	10.55
#7	1681	3361	3361	3361	3361	2521	2521	3361	3361	3361	3361	1681	12.48
#6	978	3913	2935	3913	2935	2935	2935	2935	3913	2935	3913	978	14.55
#5	2230	3345	4459	3345	4459	2230	3345	4459	3345	4459	3345	2230	16.59
#4	2499	4999	4999	4999	4999	3749	3749	4999	4999	4999	4999	2499	18.61
#3	2772	5544	5544	5544	5544	4158	4158	5544	5544	5544	5544	2772	20.66
#2	1523	4570	6094	6094	6094	4570	4570	6094	6094	6094	4570	1523	22.74
#1	0	0	1691	5072	6763	5072	5072	6763	5072	1691	0	0	25.27

Accumulated pressure (kN/mm run)

Trough plate													Length TP to TP
#10	0.000	0.000	1.117	1.675	2.234	1.675	1.675	2.234	1.675	1.117	0.000	0.000	816
#9	0.000	1.728	3.207	3.658	4.109	3.082	3.082	4.109	3.658	3.207	1.728	0.000	1010
#8	1.190	3.842	5.093	5.475	5.857	4.392	4.392	5.857	5.475	5.093	3.842	1.190	1194
#7	2.270	5.817	6.911	7.244	7.578	5.683	5.683	7.578	7.244	6.911	5.817	2.270	1367
#6	2.654	7.716	8.051	8.984	8.644	6.961	6.961	8.644	8.984	8.051	7.716	2.654	1537
#5	3.718	8.962	9.923	10.111	10.460	7.620	8.277	10.460	10.111	9.923	8.962	3.718	1697
#4	4.803	11.018	11.907	12.081	12.404	9.095	9.703	12.404	12.081	11.907	11.018	4.803	1834
#3	5.913	13.148	13.981	14.144	14.446	10.640	11.209	14.446	14.144	13.981	13.148	5.913	1958
#2	6.331	14.647	16.171	16.325	16.611	12.274	12.813	16.611	16.325	16.171	14.647	6.331	2070
#1	5.940	13.744	15.940	17.618	18.653	13.817	14.322	18.653	17.618	15.940	13.744	5.940	2206

Accumulated radial stress at spacer (N/mm2)

COMPRESSIVE STRESS Minimum spacer width = 25 mm Bottom trough plate bears onto tower top plate

Trough plate													
#10	0	0	17	22	30	34	34	30	22	15	0	0	
#9	0	29	49	49	55	62	62	55	49	43	23	0	
#8	48	64	78	73	78	88	88	78	73	68	51	8	
#7	91	97	106	97	101	114	114	101	97	92	78	15	
#6	106	129	124	120	115	139	139	115	120	107	103	18	
#5	149	149	153	135	139	152	166	139	135	132	119	25	
#4	192	184	183	161	165	182	194	165	161	159	147	32	
#3	237	219	215	189	193	213	224	193	189	186	175	39	
#2	253	244	249	218	221	245	256	221	218	216	195	42	
#1	~~238~~	~~229~~	~~245~~	~~235~~	~~249~~	~~276~~	~~286~~	~~249~~	~~235~~	~~213~~	~~183~~	~~40~~	ignore

Accompanying shear stress not applicable Max = 286

2. PPWS in the slots will spread laterally due to the vertical force Spreading factor 0.65

Horizontal force at each slot (kN/mm run) Radial bearing force/length of trough plate*spreading factor

Trough plate \ Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
#10	0.00	0.00	0.73	1.09	1.45	1.09	1.09	1.45	1.09	0.73	0.00	0.00
#9	0.00	1.12	1.50	1.50	1.50	1.12	1.12	1.50	1.50	1.50	1.12	0.00
#8	0.77	1.55	1.55	1.55	1.55	1.16	1.16	1.55	1.55	1.55	1.55	0.77
#7	0.80	1.60	1.60	1.60	1.60	1.20	1.20	1.60	1.60	1.60	1.60	0.80
#6	0.41	1.65	1.24	1.65	1.24	1.24	1.24	1.24	1.65	1.24	1.65	0.41
#5	0.85	1.28	1.71	1.28	1.71	0.85	1.28	1.71	1.28	1.71	1.28	0.85
#4	0.89	1.77	1.77	1.77	1.77	1.33	1.33	1.77	1.77	1.77	1.77	0.89
#3	0.92	1.84	1.84	1.84	1.84	1.38	1.38	1.84	1.84	1.84	1.84	0.92
#2	0.48	1.44	1.91	1.91	1.91	1.44	1.44	1.91	1.91	1.91	1.44	0.48
#1	0.00	0.00	0.50	1.49	1.99	1.49	1.49	1.99	1.49	0.50	0.00	0.00

Stress due horizontal spreading force (N/mm2)
TENSILE STRESS (Force/base thickness) + (Force x eccentricity/modulus)

Trough plate												
#10	0	0	65	97	129	97	97	129	97	65	0	0
#9	0	100	133	133	133	100	100	133	133	133	100	0
#8	69	137	137	137	137	103	103	137	137	137	137	69
#7	71	142	142	142	142	107	107	142	142	142	142	71
#6	37	147	110	147	110	110	110	110	147	110	147	37
#5	51	76	101	76	101	51	76	101	76	101	76	51
#4	53	105	105	105	105	79	79	105	105	105	105	53
#3	55	109	109	109	109	82	82	109	109	109	109	55
#2	28	85	114	114	114	85	85	114	114	114	85	28
#1	0	0	30	89	118	89	89	118	89	30	0	0

Max = 147

Accompanying shear stress (N/mm2) Lateral direction

Trough plate												
#10	0	0	11	15	19	22	22	19	15	10	0	0
#9	0	19	23	20	20	22	22	20	20	20	15	0
#8	31	26	24	21	21	23	23	21	21	21	21	5
#7	32	27	25	21	21	24	24	21	21	21	21	5
#6	17	28	19	22	17	25	25	17	22	17	22	3
#5	34	21	26	17	23	17	26	23	17	23	17	6
#4	35	30	27	24	24	27	27	24	24	24	24	6
#3	37	31	28	25	25	28	28	25	25	25	25	6
#2	19	24	29	26	26	29	29	26	26	26	19	3
#1	0	0	8	20	27	30	30	27	20	7	0	0

Max = 37

3. Flexure of trough plate base due to radial pressure of PPWS

TENSILE STRESS Moment = W.B/12 where B = slot width + spacer width

Stress (N/mm2)

Trough plate \ Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
#10	0	0	21	33	44	18	29	44	22	22	0	0
#9	0	20	43	45	45	30	18	45	45	45	22	0
#8	10	44	45	47	47	19	31	47	47	47	47	24
#7	10	45	46	49	49	32	20	49	49	49	49	24
#6	5	47	23	50	25	20	33	25	50	25	50	13
#5	6	13	28	14	29	8	12	29	14	29	14	15
#4	6	28	29	30	30	20	12	30	30	30	30	15
#3	7	29	30	31	31	13	21	31	31	31	31	16
#2	3	14	31	33	33	22	13	33	33	33	16	8
#1	0	0	5	17	34	14	23	34	17	6	0	0

Max = 50

Accompanying shear stress (N/mm2) Radial direction

Trough plate												
#10	0	0	9	14	19	14	14	19	14	9	0	0
#9	0	14	19	19	19	14	14	19	19	19	14	0
#8	10	20	20	20	20	15	15	20	20	20	20	10
#7	10	20	20	20	20	15	15	20	20	20	20	10
#6	5	21	16	21	16	16	16	16	21	16	21	5
#5	8	12	16	12	16	8	12	16	12	16	12	8
#4	9	17	17	17	17	13	13	17	17	17	17	9
#3	9	18	18	18	18	13	13	18	18	18	18	9
#2	5	14	18	18	18	14	14	18	18	18	14	5
#1	0	0	5	14	19	14	14	19	14	5	0	0

Max = 21

4. Horizontal splay applies pressure to spacers which resist as cantilevers

TENSILE OR COMPRESSIVE STRESS conservative value is zero

Lateral force in each slot due to splaying PPWS = 2.T.sin(angle/2) (kN) REDUCE FOR FRICTION 0 VERT KI (friction between u/s PPWS and slot

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
	12	11	10	9	8	7	6	5	4	3	2	1
Horizontal angle (degrees)												
Trough plate	1.64	3.10	4.13	5.12	6.02	6.93	8.06	9.18	10.10	11.04	11.96	11.94
#10	0	0	557	1035	1624	1402	1629	2473	2041	1487	0	0
#9	0	627	1113	1380	1624	1402	1629	2473	2721	2974	2416	0
#8	221	836	1113	1380	1624	1402	1629	2473	2721	2974	3221	1607
#7	221	836	1113	1380	1624	1402	1629	2473	2721	2974	3221	1607
#6	110	836	835	1380	1218	1402	1629	1855	2721	2230	3221	804
#5	221	627	1113	1035	1624	935	1629	2473	2041	2974	2416	1607
#4	221	836	1113	1380	1624	1402	1629	2473	2721	2974	3221	1607
#3	221	836	1113	1380	1624	1402	1629	2473	2721	2974	3221	1607
#2	110	627	1113	1380	1624	1402	1629	2473	2721	2974	2416	804
#1	0	0	278	1035	1624	1402	1629	2473	2041	743	0	0

Horizontal force is resisted over the length of trough plate between TP-H1 and TP-H2

Stress in spacers (N/mm2) (can be +/-)

Trough plate													Arc length (mm) - horiz
#10	0	0	10	14	22	42	49	33	27	20	0	0	2795
#9	0	13	20	19	22	43	50	34	37	41	33	0	2729
#8	28	18	21	19	23	44	51	35	38	42	45	6	2667
#7	28	19	21	20	23	45	52	35	39	43	46	6	2606
#6	14	19	16	20	18	46	53	27	40	33	47	3	2560
#5	30	15	22	15	24	31	55	37	31	44	36	6	2497
#4	30	20	23	21	25	48	56	38	42	45	49	6	2441
#3	29	19	22	20	24	47	54	37	40	44	48	6	2524
#2	14	14	21	19	23	44	51	34	38	41	34	3	2685
#1	0	0	5	14	23	44	51	35	29	10	0	0	2671
Max = 56													

Accompanying shear stress (N/mm2) Lateral direction

Trough plate												
#10	0	0	3	5	8	10	12	12	10	7	0	0
#9	0	4	6	7	8	10	12	12	13	15	12	0
#8	3	5	6	7	8	11	12	12	14	15	16	4
#7	3	5	7	7	8	11	12	13	14	15	16	4
#6	2	5	5	7	6	11	13	10	14	12	17	2
#5	4	4	7	6	9	7	13	13	11	16	13	4
#4	4	6	7	8	9	11	13	14	15	16	18	4
#3	3	6	7	7	9	11	13	13	14	16	17	4
#2	2	4	6	7	8	10	12	12	14	15	12	2
#1	0	0	2	5	8	10	12	12	10	4	0	0
Max = 18												

5. Accumulated horizontal splay forces reacted by equal and opposite force from other cable

TENSILE STRESS

Stress in trough plate base (N/mm2) The stress will distributed over the whole length of an individual trough

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Arc length (mm) - horiz
Trough plate	max					<------accumulate this way						min	
#10	73	73	73	70	64	54	45	36	21	9	0	0	2795
#9	112	112	108	101	93	83	75	65	50	33	15	0	2729
#8	132	131	126	119	110	100	91	81	66	49	30	10	2667
#7	136	134	129	122	113	102	94	83	67	50	31	10	2606
#6	119	118	113	107	98	90	81	71	58	41	26	5	2560
#5	94	92	89	84	79	70	66	58	45	35	20	8	2497
#4	109	107	103	97	90	82	75	67	54	40	25	8	2441
#3	105	104	100	94	87	79	72	64	52	39	24	8	2524
#2	90	89	86	81	75	67	61	53	41	29	15	4	2685
#1	53	53	53	51	46	39	32	25	13	3	0	0	2671
Max = 136												(formula is different)	

Accompanying shear stress not applicable

6. Moment from spacer enters base of trough plate Max = 143 Stress distributed over length between tangent points

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Lever arm (mm)
Trough plate	**Stress caused by moment N/mm2**				tension and compression, lateral direction								
#10	0	0	23	42	66	57	66	101	83	61	0	0	102.5
#9	0	26	46	58	68	59	68	103	114	124	101	0	102.5
#8	9	36	48	59	69	60	70	106	116	127	138	69	102.5
#7	10	37	49	60	71	61	71	108	119	130	141	70	102.5
#6	5	37	37	61	54	62	72	83	121	99	143	36	102.5
#5	6	18	31	29	46	26	46	70	57	84	68	45	112.5
#4	6	24	32	40	47	40	47	71	78	86	93	46	112.5
#3	6	23	31	38	45	39	45	69	76	83	90	45	112.5
#2	3	16	29	36	43	37	43	65	71	78	63	21	112.5
#1	0	0	7	27	43	37	43	65	54	20	0	0	112.5
Max = 143													

COMBINE STRESSES

		Radial		Lateral				Shear				
	Load case	1	4 Op.2	2	3	5	6	2	4 Op.2	3		
	Direction	C	C	T	T	T	T	Lat	Lat	Rad		
Trough plate												
#10	73	73	196	262	332	272	288	346	251	176	0	0
#9	112	282	371	376	384	337	331	398	392	384	270	0
#8	267	396	414	416	424	367	384	439	433	426	409	178
#7	304	428	444	443	450	406	401	465	460	453	438	187
#6	249	442	373	452	372	409	428	380	477	366	461	102
#5	291	315	370	307	366	294	364	378	311	371	290	137
#4	344	407	413	397	403	391	402	414	409	404	390	145
#3	383	437	439	419	425	410	433	436	431	427	414	151
#2	347	402	459	434	440	435	444	450	446	442	355	93
#1	268	259	309	377	445	438	460	456	380	257	183	40
Max = 477												

		Radial		Lateral				Shear				
	Load case	1	4 Op.2	2	3	5	6	2	4 Op.2	3		
	Direction	C	T	T	T	T	C	Lat	Lat	Rad		
Trough plate												
#10	73	73	140	162	175	108	99	107	55	34	0	0
#9	112	214	254	239	222	165	131	152	121	89	34	0
#8	213	302	294	275	258	188	177	186	155	122	81	36
#7	245	331	320	298	280	222	187	207	175	142	101	42
#6	217	343	279	306	243	221	209	184	188	131	119	30
#5	229	259	277	230	243	194	190	192	159	147	111	41
#4	280	331	318	290	278	238	223	224	200	177	144	49
#3	319	363	348	316	305	261	261	253	231	208	178	58
#2	316	350	373	338	327	295	282	280	259	239	194	52
#1	268	259	289	307	333	299	299	287	245	212	183	40
Max = 373												

MAXIMUM UTILISATION	**0.95**	
Saddle slip due to unzipping of the splaying cable		
In this mode, the slippage of the saddle towards the side span due to the splaying of the cable		
The resistance is by friction between the base and sides of the grooves		
Min horizontal angle	1.636	degrees
Max horizontal angle	11.961	degrees
Average horizontal angle	5.162	degrees
Half of horizontal deviation angle	2.581	degrees
Max allowable SILS tension (single cable)	1395	MN
Resultant splay force (single cable)	126	MN
Longitudinal component (unzip)	5.7	MN
Long'l unzip force (double cable)	11.3	MN
Transverse component (single cable)	126	MN
Reaction on base of grooves (double cable)	387	MN
Coeff. of friction - wires and grooves	0.20	
Gamma M friction at SILS	1.00	
Resistance to unzip force	128	MN
UTILISATION	**0.09**	
Shear keys		
Free cable Horiz tension	654.6	MN
Number of strands in side span cable	361	
Cable angle at spaly saddle	16.02	degrees
Max transverse angle of strand	17.2	degrees
Tension in strand	1887	kN
Max transverse force per four strand group	2336	kN
Shear key	70	mm
Max allowable stress at SLS	238	N/mm^2
Shear resistance of keys at SLS	17	kN/mm
Minimum length of shear key	816.3	mm
Resistance of shear key	13605	kN
gamma m SLS	1.25	
UTILISATION	**0.17**	
Holding down bolts		
Tensile capacity M30	283	kN
Number of bolts provided per trough plate	6	
Side face of shear key at	26.5	degrees
Tension generated in bolts w/out friction	1165	kN
UTILISATION	**0.69**	

SICILY SPLAY SADDLE - ULS CHECK ON TROUGH PLATES

Trough Plate Design	Cast steel, grade		
Material yield	500	N/mm^2	
Gamma M0 at ULS	1.05		
Limiting stress	476	N/mm^2	
Max allowable ULS tension (single cable)	1169	MN	
Resultant ULS axial force in splay saddle	325	MN	(double cable)
Number of strands in this cable	361		

Trough plate dimensions		
Min spacer thickness	25	mm
4-PPWS slot height	105	mm
4-PPWS slot width	138	mm
Total width of grooves	1510	mm
Gap over strand with wire control	50	mm - Specified by YY as overall trough plt height
Gap over strand without wire control	30	mm
2-PPWS slot width	65	mm
Max gap under PPWS at exit	10	mm
Lever arm of action on spacer above base	73	mm

	INNER COLUMN										OUTER COLUMN	
Strand Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	WIDTH
Spacer thickness	25	60	65	75	75	50	50	75	75	75	75	150	2360

Trough plate	Base thickness (mm)		Trough plate thickness (mm)
#10	60		215
#9	60		215
#8	60		215
#7	60		215
#6	60		215
#5	80		215
#4	80		215
#3	80		215
#2	80		215
#1	80		215
		Total	2150

Force applied by PPWS = (2 x PPWS tension x sin [half of deviation angle])

No. PPWS in a slot

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Total
Trough plate		Table is not automatically updated if strand arrangement changes											
#10	0	0	2	3	4	3	3	4	3	2	0	0	24
#9	0	3	4	4	4	3	3	4	4	4	3	0	36
#8	2	4	4	4	4	3	3	4	4	4	4	2	42
#7	2	4	4	4	4	3	3	4	4	4	4	2	42
#6	1	4	3	4	3	3	3	3	4	3	4	1	36
#5	2	3	4	3	4	2	3	4	3	4	3	2	37
#4	2	4	4	4	4	3	3	4	4	4	4	2	42
#3	2	4	4	4	4	3	3	4	4	4	4	2	42
#2	1	3	4	4	4	3	3	4	4	4	3	1	38
#1	0	0	1	3	4	3	3	4	3	1	0	0	22
													361

Width of slot at lowest point (mm)

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Trough plate		Table is not automatically updated if strand arrangement changes										
#10	65	138	138	138	138	65	138	138	65	138	138	65
#9	65	65	138	138	138	138	65	138	138	138	65	65
#8	65	138	138	138	138	65	138	138	138	138	138	65
#7	65	138	138	138	138	138	65	138	138	138	138	65
#6	65	138	65	138	65	65	138	65	138	65	138	65
#5	65	65	138	65	138	65	65	138	65	138	65	65
#4	65	138	138	138	138	138	65	138	138	138	138	65
#3	65	138	138	138	138	65	138	138	138	138	138	65
#2	65	65	138	138	138	138	65	138	138	138	65	65
#1	65	138	65	65	138	65	138	138	65	65	138	65

CHECK STRESSES AT THE ROOT OF THE SPACERS

1. Vertical deviation causes a radial pressure on trough plates spacers.

Radial bearing of each trough plate (kN)

Column Trough plate	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Vert. (degre
#10	0	0	764	1146	1529	1146	1146	1529	1146	764	0	0	6.763
#9	0	1464	1952	1952	1952	1464	1464	1952	1952	1952	1464	0	8.639
#8	1191	2382	2382	2382	2382	1787	1787	2382	2382	2382	2382	1191	10.548
#7	1409	2818	2818	2818	2818	2114	2114	2818	2818	2818	2818	1409	12.485
#6	820	3281	2461	3281	2461	2461	2461	2461	3281	2461	3281	820	14.545
#5	1869	2804	3738	2804	3738	1869	2804	3738	2804	3738	2804	1869	16.588
#4	2095	4190	4190	4190	4190	3143	3143	4190	4190	4190	4190	2095	18.610
#3	2324	4647	4647	4647	4647	3485	3485	4647	4647	4647	4647	2324	20.660
#2	1277	3832	5109	5109	5109	3832	3832	5109	5109	5109	3832	1277	22.738
#1	0	0	1417	4252	5670	4252	4252	5670	4252	1417	0	0	25.273

Accumulated pressure (kN/mm run)

Trough plate													Length TP to
#10	0.000	0.000	0.936	1.404	1.873	1.404	1.404	1.873	1.404	0.936	0.000	0.000	816
#9	0.00	1.45	2.69	3.07	3.44	2.58	2.58	3.44	3.07	2.69	1.45	0.00	1010
#8	1.00	3.22	4.27	4.59	4.91	3.68	3.68	4.91	4.59	4.27	3.22	1.00	1194
#7	1.90	4.88	5.79	6.07	6.35	4.76	4.76	6.35	6.07	5.79	4.88	1.90	1367
#6	2.22	6.47	6.75	7.53	7.25	5.84	5.84	7.25	7.53	6.75	6.47	2.22	1537
#5	3.12	7.51	8.32	8.48	8.77	6.39	6.94	8.77	8.48	8.32	7.51	3.12	1697
#4	4.03	9.24	9.98	10.13	10.40	7.62	8.13	10.40	10.13	9.98	9.24	4.03	1834
#3	4.96	11.02	11.72	11.86	12.11	8.92	9.40	12.11	11.86	11.72	11.02	4.96	1958
#2	5.31	12.28	13.56	13.69	13.93	10.29	10.74	13.93	13.69	13.56	12.28	5.31	2070
#1	4.98	11.52	13.36	14.77	15.64	11.58	12.01	15.64	14.77	13.36	11.52	4.98	2206

Accumulated radial stress at spacer (N/mm2)

COMPRESSIVE STRESS Minimum spacer width = 25 mm Bottom trough plate bears onto tower top plate

Trough plate													
#10	0	0	14	19	25	28	28	25	19	12	0	0	
#9	0	24	41	41	46	52	52	46	41	36	19	0	
#8	40	54	66	61	65	74	74	65	61	57	43	7	
#7	76	81	89	81	85	95	95	85	81	77	65	13	
#6	89	108	104	100	97	117	117	97	100	90	86	15	
#5	125	125	128	113	117	128	139	117	113	111	100	21	
#4	161	154	154	135	139	152	163	139	135	133	123	27	
#3	198	184	180	158	161	178	188	161	158	156	147	33	
#2	212	205	209	182	186	206	215	186	182	181	164	35	
#1	~~199~~	~~192~~	~~206~~	~~197~~	~~208~~	~~232~~	~~240~~	~~208~~	~~197~~	~~178~~	~~154~~	~~33~~	ignore

Accompanying shear stress not applicable Max = 240

2. PPWS in the slots will spread laterally due to the vertical force Spreading factor 0.65

Horizontal force at each slot (kN/mm run) Radial bearing force/length of trough plate*spreading factor

Column / Trough plate	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
#10	0.000	0.000	0.609	0.913	1.217	0.913	0.913	1.217	0.913	0.609	0.000	0.000
#9	0.000	0.942	1.256	1.256	1.256	0.942	0.942	1.256	1.256	1.256	0.942	0.000
#8	0.648	1.297	1.297	1.297	1.297	0.973	0.973	1.297	1.297	1.297	1.297	0.648
#7	0.670	1.340	1.340	1.340	1.340	1.005	1.005	1.340	1.340	1.340	1.340	0.670
#6	0.347	1.387	1.040	1.387	1.040	1.040	1.040	1.040	1.387	1.040	1.387	0.347
#5	0.716	1.074	1.432	1.074	1.432	0.716	1.074	1.432	1.074	1.432	1.074	0.716
#4	0.743	1.485	1.485	1.485	1.485	1.114	1.114	1.485	1.485	1.485	1.485	0.743
#3	0.771	1.542	1.542	1.542	1.542	1.157	1.157	1.542	1.542	1.542	1.542	0.771
#2	0.401	1.203	1.604	1.604	1.604	1.203	1.203	1.604	1.604	1.604	1.203	0.401
#1	0.000	0.000	0.418	1.253	1.671	1.253	1.253	1.671	1.253	0.418	0.000	0.000

Stress due horizontal spreading force (N/mm2)

TENSILE STRESS (Force/base thickness) + (Force x eccentricity/modulus)

Trough plate												
#10	0	0	54	81	108	81	81	108	81	54	0	0
#9	0	84	112	112	112	84	84	112	112	112	84	0
#8	58	115	115	115	115	86	86	115	115	115	115	58
#7	60	119	119	119	119	89	89	119	119	119	119	60
#6	31	123	92	123	92	92	92	92	123	92	123	31
#5	43	64	85	64	85	43	64	85	64	85	64	43
#4	44	88	88	88	88	66	66	88	88	88	88	44
#3	46	92	92	92	92	69	69	92	92	92	92	46
#2	24	71	95	95	95	71	71	95	95	95	71	24
#1	0	0	25	74	99	74	74	99	74	25	0	0
Max =	123											

Accompanying shear stress (N/mm2) Lateral direction

Trough plate												
#10	0	0	9	12	16	18	18	16	12	8	0	0
#9	0	16	19	17	17	19	19	17	17	17	13	0
#8	26	22	20	17	17	19	19	17	17	17	17	4
#7	27	22	21	18	18	20	20	18	18	18	18	4
#6	14	23	16	18	14	21	21	14	18	14	18	2
#5	29	18	22	14	19	14	21	19	14	19	14	5
#4	30	25	23	20	20	22	22	20	20	20	20	5
#3	31	26	24	21	21	23	23	21	21	21	21	5
#2	16	20	25	21	21	24	24	21	21	21	16	3
#1	0	0	6	17	22	25	25	22	17	6	0	0
Max =	31											

3. Flexure of trough plate base due to radial pressure of PPWS

TENSILE STRESS

Moment = W.B/12 where B = slot width + spacer width

Stress (N/mm2)

Trough plate \ Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
#10	0	0	18	28	37	15	24	37	18	18	0	0
#9	0	17	36	38	38	25	15	38	38	38	19	0
#8	8	37	37	39	39	16	26	39	39	39	39	20
#7	9	38	39	41	41	27	16	41	41	41	41	21
#6	4	39	19	42	21	17	28	21	42	21	42	11
#5	5	11	23	12	24	7	10	24	12	24	12	12
#4	5	24	24	25	25	17	10	25	25	25	25	13
#3	6	24	25	26	26	11	17	26	26	26	26	13
#2	3	12	26	27	27	18	11	27	27	27	13	7
#1	0	0	4	14	29	12	19	29	14	5	0	0

Max = 42

Accompanying shear stress (N/mm2) Radial direction

Trough plate												
#10	0	0	8	12	16	12	12	16	12	8	0	0
#9	0	12	16	16	16	12	12	16	16	16	12	0
#8	8	17	17	17	17	12	12	17	17	17	17	8
#7	9	17	17	17	17	13	13	17	17	17	17	9
#6	4	18	13	18	13	13	13	13	18	13	18	4
#5	7	10	14	10	14	7	10	14	10	14	10	7
#4	7	14	14	14	14	11	11	14	14	14	14	7
#3	7	15	15	15	15	11	11	15	15	15	15	7
#2	4	12	15	15	15	12	12	15	15	15	12	4
#1	0	0	4	12	16	12	12	16	12	4	0	0

Max = 18

4. Horizontal splay applies pressure to spacers which resist as cantilevers

TENSILE OR COMPRESSIVE STRESS REDUCE FOR FRICTION conservative value is zero

Lateral force in each slot due to splaying PPWS = 2.T.sin(angle/2) (kN) 0 VERT K (friction between u/s PPWS and slot)

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
	12	11	10	9	8	7	6	5	4	3	2	1

Horizontal angle (degrees)

Trough plate	1.636	3.099	4.127	5.115	6.023	6.933	8.058	9.176	#####	#####	#####	#####
#10	0	0	467	867	1362	1175	1366	2073	1711	1246	0	0
#9	0	526	933	1156	1362	1175	1366	2073	2281	2493	2025	0
#8	185	701	933	1156	1362	1175	1366	2073	2281	2493	2700	1347
#7	185	701	933	1156	1362	1175	1366	2073	2281	2493	2700	1347
#6	93	701	700	1156	1021	1175	1366	1555	2281	1870	2700	674
#5	185	526	933	867	1362	784	1366	2073	1711	2493	2025	1347
#4	185	701	933	1156	1362	1175	1366	2073	2281	2493	2700	1347
#3	185	701	933	1156	1362	1175	1366	2073	2281	2493	2700	1347
#2	93	526	933	1156	1362	1175	1366	2073	2281	2493	2025	674
#1	0	0	233	867	1362	1175	1366	2073	1711	623	0	0

Horizontal force is resisted over the length of trough plate between TP-H1 and TP-H2

Stress in spacers (N/mm2) (can be +/-)

Trough plate													Arc length (mm) -
#10	0	0	8	12	18	35	41	28	23	17	0	0	2795
#9	0	11	17	16	19	36	42	28	31	34	28	0	2729
#8	23	15	17	16	19	37	43	29	32	35	38	5	2667
#7	24	16	18	17	20	38	44	30	33	36	39	5	2606
#6	12	16	14	17	15	39	45	23	33	27	39	2	2560
#5	25	12	19	13	20	26	46	31	26	37	30	5	2497
#4	25	17	19	18	21	40	47	32	35	38	41	5	2441
#3	25	16	18	17	20	39	45	31	34	37	40	5	2524
#2	12	11	17	16	19	37	43	29	32	35	28	2	2685
#1	0	0	4	12	19	37	43	29	24	9	0	0	2671
Max = 47													

Accompanying shear stress (N/mm2) Lateral direction

Trough plate												
#10	0	0	3	4	6	8	10	10	8	6	0	0
#9	0	3	5	6	7	9	10	10	11	12	10	0
#8	3	4	5	6	7	9	10	10	11	12	13	3
#7	3	4	6	6	7	9	10	11	12	13	14	3
#6	1	5	4	6	5	9	11	8	12	10	14	2
#5	3	4	6	5	7	6	11	11	9	13	11	4
#4	3	5	6	6	7	10	11	11	12	14	15	4
#3	3	5	6	6	7	9	11	11	12	13	14	4
#2	1	3	5	6	7	9	10	10	11	12	10	2
#1	0	0	1	4	7	9	10	10	9	3	0	0
Max = 15												

5. Accumulated horizontal splay forces reacted by equal and opposite force from other cable

TENSILE STRESS

Stress in trough plate base (N/mm2)

The stress will distributed over the whole length of an individual tr

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Arc length (mm) -
Trough plate	max					<------accumulate this way						min	
#10	61	61	61	58	53	45	38	30	18	7	0	0	2795
#9	94	94	91	85	78	70	63	54	42	28	12	0	2729
#8	111	110	106	100	92	84	77	68	55	41	25	8	2667
#7	114	112	108	102	95	86	78	70	56	42	26	9	2606
#6	100	99	94	90	82	76	68	59	49	34	22	4	2560
#5	78	78	75	70	66	59	55	48	38	29	17	7	2497
#4	91	90	86	82	76	69	63	56	45	33	21	7	2441
#3	88	87	84	79	73	67	61	54	44	32	20	7	2524
#2	75	75	72	68	63	56	51	44	35	24	13	3	2685
#1	44	44	44	43	39	33	27	21	11	3	0	0	2671
Max =	114												(formula is diffe

Accompanying shear stress not applicable

6. Moment from spacer enters base of trough plate Max = 120 Stress distributed over length between tangent points

Column	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	Lever arm
Trough plate	Stress caused by moment N/mm2					tension and compression, lateral direction							
#10	0	0	19	35	55	48	56	84	70	51	0	0	102.5
#9	0	22	39	48	57	49	57	87	95	104	85	0	102.5
#8	8	30	40	49	58	50	58	89	97	106	115	58	102.5
#7	8	31	41	51	59	51	60	91	100	109	118	59	102.5
#6	4	31	31	51	45	52	61	69	102	83	120	30	102.5
#5	5	15	26	24	38	22	38	58	48	70	57	38	112.5
#4	5	20	27	33	39	34	39	60	66	72	78	39	112.5
#3	5	20	26	32	38	33	38	58	64	69	75	38	112.5
#2	2	14	24	30	36	31	36	54	60	65	53	18	112.5
#1	0	0	6	23	36	31	36	55	45	16	0	0	112.5
Max =	120												

COMBINE STRESSES

		Radial		Lateral				Shear				
Load case		1	4 Op.2	2	3	5	6	2	4 Op.2	3		
Direction		C	C	T	T	T	T	Lat	Lat	Rad		
Trough plate												
#10	61	61	165	219	278	228	242	290	211	148	0	0
#9	94	236	311	315	322	282	278	334	329	322	227	0
#8	224	332	347	349	355	307	322	368	363	357	343	150
#7	255	359	372	371	377	340	336	390	386	380	367	157
#6	209	370	313	379	312	343	358	319	400	307	386	86
#5	244	264	310	258	306	247	305	317	261	311	243	115
#4	289	341	346	332	338	328	337	347	343	339	327	122
#3	321	366	368	351	357	344	363	366	362	358	347	127
#2	291	337	385	364	369	365	372	378	374	370	297	78
#1	224	217	259	316	373	367	386	382	319	216	154	33
Max =	400											

		Radial		Lateral				Shear				
Load case		1	4 Op.2	2	3	5	6	2	4 Op.2	3		
Direction		C	T	T	T	T	C	Lat	Lat	Rad		
Trough plate												
#10	61	61	117	136	147	90	83	90	46	28	0	0
#9	94	180	213	200	186	138	110	127	102	75	29	0
#8	178	253	246	231	216	158	149	156	130	102	68	30
#7	205	278	268	250	235	187	157	173	147	119	85	35
#6	182	288	234	256	204	185	175	154	158	110	100	25
#5	192	217	232	192	204	163	159	161	133	124	93	35
#4	235	277	266	243	233	199	187	188	168	148	121	41
#3	268	304	291	265	255	219	219	213	193	175	149	49
#2	265	294	313	283	274	248	237	235	217	200	163	44
#1	224	217	242	257	279	250	250	241	206	178	154	33
Max =	313											

MAXIMUM UTILISATION **0.84**

Saddle slip due to unzipping of the splaying cable

In this mode, the slippage of the saddle towards the side span due to the splaying of the cable
The resistance is by friction between the base and sides of the grooves

Min horizontal angle	1.636	degrees
Max horizontal angle	11.961	degrees
Average horizontal angle	5.162	degrees
Half of horizontal deviation angle	2.581	degrees
Max allowable ULS tension (single cable)	1169	MN
Resultant splay force (single cable)	105	MN
Longitudinal component (unzip)	4.7	MN
Long'l unzip force (double cable)	9.5	MN
Transverse component (single cable)	105	MN
Reaction on base of grooves (double cable)	325	MN
Coeff. of friction - wires and grooves	0.20	
Gamma M friction at ULS	1.65	
Resistance to unzip force	65	MN
UTILISATION	**0.15**	

SICILY SPLAY SADDLE - SILS & ULS CHECK ON CENTRAL PART

Design of the castings and fabrications that support the trough plates, and of the rocker bearing

Materials			SILS	ULS
Cast steel, grade G24Mn6+QT2 (1.1118) to UNI EN 10340		gamma M0	1.00	1.05
Material yield	370 N/mm^2	gamma M2	1.00	1.25
UTS	620 N/mm^2			
Hot-rolled steel, S420ML to EN 10025-4 UP TO 100MM				
Material yield	420 N/mm^2			
Hot-rolled steel, S420ML to EN 10025-4 OVER 100MM				
Material yield	360 N/mm^2			

Geometry

Angle towards side span	7.98 degrees	
Angle towards splay chamber	17.36 degrees	
Central stiff	150 mm	1 off
Curtailed stiffs	100 mm	2 off
Outstand stiffs	100 mm	6 effective

Note: The curtailed stiffs are assymmetric
Check whether they are needed for load bearing or if they can serve solely as restraints to the outstand

Top plate spreading into central section

		SILS	ULS
Width of top plate at entry	5200 mm		
Width of top plate at exit	6400 mm		
Average width of top plate	5800 mm		
Minimum thickness of top plt	280 mm		
Length of top plate	3250 mm		
Reaction from double cable		387	325 MN
Pressure applied to top plate		21	17 N/mm2
Transverse spacing of stiffeners below top plt	900 mm		
Longitudinal spacing of stiffs below top plt	1850 mm		
Transverse flexure, Mt		2080473	1744109 N.mm/mm
Transverse bending stress		106	89 N/mm2
Shear		33	28 N/mm2
Total equivalent direct stress		122	103 N/mm2
Gamma M0		1.00	1.05
UTILISATION		**0.33**	**0.29**

				Areas of section (mm2)			
Location of section	Radius	Symmetrical width	Length	Central stiff	Curtailed stiffs	Outstand stiffs	Total Area
Top of top casting	5000	1393	4800	6685309	0	0	6685309
Underside of top casting	4700	1375	4800	720000	840000	735124	2295124
Underside of curtailed stiffs	3600	1311	5725	858750	0	696478	1555228
Top of bearing casting	300	1100	8500	1275000	0	533538	1808538

Note: Stiff bearing from the rocker contact through the base plate shall be at 60 degrees (EN 1337-6, fig 3)
The outstand stiffs at bearing only empoyed by stiff bearing of bearing top plate

Check effectiveness of outstand stiffeners as outstand compression elements (EN 1993-1-5, cl. 4.4)

Outstand stiffs b/t	6.13	nu	0.3
sigma2/sigma1	1.00	E	210000
k-sigma	0.43 (table 4.2)		
sigma crit	2175		
lamda p bar	0.44		
rho	1.00		
Fully effective			

	SILS	ULS	
Force in one saddle is for two cables	387	325	MN
Stress at critical sections			
Top of top casting	58	49	N/mm2
Underside of top casting	169	141	N/mm2
Underside of curtailed stiffs	249	209	N/mm2
Top of bearing casting	214	180	N/mm2
gamma M0	1.00	1.05	
MAXIMUM UTILISATION	**0.69**	**0.61**	

		SILS	ULS	
Rocker bearing				
Applied loading		387	325	MN
Radius of upper part	3000 mm dia.			
Radius of lower part	6000 mm dia.			
Dowels	100 mm dia.			
No off dowels	2 No			
Effective length of bearing	8300 mm			
KD D1.D2/(D1 - D2)	12000 mm	(Roark, 5th ed. p. 517, case 2c)		
		SILS	ULS	
Max stress in contact zone		528	483	N/mm2
N'Rk (EN 1337-6 -2004, 6.5.1)		126303	126303	N/mm
Gamma M		1.00	1.10	(note: EN 1337 recommend:
Design resistance (N'Rd)		1048	866	MN
Gamma M2		1.00	1.25	
UTILISATION		**0.37**	**0.47**	

Pressure onto concrete - by stiff bearing of base plate

Thickness to concrete below contact point	450 mm			
Width of contact at rocker	103 mm	(Roark, 5th ed. p. 517, case 2c)		
Width of contact	1662 mm	Distribution angle	60	degrees
		SILS	ULS	
Bearing pressure on concrete		27	23	N/mm2
Concrete grade	45 N/mm2			
Estimate local pressure limit factor on fcd		1.00	0.85	(EN1992-1-1,cl. 10.9.5.2(2))
Limiting pressure		45	38.25	N/mm2
UTILISATION		**0.61**	**0.60**	