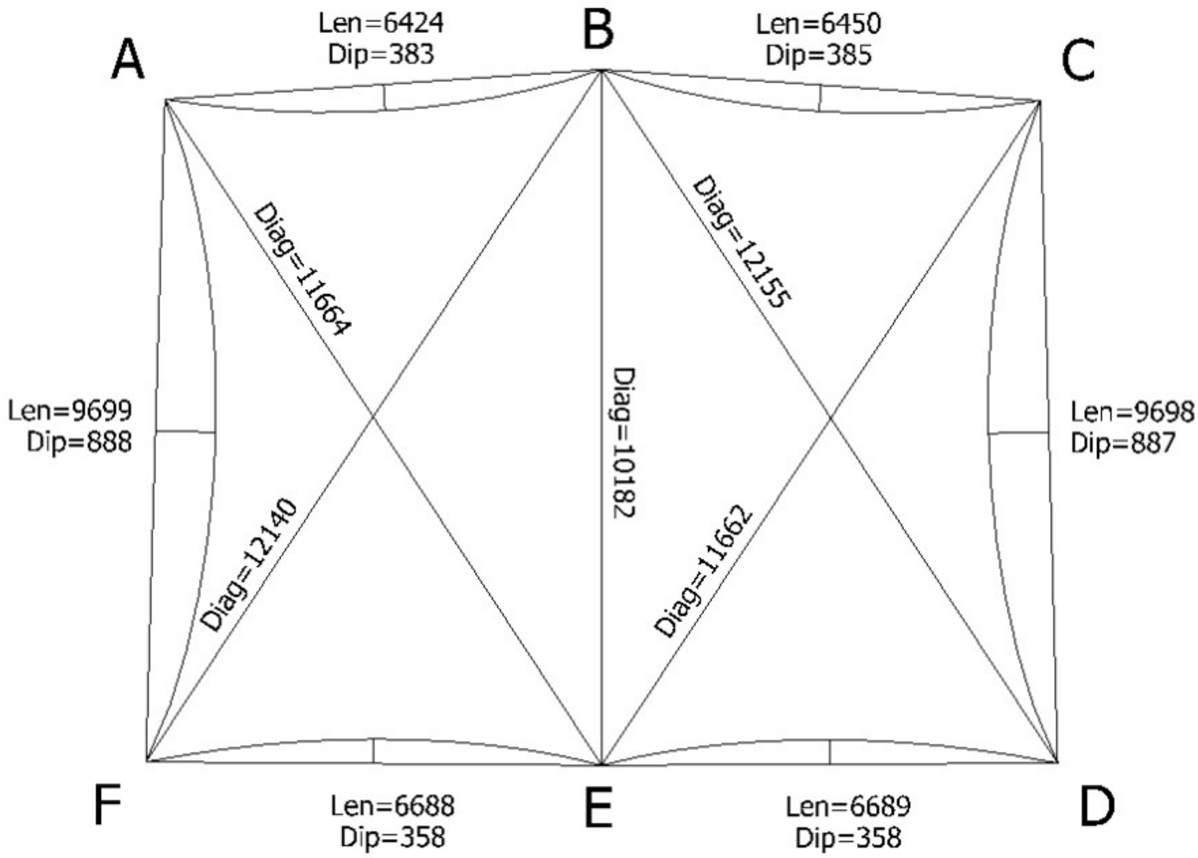
STRUCTURAL CALCULATIONS

PER IBC 2018, BS EN 1993 Eurocode 3



FOR TENSION FABRIC STRUCTURES

APRIL 07 2021

DESIGN INFORMATION

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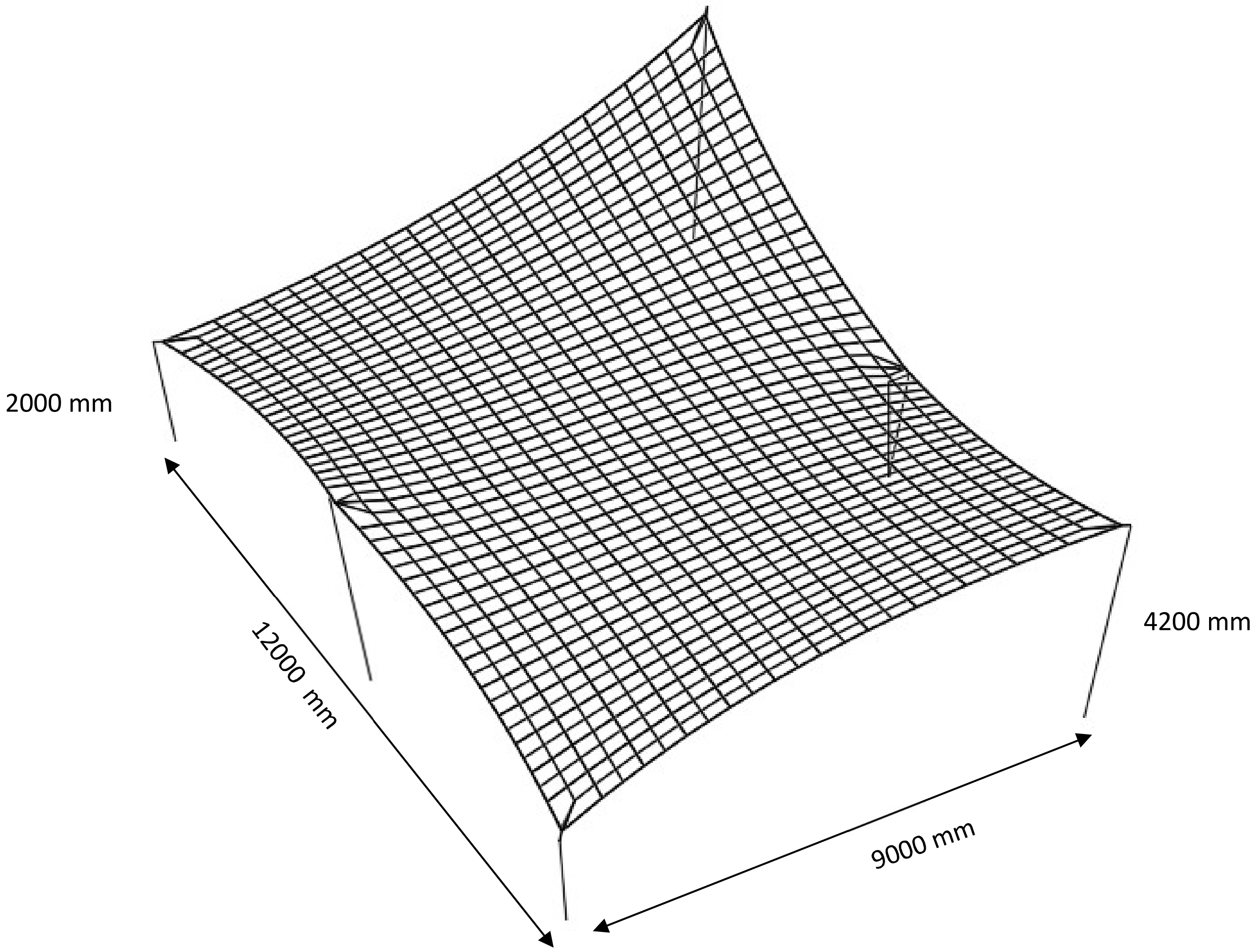
Preliminaries



General Dimensions of the Structure

Dead Loads

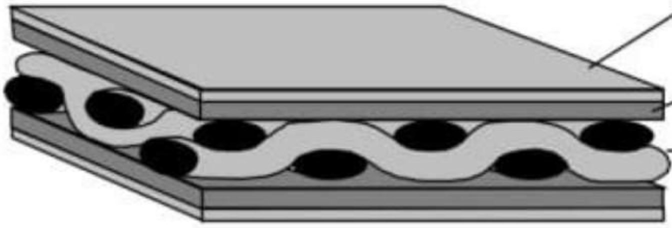
PVC Tensile Fabric	0.006	kN/m2
Steel Members	77	kN/m3

Live Loads

Roof Live Load	0.2	kN/m2
Snow Load(min)	0.2	kN/m2
Wind Load(min)	0.5	kN/m2

Tensile Fabric Material Properties

A fabric material consists of three main components are fabric substrate, coating, and top coating.



1. Tensile Strength

It is a basic indicator of relative strength. It is fundamental for architectural fabrics that function primarily in tension.

2. Tear Strength

Tear strength is important in that if a fabric ruptures in place, it generally will do so by tearing.

3. Adhesion Strength

It is a measure of the strength of the bond between the base material and coating or film laminate that protects it. It is useful for evaluating the strength of welded joints for connecting strips of fabric into fabricated assembly.

4. Flame Retardancy

Fabric that contains a flame-retardant coating can withstand even a very hot point source. However, it can still burn if a large ignition source is present.

PVC Tensile fabric Material Properties: Let's take the Tear Strength and Tensile Strength of the fabric Material as 0.3 kN, 54 kN/m and the density as 580 g/m2. Thickness of the fabric is 0.48 mm.

Tear Strength:

Warp: 300 N
Weft : 230 N

Tensile Strength:

Warp: 54 kN/m
Weft : 46 kN/m

Wind loads are the main consideration for membrane structures. In order to resist these loads, the membrane must have sufficient tensioning and curvature while load coefficients are easily assessable in most places, other tests such as a wind tunnel test maybe necessary for larger and more complex structures to determine loading distributions.

When loading is applied to the membrane, equilibrium is regained by changes in both the geometry of the membrane as well as the change in stress. Other structures, such as beams, have shear and flexural stiffness and therefore can resist the loads without significant deflection. However, membranes, which lack both shear and flexural stiffness, must "make up" for this Down load by big deflections.

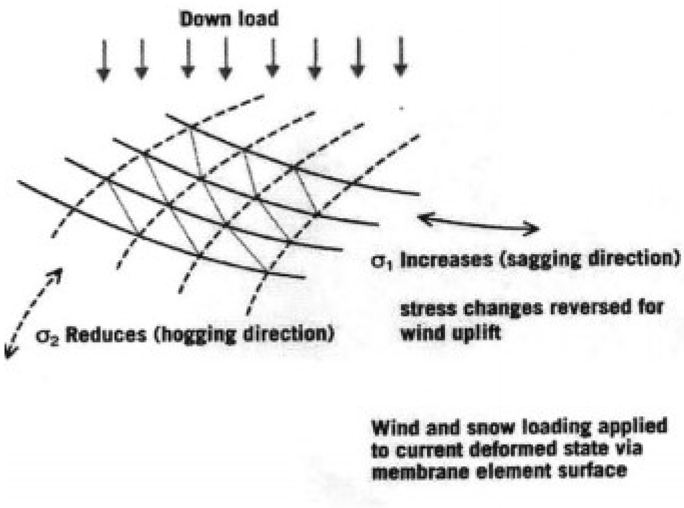


Figure 15: The change in stress in the sagging and hogging directions of a membrane under vertical load (Koch et al., 2004)

The span: sag ratio should be kept at less than 15. With increased spans, lower ratio and/or cable reinforcement is needed.

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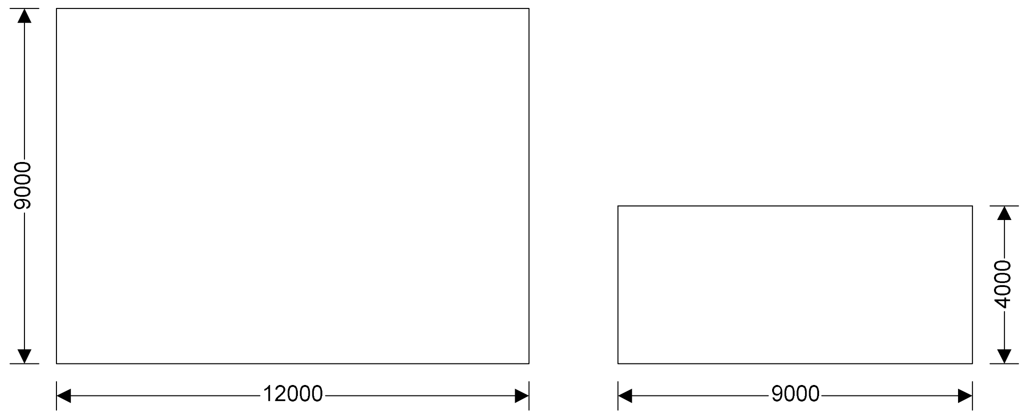
Design Calculations

WIND LOADING

In accordance with EN1991-1-4:2005+A1:2010 and the UK national annex



Plan Elevation

Building data

Type of roof;	Tensile fabric
Length of building;	L = **12000** mm
Width of building;	W = **9000** mm
Height to eaves;	H = **4000** mm
Eaves type;	Sharp
Total height;	h = **4000** mm

Basic values

Location;	Leeds
Wind speed velocity (FigureNA.1);	$v_{b,map}$ = **22.6** m/s
Distance to shore;	L_{shore} = **88.00** km
Altitude above sea level;	A_{alt} = **70.0**m
Altitude factor;	$c_{alt} = A_{alt}/1m * 0.001 + 1$ = **1.070**
Fundamental basic wind velocity;	$v_{b,0} = v_{b,map} * c_{alt}$ = **24.2** m/s
Direction factor;	c_{dir} = **1.00**
Season factor;	c_{season} = **1.00**
Shape parameter K;	K = **0.2**
Exponent n;	n = **0.5**
Air density;	ρ = **1.226** kg/m^3
Probability factor;	$c_{prob} = [(1 - K * \ln(-\ln(1-p)))/(1 - K * \ln(-\ln(0.98)))]^n$ = **1.00**
Basic wind velocity (Exp. 4.1);	$v_b = c_{dir} * c_{season} * v_{b,0} * c_{prob}$ = **24.2** m/s
Reference mean velocity pressure;	$q_b = 0.5 * \rho * v_b^2$ = **0.358** kN/m^2

Orography

Orography factor not significant;	c_o = 1.0
Terrain category;	Town
Displacement height (sheltering effect excluded);	h_{dis} = 0mm

The velocity pressure for the windward face of the building with a 0 degree wind is to be considered as 1 part as the height h is less than b (cl.7.2.2)

The velocity pressure for the windward face of the building with a 90 degree wind is to be considered as 1 part as the height h is less than b (cl.7.2.2)

Peak velocity pressure - windward wall - Wind 0 deg and roof

Reference height (at which q is sought); z = **4000**mm

Displacement height (sheltering effects excluded); h_{dis} = **0** mm

Exposure factor (Figure NA.7); c_e = **1.78**

Exposure correction factor (Figure NA.8); $c_{e,T}$ = **0.80**

Peak velocity pressure; $q_p = c_e * c_{e,T} * q_b$ = **0.51** kN/m^2

Structural factor

Structural damping; δ_s = **0.100**

Height of element; h_{part} = **4000** mm

Size factor (Table NA.3); c_s = **0.856**

Dynamic factor (Figure NA.9); c_d = **1.007**

Structural factor; $c_sc_d = c_s \times c_d$ = **0.862**

Peak velocity pressure - windward wall - Wind 90 deg and roof

Reference height (at which q is sought); z = **4000**mm

Displacement height (sheltering effects excluded); h_{dis} = **0** mm

Exposure factor (Figure NA.7); c_e = **1.78**

Exposure correction factor (Figure NA.8); $c_{e,T}$ = **0.80**

Peak velocity pressure; $q_p = c_e * c_{e,T} * q_b$ = **0.51** kN/m^2

Structural factor

Structural damping; δ_s = **0.100**

Height of element; h_{part} = **4000** mm

Size factor (Table NA.3); c_s = **0.868**

Dynamic factor (Figure NA.9); c_d = **1.012**

Structural factor; $c_sc_d = c_s \times c_d$ = **0.879**

Peak velocity pressure for internal pressure

Peak velocity pressure – internal (as roof press.); $q_{p,i}$ = **0.51** kN/m^2

Pressures and forces

Net pressure; $p = c_sc_d * q_p * c_{pe} - q_{p,i} * c_{pi}$;

Net force; $F_w = p_w * A_{ref}$;

Roof load case 1 - Wind 0, c_{pi} 0.20, - c_{pe}

Zone	Ext pressure coefficient c_{pe}	Peak velocity pressure q_p, (kN/m^2)	Net pressure p (kN/m^2)	Area A_{ref} (m^2)	Net force F_w (kN)
F (-ve)	-2.00	0.51	-0.99	3.20	-3.16
G (-ve)	-1.40	0.51	-0.72	6.40	-4.63
H (-ve)	-0.70	0.51	-0.41	38.40	-15.86
I (-ve)	-0.20	0.51	-0.19	60.00	-11.49

Total vertical net force; $F_{w,v}$ = **-35.14** kN

Total horizontal net force; $F_{w,h}$ = **0.00** kN

Walls load case 1 - Wind 0, c_{pi} 0.20, - c_{pe}

Zone	Ext pressure coefficient c_{pe}	Peak velocity pressure q_p, (kN/m^2)	Net pressure p (kN/m^2)	Area A_{ref} (m^2)	Net force F_w (kN)
A	-1.20	0.51	-0.63	6.40	-4.06
B	-0.80	0.51	-0.46	25.60	-11.71
C	-0.50	0.51	-0.32	4.00	-1.30
D	0.73	0.51	0.22	48.00	10.50
E	-0.35	0.51	-0.26	48.00	-12.42

Overall loading

Equiv leeward net force for overall section; $F_l = F_{w,wE}$ = **-12.4** kN

Net windward force for overall section; $F_w = F_{w,wD}$ = **10.5** kN

Lack of correlation (cl.7.2.2(3) – Note); f_{corr} = **0.85**; as h/W is 0.444

Overall loading overall section; $F_{w,D} = f_{corr} * (F_w - F_l + F_{w,h})$ = **19.5** kN

Roof load case 2 - Wind 90, c_{pi} 0.20, - c_{pe}

Zone	Ext pressure coefficient c_{pe}	Peak velocity pressure q_p, (kN/m^2)	Net pressure p (kN/m^2)	Area A_{ref} (m^2)	Net force F_w (kN)
F (-ve)	-2.00	0.51	-1.01	3.20	-3.22
G (-ve)	-1.40	0.51	-0.74	4.00	-2.94
H (-ve)	-0.70	0.51	-0.42	28.80	-12.07
I (-ve)	-0.20	0.51	-0.19	72.00	-13.91

Total vertical net force; $F_{w,v}$ = **-32.14** kN

Total horizontal net force; $F_{w,h}$ = **0.00** kN

Walls load case 2 - Wind 90, c_{pi} 0.20, - c_{pe}

Zone	Ext pressure coefficient c_{pe}	Peak velocity pressure q_p, (kN/m^2)	Net pressure p (kN/m^2)	Area A_{ref} (m^2)	Net force F_w (kN)
A	-1.20	0.51	-0.64	6.40	-4.13
B	-0.80	0.51	-0.46	25.60	-11.88
C	-0.50	0.51	-0.33	16.00	-5.26
D	0.71	0.51	0.22	36.00	7.86
E	-0.32	0.51	-0.25	36.00	-8.94

Overall loading

Equiv leeward net force for overall section; $F_l = F_{w,wE}$ = **-8.9** kN

Net windward force for overall section; $F_w = F_{w,wD}$ = **7.9** kN

Lack of correlation (cl.7.2.2(3) – Note); f_{corr} = **0.85**; as h/L is 0.333

Overall loading overall section; $F_{w,D} = f_{corr} * (F_w - F_l + F_{w,h})$ = **14.3** kN

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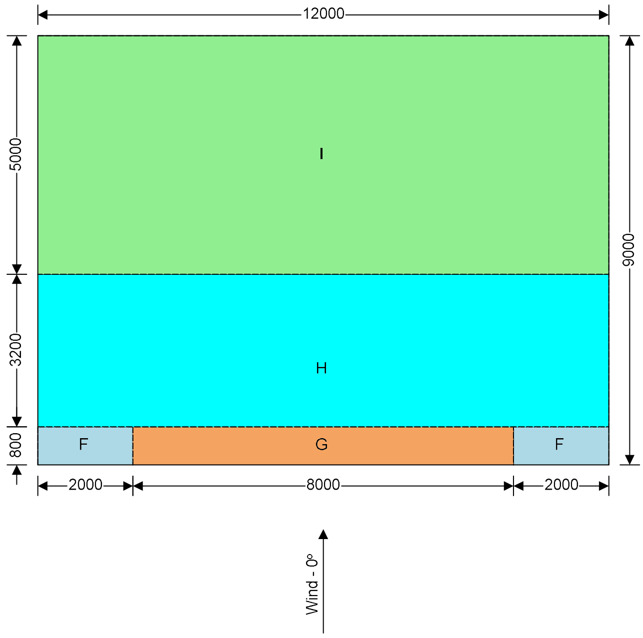
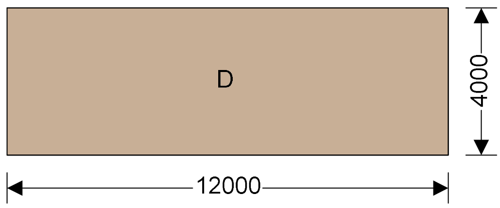
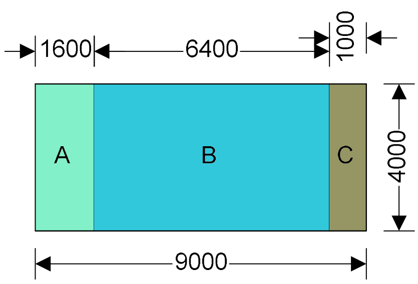


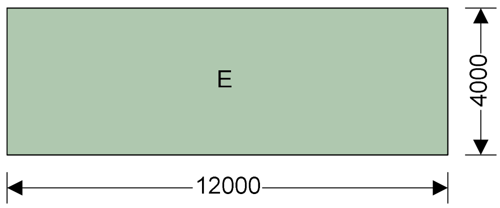
Plan view - Flat roof



Windward face



Side face



Leeward face

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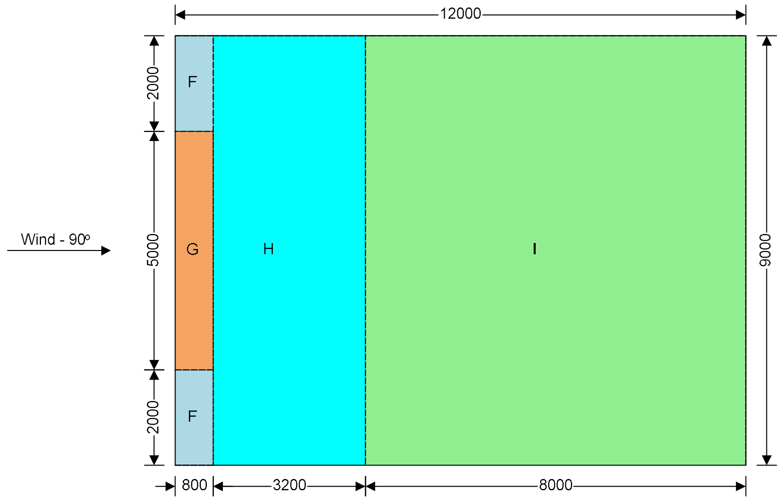
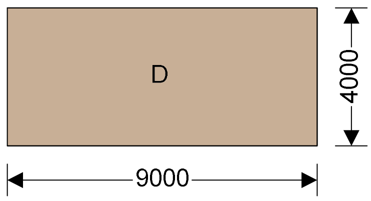
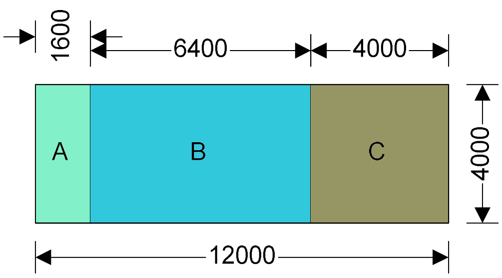
Project: Structural calculations Tensile fabric Structure	Project: 2021-25
Address: -	Sheet:
	Date: 13/04/2021



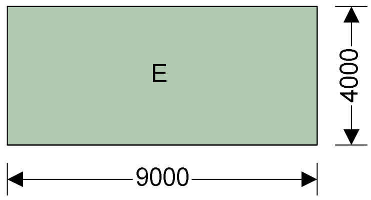
Plan view - Flat roof



Windward face

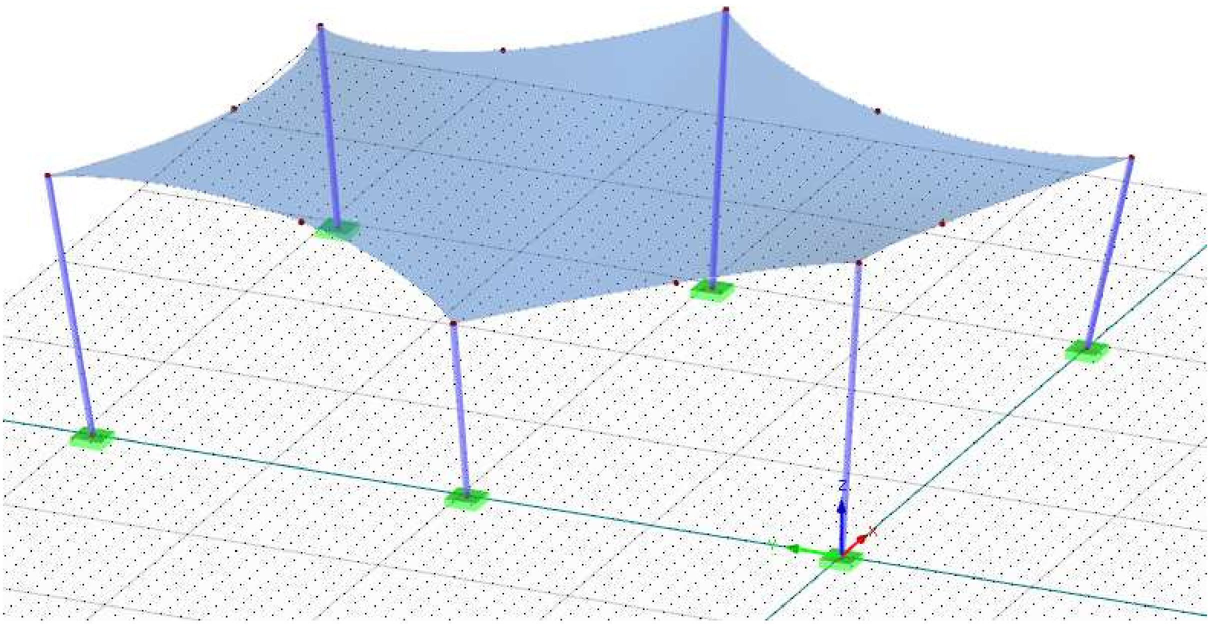


Side face

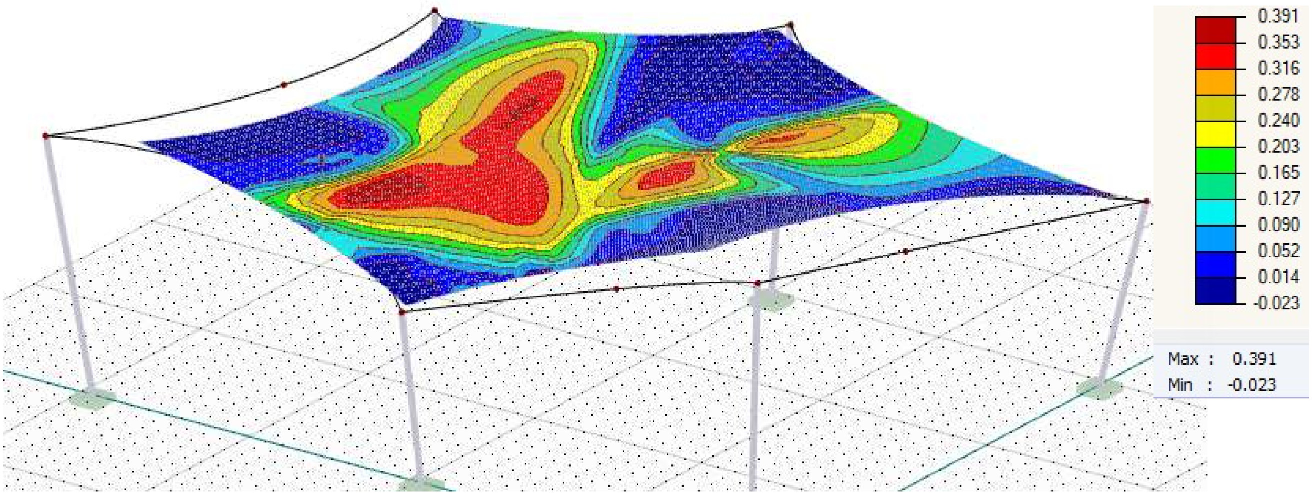


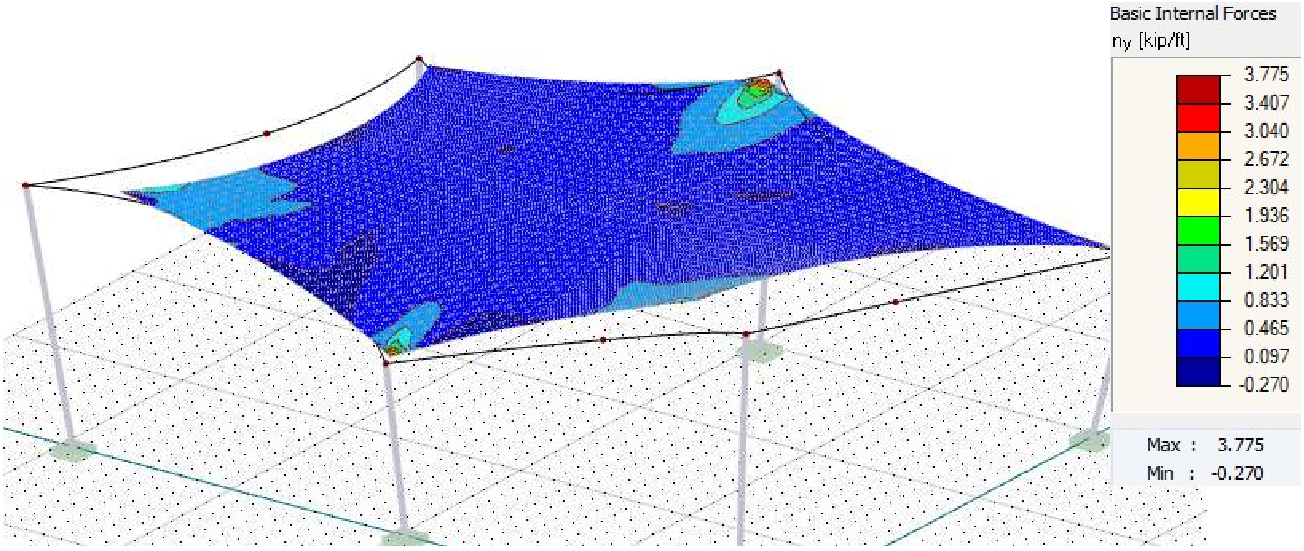
Leeward face

Developed FEM Model



Tensile Fabric Analysis





Finite Element Model for the Tensile Fabric

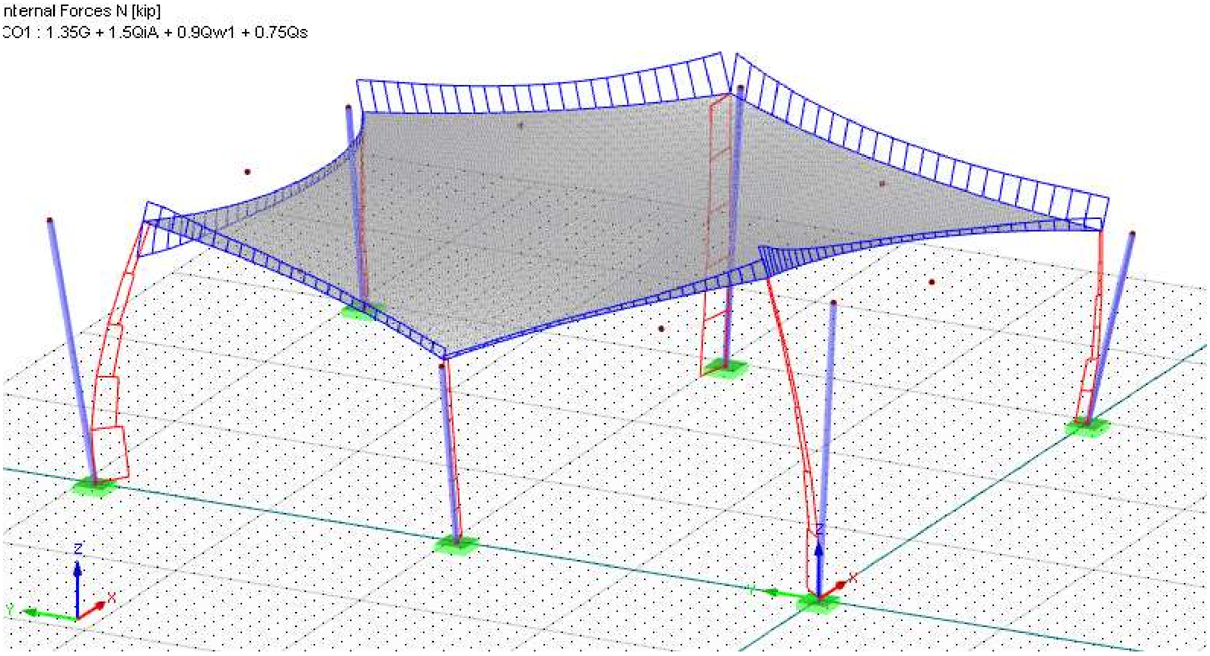
Loads acting on the fabric

Roof Live Load	0.2	kN/m2
Wind Load	0.45	kN/m2

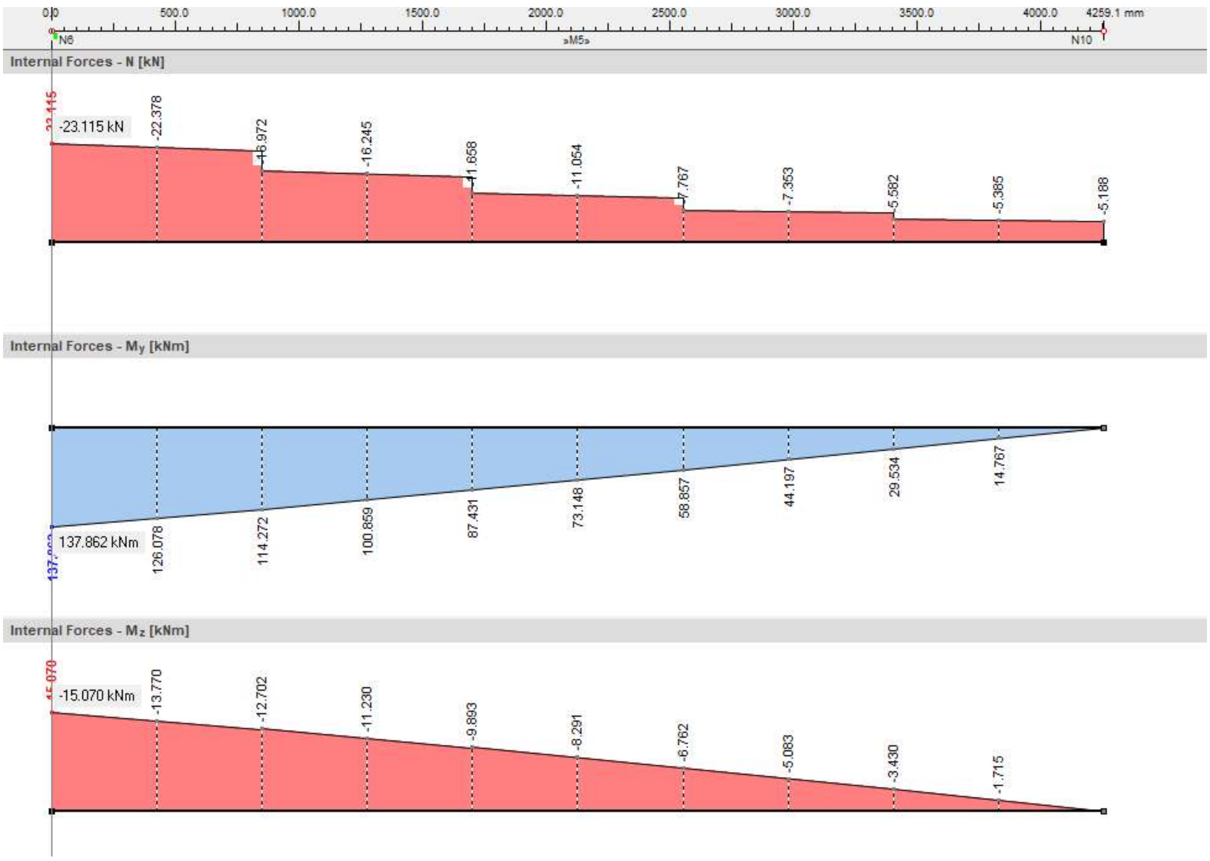
Sail Fabric Resultant Tensile Loading table

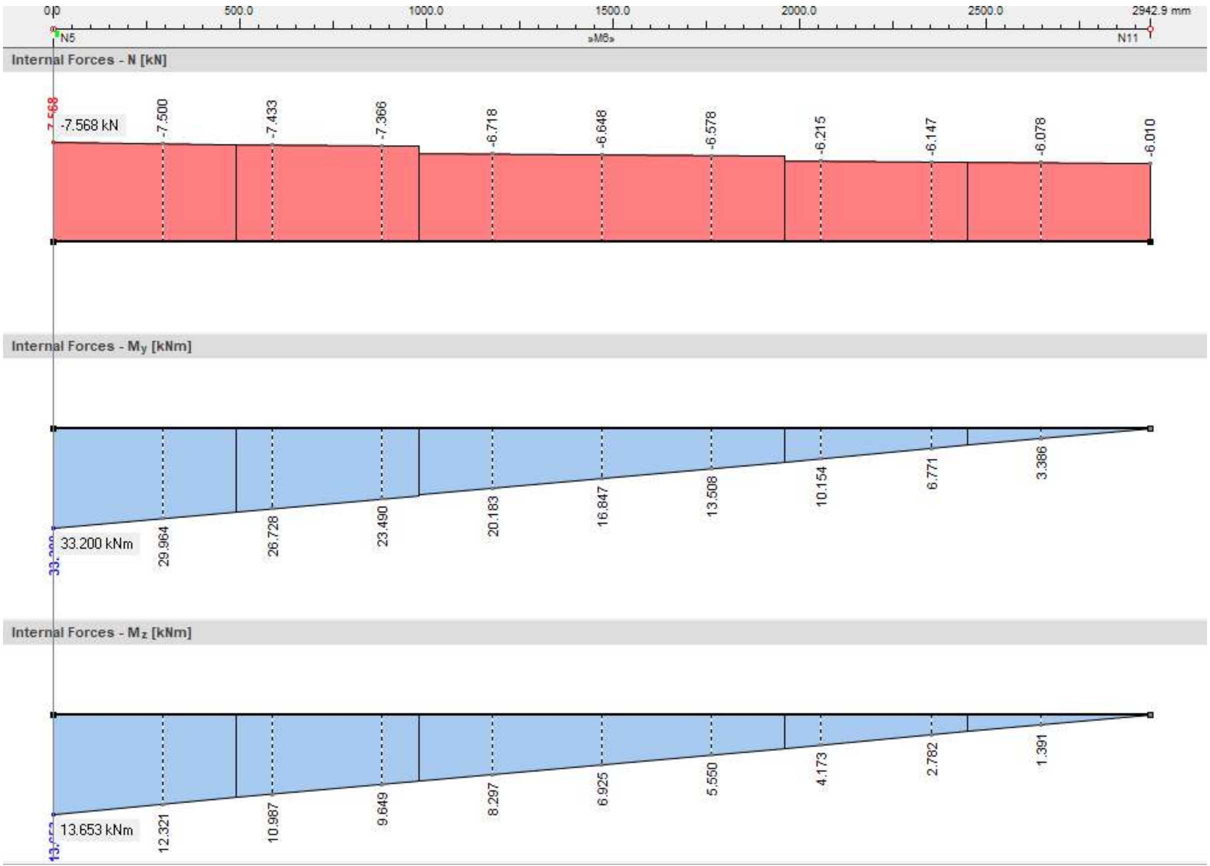
Load Case	Direction	Maximum Force	Minimum Force	Utility Factor	Status
1.35DL+1.5LL+0.9WL+0.75SL	F11	5.7	-0.336	0.12	Ok
1.35DL+1.5LL+0.9WL+0.75SL	F22	55	-3.93	1.01	On Margin

Analysis of Structural Members



Steel Column Analysis





SELECTED CHS SECTION (4200 MM HEIGHT) = CHS 244.5X 8

SELECTED CHS SECTION (2900 MM HEIGHT) = CHS 168.3X6.3

STEEL COLUMN DESIGN

In accordance with EN1993-1-1:2005 incorporating Corrigenda February 2006 and April 2009 and the UK national annex

Design summary

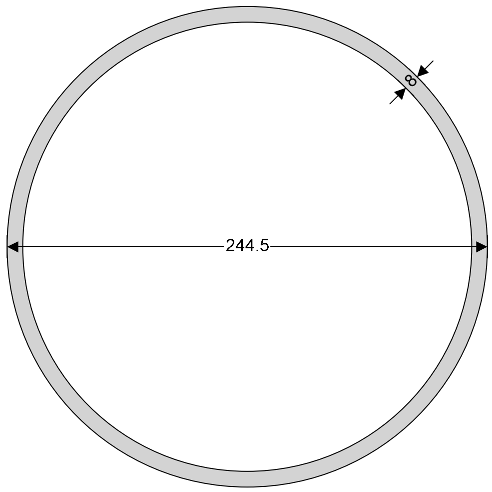
Description	Unit	Provided	Required	Utilisation	Result
Shear resistance (y-y)	kN	513	25	0.049	PASS
Shear resistance (z-z)	kN	513	25	0.049	PASS
Axial compression	kN	1397	25	0.018	PASS
Bending resistance (y-y)	kNm	105	100	0.951	PASS
Bending resistance (z-z)	kNm	105	16	0.152	PASS
Biaxial bending				0.929	PASS
Buckling in compression	kN	1220	25	0.020	PASS
Buckling in bending	kNm	105	100	0.951	PASS
Combined buckling				0.652	PASS

Partial factors - Section 6.1

Resistance of cross-sections; γ_{M0} = **1**

Resistance of members to instability; γ_{M1} = **1**

Resistance of cross-sections in tension to fracture; γ_{M2} = **1.1**



CHS 244.5x8.0 (Tata Steel Celsius)
Diameter, d, 244.5 mm
Mass of section, Mass, 46.7 kg/m
Section thickness, t, 8 mm
Area of section, A, 5944 mm^2
Radius of gyration about y-axis, i_y, 83.663 mm
Radius of gyration about z-axis, i_z, 83.663 mm
Elastic section modulus about y-axis, $W_{el.y}$, 340323 mm^3
Elastic section modulus about z-axis, $W_{el.z}$, 340323 mm^3
Plastic section modulus about y-axis, $W_{pl.y}$, 447629 mm^3
Plastic section modulus about z-axis, $W_{pl.z}$, 447629 mm^3
Second moment of area about y-axis, I_y, 41604467 mm^4
Second moment of area about z-axis, I_z, 41604467 mm^4

Column details

Column section	**CHS 244.5x8.0**
Steel grade	**S235H**
Yield strength	f_y = **235** N/mm^2
Ultimate strength	f_u = **360** N/mm^2
Modulus of elasticity	E = **210** kN/mm^2
Poisson's ratio	ν = **0.3**
Shear modulus	$G = E / [2 \times (1 + \nu)]$ = **80.8** kN/mm^2

Column geometry

System length for buckling - Major axis	L_y = **4200** mm
System length for buckling - Minor axis	L_z = **4200** mm

The column is not part of a sway frame in the direction of the minor axis
The column is not part of a sway frame in the direction of the major axis

Column loading

Axial load	N_{Ed} = **25** kN (Compression)
Major axis moment at end 1 - Bottom	$M_{y,Ed1}$ = **100.0** kNm
Major axis moment at end 2 - Top	$M_{y,Ed2}$ = **0.0** kNm
	Major axis bending is single curvature
Minor axis moment at end 1 - Bottom	$M_{z,Ed1}$ = **16.0** kNm
Minor axis moment at end 2 - Top	$M_{z,Ed2}$ = **0.0** kNm
	Minor axis bending is single curvature
Major axis shear force	$V_{y,Ed}$ = **25** kN
Minor axis shear force	$V_{z,Ed}$ = **25** kN

Buckling length for flexural buckling - Major axis

End restraint factor;	K_y = **1.200**
Buckling length;	$L_{cr\_y} = L_y \times K_y$ = **5040** mm

Buckling length for flexural buckling - Minor axis

End restraint factor;	K_z = **1.200**
Buckling length;	$L_{cr\_z} = L_z \times K_z$ = **5040** mm

Section classification (Table 5.2)

Coefficient depending on f_y;	$\varepsilon = \sqrt{(235\ N/mm^2 / f_y)}$ = **1.000**
Ratio of d/t;	ratio = d / t = **30.56**

Limit of d/t for class 1 section; $Limit_1 = 50 \times \varepsilon^2 =$ **50.00**

Limit of d/t for class 2 section; $Limit_2 = 70 \times \varepsilon^2 =$ **70.00**

Limit of d/t for class 3 section; $Limit_3 = 90 \times \varepsilon^2 =$ **90.00**

The section is class 1

Resistance of cross section (cl. 6.2)

Shear - Major axis (cl. 6.2.6)

Design shear force; $V_{y,Ed}$ = **25.0** kN

Shear area; $A_{vy} = 2 * A / \pi$ = ;**3784**; mm^2

Plastic shear resistance; $V_{pl,y,Rd} = A_{vy} \times (f_y / \sqrt{(3)}) / \gamma_{M0}$ = **513.4** kN

$V_{y,Ed} / V_{pl,y,Rd}$ = **0.049**

PASS - Shear resistance exceeds the design shear force

$V_{y,Ed}$ <= 0.5*$V_{pl,y,Rd}$ - No reduction in f_y required for bending/axial force

Shear - Minor axis (cl. 6.2.6)

Design shear force; $V_{z,Ed}$ = **25.0** kN

Shear area; $A_{vz} = 2 * A / \pi$ = ;**3784**; mm^2

Plastic shear resistance; $V_{pl,z,Rd} = A_{vz} \times (f_y / \sqrt{(3)}) / \gamma_{M0}$ = **513.4** kN

$V_{z,Ed} / V_{pl,z,Rd}$ = **0.049**

PASS - Shear resistance exceeds the design shear force

$V_{z,Ed}$ <= 0.5*$V_{pl,z,Rd}$ - No reduction in f_y required for bending/axial force

Compression (cl. 6.2.4)

Design force; N_{Ed} = **25** kN

Design resistance; $N_{c,Rd} = N_{pl,Rd} = A \times f_y / \gamma_{M0}$ = **1397** kN

$N_{Ed} / N_{c,Rd}$ = **0.018**

PASS - The compression design resistance exceeds the design force

Bending - Major axis (cl. 6.2.5)

Design bending moment; $M_{y,Ed} = max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **100.0** kNm

Section modulus; $W_y = W_{pl.y}$ = ;**447.6**; cm^3

Design resistance; $M_{c,y,Rd} = W_y \times f_y / \gamma_{M0}$ = **105.2** kNm

$M_{y,Ed} / M_{c,y,Rd}$ = **0.951**

PASS - The bending design resistance exceeds the design moment

Bending - Major axis(cl. 6.2.5)

Design bending moment; $M_{z,Ed} = max(abs(M_{z,Ed1}), abs(M_{z,Ed2}))$ = **16.0** kNm

Section modulus; $W_z = W_{pl.z}$ = ;**447.6**; cm^3

Design resistance; $M_{c,z,Rd} = W_z \times f_y / \gamma_{M0}$ = **105.2** kNm

$M_{z,Ed} / M_{c,z,Rd}$ = **0.152**

PASS - The bending design resistance exceeds the design moment

Combined bending and axial force (cl. 6.2.9)

Ratio design axial to design plastic resistance; $n = abs(N_{Ed}) / N_{pl,Rd}$ = **0.018**

Bending - Major axis (cl. 6.2.9.1)

Design bending moment; $M_{y,Ed} = max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **100.0** kNm

Plastic design resistance; $M_{pl,y,Rd} = W_{pl.y} \times f_y / \gamma_{M0}$ = **105.2** kNm

Modified design resistance; $M_{N,y,Rd} = M_{pl,y,Rd} \times min(1, (1 - n^{1.7}))$ = **105.1** kNm

$M_{y,Ed} / M_{N,y,Rd}$ = **0.952**

PASS - Bending resistance in presence of axial load exceeds design moment

Bending - Minor axis (cl. 6.2.9.1)

Design bending moment; $M_{z,Ed} = max(abs(M_{z,Ed1}), abs(M_{z,Ed2}))$ = **16.0** kNm

Plastic design resistance; $M_{pl,z,Rd} = W_{pl.z} \times f_y / \gamma_{M0}$ = **105.2** kNm

Modified design resistance; $M_{N,z,Rd} = M_{pl,z,Rd} \times \min(1, (1 - n^{1.7}))$ = **105.1** kNm

$M_{z,Ed} / M_{N,z,Rd}$ = **0.152**

PASS - Bending resistance in presence of axial load exceeds design moment

Biaxial bending

Exponent α; α = ;**2.00**

Exponent β; β = ;**2.00**

Section utilisation at end 1; $UR_{CS\_1} = [abs(M_{y,Ed1}) / M_{N,y,Rd}]^{\alpha} + [abs(M_{z,Ed1}) / M_{N,z,Rd}]^{\beta}$
= **0.929**

Section utilisation at end 2; $UR_{CS\_2} = [abs(M_{y,Ed2}) / M_{N,y,Rd}]^{\alpha} + [abs(M_{z,Ed2}) / M_{N,z,Rd}]^{\beta}$
= **0.000**

PASS - The cross-section resistance is adequate

Buckling resistance (cl. 6.3)

Yield strength for buckling resistance; f_y = **235** N/mm^2

Flexural buckling - Major axis

Elastic critical buckling force; $N_{cr,y} = \pi^2 \times E \times I_y / L_{cr\_y}^2$ = **3395** kN

Non-dimensional slenderness; $\bar{\lambda}_y = \sqrt{(A \times f_y / N_{cr,y})}$ = **0.641**

Buckling curve (Table 6.2); **a**

Imperfection factor (Table 6.1); α_y = **0.21**

Parameter Φ; $\Phi_y = 0.5 \times [1 + \alpha_y \times (\bar{\lambda}_y - 0.2) + \bar{\lambda}_y^2]$ = **0.752**

Reduction factor; $\chi_y = \min(1.0, 1 / [\Phi_y + \sqrt{(\Phi_y^2 - \bar{\lambda}_y^2)}])$ = **0.874**

Design buckling resistance; $N_{b,y,Rd} = \chi_y \times A \times f_y / \gamma_{M1}$ = **1220.2** kN

$N_{Ed} / N_{b,y,Rd}$ = **0.02**

PASS - The flexural buckling resistance exceeds the design axial load

Flexural buckling - Minor axis

Elastic critical buckling force; $N_{cr,z} = \pi^2 \times E \times I_z / L_{cr\_z}^2$ = **3395** kN

Non-dimensional slenderness; $\bar{\lambda}_z = \sqrt{(A \times f_y / N_{cr,z})}$ = **0.641**

Buckling curve (Table 6.2); **a**

Imperfection factor (Table 6.1); α_z = **0.21**

Parameter Φ; $\Phi_z = 0.5 \times [1 + \alpha_z \times (\bar{\lambda}_z - 0.2) + \bar{\lambda}_z^2]$ = **0.752**

Reduction factor; $\chi_z = \min(1.0, 1 / [\Phi_z + \sqrt{(\Phi_z^2 - \bar{\lambda}_z^2)}])$ = **0.874**

Design buckling resistance; $N_{b,z,Rd} = \chi_z \times A \times f_y / \gamma_{M1}$ = **1220.2** kN

$N_{Ed} / N_{b,z,Rd}$ = **0.02**

PASS - The flexural buckling resistance exceeds the design axial load

Minimum buckling resistance

Minimum buckling resistance; $N_{b,Rd} = \min(N_{b,y,Rd}, N_{b,z,Rd})$ = **1220.2** kN

$N_{Ed} / N_{b,Rd}$ = **0.02**

PASS - The axial load buckling resistance exceeds the design axial load

Buckling resistance moment (cl.6.3.2.1)

Circular hollow section not subject to lateral torsional buckling therefore:-

Reduction factor; χ_{LT} = **1.0**

Design buckling resistance moment; $M_{b,Rd} = \chi_{LT} \times W_y \times f_y / \gamma_{M1}$ = **105.2** kNm

Design bending moment; $M_{y,Ed} = \max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **100.0** kNm

$M_{y,Ed} / M_{b,Rd}$ = **0.951**

PASS - The design buckling resistance moment exceeds the maximum design moment

Combined bending and axial compression (cl. 6.3.3)

Characteristic resistance to normal force; $N_{Rk} = A \times f_y =$ **1397** kN

Characteristic moment resistance - Major axis; $M_{y,Rk} = W_{pl.y} * f_y =$;**105.2**; kNm

Characteristic moment resistance - Minor axis; $M_{z,Rk} = W_{pl.z} * f_y =$;**105.2**; kNm

ψ_y = if(abs($M_{y,Ed1}$)<=abs($M_{y,Ed2}$), $M_{y,Ed1}$ / if($M_{y,Ed2}$>=0 kNm,max($M_{y,Ed2}$,0.0001 kNm),$M_{y,Ed2}$), $M_{y,Ed2}$ / if($M_{y,Ed1}$>=0 kNm,max($M_{y,Ed1}$,0.0001 kNm),$M_{y,Ed1}$)) = **0.000**

Moment distribution factor - Major axis; $\psi_y = M_{y,Ed2} / M_{y,Ed1} =$;**0.000**

Moment factor - Major axis; $C_{my} = \max(0.4, 0.6 + 0.4 \times \psi_y) =$ **0.600**

Moment distribution factor - Minor axis; $\psi_z = M_{z,Ed2} / M_{z,Ed1} =$;**0.000**

Moment factor - Minor axis; $C_{mz} = \max(0.4, 0.6 + 0.4 \times \psi_z) =$ **0.600**

Moment distribution factor for LTB; $\psi_{LT} = M_{y,Ed2} / M_{y,Ed1} =$;**0.000**

Moment factor for LTB; $C_{mLT} = \max(0.4, 0.6 + 0.4 \times \psi_{LT}) =$ **0.600**

Interaction factor k_{yy}; $k_{yy} = C_{my} \times [1 + \min(0.8, \bar{\lambda}_y - 0.2) \times N_{Ed} / (\chi_y \times N_{Rk} / \gamma_{M1})]$ = **0.605**

Interaction factor k_{zy}; $k_{zy} = 0.6 \times k_{yy} =$ **0.363**

Interaction factor k_{zz}; $k_{zz} = C_{mz} * [1 + \min(1.4, 2 * \bar{\lambda}_z - 0.6) * N_{Ed} / (\chi_z * N_{Rk} / \gamma_{M1})] =$;**0.608**

Interaction factor k_{yz}; $k_{yz} = 0.6 \times k_{zz} =$ **0.365**

Section utilisation; $UR_{B\_1} = N_{Ed} / (\chi_y \times N_{Rk} / \gamma_{M1}) + k_{yy} \times M_{y,Ed} / (\chi_{LT} \times M_{y,Rk} / \gamma_{M1}) + k_{yz} \times M_{z,Ed} / (M_{z,Rk} / \gamma_{M1})$

$UR_{B\_1} =$ **0.652**

$UR_{B\_2} = N_{Ed} / (\chi_z \times N_{Rk} / \gamma_{M1}) + k_{zy} \times M_{y,Ed} / (\chi_{LT} \times M_{y,Rk} / \gamma_{M1}) + k_{zz} \times M_{z,Ed} / (M_{z,Rk} / \gamma_{M1})$

$UR_{B\_2} =$ **0.458**

PASS - The buckling resistance is adequate

STEEL COLUMN DESIGN

In accordance with EN1993-1-1:2005 incorporating Corrigenda February 2006 and April 2009 and the UK national annex

Design summary

Description	Unit	Provided	Required	Utilisation	Result
Shear resistance (y-y)	kN	277	25	0.090	PASS
Shear resistance (z-z)	kN	277	25	0.090	PASS
Axial compression	kN	753	10	0.013	PASS
Bending resistance (y-y)	kNm	39	35	0.900	PASS
Bending resistance (z-z)	kNm	39	15	0.386	PASS
Biaxial bending				0.961	PASS
Buckling in compression	kN	657	10	0.015	PASS
Buckling in bending	kNm	39	35	0.900	PASS
Combined buckling				0.699	PASS

Partial factors - Section 6.1

Resistance of cross-sections; $\gamma_{M0} =$ **1**

Resistance of members to instability; $\gamma_{M1} =$ **1**

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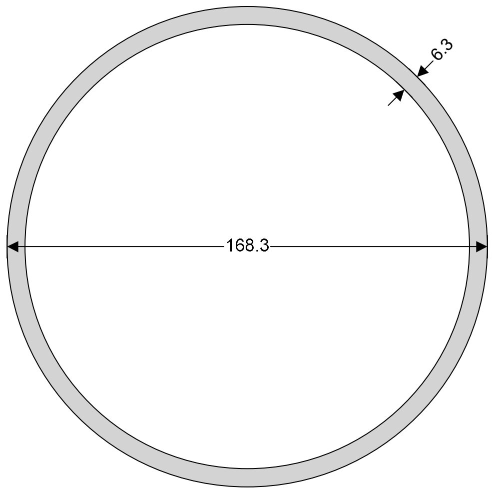
Resistance of cross-sections in tension to fracture; γ_{M2} = **1.1**



CHS 168.3x6.3 (Tata Steel Celsius)
Diameter, d, 168.3 mm
Mass of section, Mass, 25.2 kg/m
Section thickness, t, 6.3 mm
Area of section, A, 3206 mm^2
Radius of gyration about y-axis, i_y, 57.319 mm
Radius of gyration about z-axis, i_z, 57.319 mm
Elastic section modulus about y-axis, $W_{el.y}$, 125184 mm^3
Elastic section modulus about z-axis, $W_{el.z}$, 125184 mm^3
Plastic section modulus about y-axis, $W_{pl.y}$, 165421 mm^3
Plastic section modulus about z-axis, $W_{pl.z}$, 165421 mm^3
Second moment of area about y-axis, I_y, 10534205 mm^4
Second moment of area about z-axis, I_z, 10534205 mm^4

Column details

Column section	**CHS 168.3x6.3**
Steel grade	**S235H**
Yield strength	f_y = **235** N/mm^2
Ultimate strength	f_u = **360** N/mm^2
Modulus of elasticity	E = **210** kN/mm^2
Poisson's ratio	ν = **0.3**
Shear modulus	$G = E / [2 \times (1 + \nu)]$ = **80.8** kN/mm^2

Column geometry

System length for buckling - Major axis	L_y = **2900** mm
System length for buckling - Minor axis	L_z = **2900** mm

The column is not part of a sway frame in the direction of the minor axis
The column is not part of a sway frame in the direction of the major axis

Column loading

Axial load	N_{Ed} = **10** kN (Compression)
Major axis moment at end 1 - Bottom	$M_{y,Ed1}$ = **35.0** kNm
Major axis moment at end 2 - Top	$M_{y,Ed2}$ = **0.0** kNm
	Major axis bending is single curvature
Minor axis moment at end 1 - Bottom	$M_{z,Ed1}$ = **15.0** kNm
Minor axis moment at end 2 - Top	$M_{z,Ed2}$ = **0.0** kNm
	Minor axis bending is single curvature
Major axis shear force	$V_{y,Ed}$ = **25** kN
Minor axis shear force	$V_{z,Ed}$ = **25** kN

Buckling length for flexural buckling - Major axis

End restraint factor;	K_y = **1.200**
Buckling length;	$L_{cr\_y} = L_y \times K_y$ = **3480** mm

Buckling length for flexural buckling - Minor axis

End restraint factor;	K_z = **1.200**
Buckling length;	$L_{cr\_z} = L_z \times K_z$ = **3480** mm

Section classification (Table 5.2)

Coefficient depending on f_y; $\varepsilon = \sqrt{(235 \text{ N/mm}^2 / f_y)}$ = **1.000**

Ratio of d/t; ratio = d / t = **26.71**

Limit of d/t for class 1 section; $Limit_1 = 50 \times \varepsilon^2$ = **50.00**

Limit of d/t for class 2 section; $Limit_2 = 70 \times \varepsilon^2$ = **70.00**

Limit of d/t for class 3 section; $Limit_3 = 90 \times \varepsilon^2$ = **90.00**

The section is class 1

Resistance of cross section (cl. 6.2)

Shear - Major axis (cl. 6.2.6)

Design shear force; $V_{y,Ed}$ = **25.0** kN

Shear area; $A_{vy} = 2 * A / \pi$ = ;**2041**; mm^2

Plastic shear resistance; $V_{pl,y,Rd} = A_{vy} \times (f_y / \sqrt{(3)}) / \gamma_{M0}$ = **276.9** kN

$V_{y,Ed} / V_{pl,y,Rd}$ = **0.09**

PASS - Shear resistance exceeds the design shear force

$V_{y,Ed}$ <= 0.5*$V_{pl,y,Rd}$ - No reduction in f_y required for bending/axial force

Shear - Minor axis (cl. 6.2.6)

Design shear force; $V_{z,Ed}$ = **25.0** kN

Shear area; $A_{vz} = 2 * A / \pi$ = ;**2041**; mm^2

Plastic shear resistance; $V_{pl,z,Rd} = A_{vz} \times (f_y / \sqrt{(3)}) / \gamma_{M0}$ = **276.9** kN

$V_{z,Ed} / V_{pl,z,Rd}$ = **0.09**

PASS - Shear resistance exceeds the design shear force

$V_{z,Ed}$ <= 0.5*$V_{pl,z,Rd}$ - No reduction in f_y required for bending/axial force

Compression (cl. 6.2.4)

Design force; N_{Ed} = **10** kN

Design resistance; $N_{c,Rd} = N_{pl,Rd} = A \times f_y / \gamma_{M0}$ = **753** kN

$N_{Ed} / N_{c,Rd}$ = **0.013**

PASS - The compression design resistance exceeds the design force

Bending - Major axis (cl. 6.2.5)

Design bending moment; $M_{y,Ed} = \max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **35.0** kNm

Section modulus; $W_y = W_{pl.y}$ = ;**165.4**; cm^3

Design resistance; $M_{c,y,Rd} = W_y \times f_y / \gamma_{M0}$ = **38.9** kNm

$M_{y,Ed} / M_{c,y,Rd}$ = **0.9**

PASS - The bending design resistance exceeds the design moment

Bending - Major axis(cl. 6.2.5)

Design bending moment; $M_{z,Ed} = \max(abs(M_{z,Ed1}), abs(M_{z,Ed2}))$ = **15.0** kNm

Section modulus; $W_z = W_{pl.z}$ = ;**165.4**; cm^3

Design resistance; $M_{c,z,Rd} = W_z \times f_y / \gamma_{M0}$ = **38.9** kNm

$M_{z,Ed} / M_{c,z,Rd}$ = **0.386**

PASS - The bending design resistance exceeds the design moment

Combined bending and axial force (cl. 6.2.9)

Ratio design axial to design plastic resistance; $n = abs(N_{Ed}) / N_{pl,Rd}$ = **0.013**

Bending - Major axis (cl. 6.2.9.1)

Design bending moment; $M_{y,Ed} = \max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **35.0** kNm

Plastic design resistance; $M_{pl,y,Rd} = W_{pl.y} \times f_y / \gamma_{M0}$ = **38.9** kNm

Modified design resistance; $M_{N,y,Rd} = M_{pl,y,Rd} \times \min(1, (1 - n^{1.7}))$ = **38.8** kNm

$M_{y,Ed} / M_{N,y,Rd}$ = **0.901**

PASS - Bending resistance in presence of axial load exceeds design moment

Bending - Minor axis (cl. 6.2.9.1)

Design bending moment; $M_{z,Ed} = max(abs(M_{z,Ed1}), abs(M_{z,Ed2}))$ = **15.0** kNm

Plastic design resistance; $M_{pl,z,Rd} = W_{pl.z} \times f_y / \gamma_{M0}$ = **38.9** kNm

Modified design resistance; $M_{N,z,Rd} = M_{pl,z,Rd} \times min(1, (1 - n^{1.7}))$ = **38.8** kNm

$M_{z,Ed} / M_{N,z,Rd}$ = **0.386**

PASS - Bending resistance in presence of axial load exceeds design moment

Biaxial bending

Exponent α; α = ;**2.00**

Exponent β; β = ;**2.00**

Section utilisation at end 1; $UR_{CS\_1} = [abs(M_{y,Ed1}) / M_{N,y,Rd}]^{\alpha} + [abs(M_{z,Ed1}) / M_{N,z,Rd}]^{\beta}$ = **0.961**

Section utilisation at end 2; $UR_{CS\_2} = [abs(M_{y,Ed2}) / M_{N,y,Rd}]^{\alpha} + [abs(M_{z,Ed2}) / M_{N,z,Rd}]^{\beta}$ = **0.000**

PASS - The cross-section resistance is adequate

Buckling resistance (cl. 6.3)

Yield strength for buckling resistance; f_y = **235** N/mm^2

Flexural buckling - Major axis

Elastic critical buckling force; $N_{cr,y} = \pi^2 \times E \times I_y / L_{cr\_y}^2$ = **1803** kN

Non-dimensional slenderness; $\bar{\lambda}_y = \sqrt{(A \times f_y / N_{cr,y})}$ = **0.646**

Buckling curve (Table 6.2); **a**

Imperfection factor (Table 6.1); α_y = **0.21**

Parameter Φ; $\Phi_y = 0.5 \times [1 + \alpha_y \times (\bar{\lambda}_y - 0.2) + \bar{\lambda}_y^2]$ = **0.756**

Reduction factor; $\chi_y = min(1.0, 1 / [\Phi_y + \sqrt{(\Phi_y^2 - \bar{\lambda}_y^2)}])$ = **0.871**

Design buckling resistance; $N_{b,y,Rd} = \chi_y \times A \times f_y / \gamma_{M1}$ = **656.6** kN

$N_{Ed} / N_{b,y,Rd}$ = **0.015**

PASS - The flexural buckling resistance exceeds the design axial load

Flexural buckling - Minor axis

Elastic critical buckling force; $N_{cr,z} = \pi^2 \times E \times I_z / L_{cr\_z}^2$ = **1803** kN

Non-dimensional slenderness; $\bar{\lambda}_z = \sqrt{(A \times f_y / N_{cr,z})}$ = **0.646**

Buckling curve (Table 6.2); **a**

Imperfection factor (Table 6.1); α_z = **0.21**

Parameter Φ; $\Phi_z = 0.5 \times [1 + \alpha_z \times (\bar{\lambda}_z - 0.2) + \bar{\lambda}_z^2]$ = **0.756**

Reduction factor; $\chi_z = min(1.0, 1 / [\Phi_z + \sqrt{(\Phi_z^2 - \bar{\lambda}_z^2)}])$ = **0.871**

Design buckling resistance; $N_{b,z,Rd} = \chi_z \times A \times f_y / \gamma_{M1}$ = **656.6** kN

$N_{Ed} / N_{b,z,Rd}$ = **0.015**

PASS - The flexural buckling resistance exceeds the design axial load

Minimum buckling resistance

Minimum buckling resistance; $N_{b,Rd} = min(N_{b,y,Rd}, N_{b,z,Rd})$ = **656.6** kN

$N_{Ed} / N_{b,Rd}$ = **0.015**

PASS - The axial load buckling resistance exceeds the design axial load

Buckling resistance moment (cl.6.3.2.1)

Circular hollow section not subject to lateral torsional buckling therefore:-

Reduction factor; χ_{LT} = **1.0**

Design buckling resistance moment; $M_{b,Rd} = \chi_{LT} \times W_y \times f_y / \gamma_{M1}$ = **38.9** kNm

Design bending moment; $M_{y,Ed} = max(abs(M_{y,Ed1}), abs(M_{y,Ed2}))$ = **35.0** kNm

$M_{y,Ed} / M_{b,Rd}$ = **0.9**

PASS - The design buckling resistance moment exceeds the maximum design moment

Combined bending and axial compression (cl. 6.3.3)

Characteristic resistance to normal force; $N_{Rk} = A \times f_y =$ **753** kN

Characteristic moment resistance - Major axis; $M_{y,Rk} = W_{pl.y} * f_y =$;**38.9**; kNm

Characteristic moment resistance - Minor axis; $M_{z,Rk} = W_{pl.z} * f_y =$;**38.9**; kNm

ψ_y = if(abs($M_{y,Ed1}$)<=abs($M_{y,Ed2}$), $M_{y,Ed1}$ / if($M_{y,Ed2}$>=0 kNm,max($M_{y,Ed2}$,0.0001 kNm),$M_{y,Ed2}$), $M_{y,Ed2}$ / if($M_{y,Ed1}$>=0 kNm,max($M_{y,Ed1}$,0.0001 kNm),$M_{y,Ed1}$)) = **0.000**

Moment distribution factor - Major axis; $\psi_y = M_{y,Ed2} / M_{y,Ed1} =$;**0.000**

Moment factor - Major axis; $C_{my} = \max(0.4, 0.6 + 0.4 \times \psi_y) =$ **0.600**

Moment distribution factor - Minor axis; $\psi_z = M_{z,Ed2} / M_{z,Ed1} =$;**0.000**

Moment factor - Minor axis; $C_{mz} = \max(0.4, 0.6 + 0.4 \times \psi_z) =$ **0.600**

Moment distribution factor for LTB; $\psi_{LT} = M_{y,Ed2} / M_{y,Ed1} =$;**0.000**

Moment factor for LTB; $C_{mLT} = \max(0.4, 0.6 + 0.4 \times \psi_{LT}) =$ **0.600**

Interaction factor k_{yy}; $k_{yy} = C_{my} \times [1 + \min(0.8, \bar{\lambda}_y - 0.2) \times N_{Ed} / (\chi_y \times N_{Rk} / \gamma_{M1})]$ = **0.604**

Interaction factor k_{zy}; $k_{zy} = 0.6 \times k_{yy} =$ **0.362**

Interaction factor k_{zz}; $k_{zz} = C_{mz} * [1 + \min(1.4, 2 * \bar{\lambda}_z - 0.6) * N_{Ed} / (\chi_z * N_{Rk} / \gamma_{M1})] =$;**0.606**

Interaction factor k_{yz}; $k_{yz} = 0.6 \times k_{zz} =$ **0.364**

Section utilisation; $UR_{B\_1} = N_{Ed} / (\chi_y \times N_{Rk} / \gamma_{M1}) + k_{yy} \times M_{y,Ed} / (\chi_{LT} \times M_{y,Rk} / \gamma_{M1}) + k_{yz} \times M_{z,Ed} / (M_{z,Rk} / \gamma_{M1})$

$UR_{B\_1} =$ **0.699**

$UR_{B\_2} = N_{Ed} / (\chi_z \times N_{Rk} / \gamma_{M1}) + k_{zy} \times M_{y,Ed} / (\chi_{LT} \times M_{y,Rk} / \gamma_{M1}) + k_{zz} \times M_{z,Ed} / (M_{z,Rk} / \gamma_{M1})$

$UR_{B\_2} =$ **0.576**

PASS - The buckling resistance is adequate

FOUNDATION ANALYSIS (EN1992-1:2004)

In accordance with EN1997-1:2004 incorporating Corrigendum dated February 2009 and the UK National Annex incorporating Corrigendum No.1

Pad foundation details

Length of foundation; $L_x =$ **2000** mm

Width of foundation; $L_y =$ **2000** mm

Foundation area; $A = L_x \times L_y =$ **4.000** m^2

Depth of foundation; h = **450** mm

Depth of soil over foundation; $h_{soil} =$ **200** mm

Level of water; $h_{water} =$ **0** mm

Density of water; $\gamma_{water} =$ **9.8** kN/m^3

Density of concrete; $\gamma_{conc} =$ **24.5** kN/m^3

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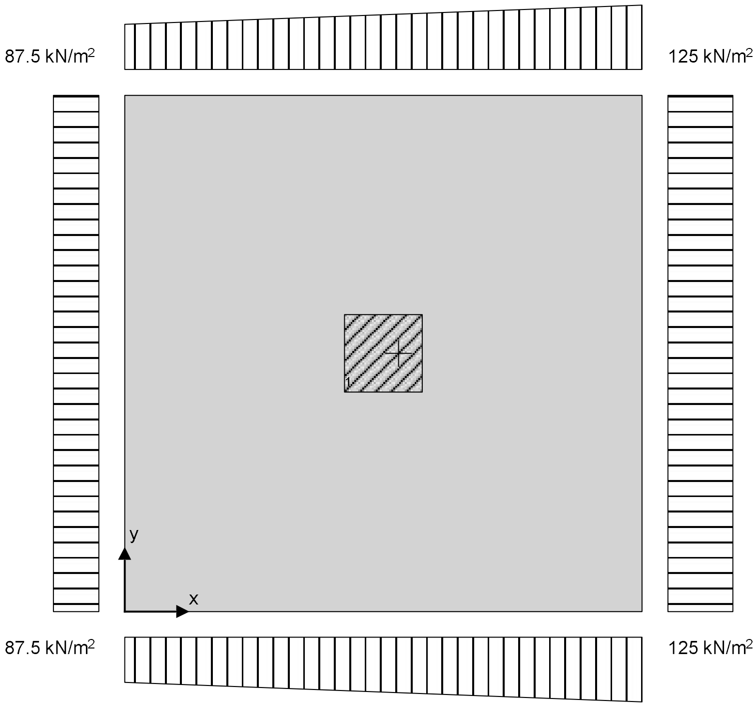

Column no.1 details

Length of column; l_{x1} = **300** mm

Width of column; l_{y1} = **300** mm

position in x-axis; x_1 = **1000** mm

position in y-axis; y_1 = **1000** mm

Soil properties

Density of soil; γ_{soil} = **20.0** kN/m^3

Characteristic cohesion; c'_k = **0** kN/m^2

Characteristic effective shear resistance angle; ϕ'_k = **25** deg

Characteristic friction angle; δ_k = **19.3** deg

Foundation loads

Self weight; $F_{swt} = h * \gamma_{conc}$ = **11.0** kN/m^2

Soil weight; $F_{soil} = h_{soil} * \gamma_{soil}$ = **4.0** kN/m^2

Column no.1 loads

Permanent load in z; F_{Gz1} = **200.0** kN

Variable load in z; F_{Qz1} = **165.0** kN

Permanent moment in x; M_{Gx1} = **15.0** kNm

Variable moment in x; M_{Qx1} = **10.0** kNm

Bearing resistance (Section 6.5.2)

Forces on foundation

Force in z-axis; $F_{dz} = A * (F_{swt} + F_{soil}) + F_{Gz1} + F_{Qz1}$ = **425.1** kN

Moments on foundation

Moment in x-axis; $M_{dx} = A * (F_{swt} + F_{soil}) * L_x / 2 + F_{Gz1} * x_1 + M_{Gx1} + F_{Qz1} * x_1 + M_{Qx1}$ = **450.1** kNm

Moment in y-axis; $M_{dy} = A * (F_{swt} + F_{soil}) * L_y / 2 + F_{Gz1} * y_1 + F_{Qz1} * y_1 =$ **425.1** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-axis; $e_x = M_{dx} / F_{dz} - L_x / 2 =$ **59** mm

Eccentricity of base reaction in y-axis; $e_y = M_{dy} / F_{dz} - L_y / 2 =$ **0** mm

Pad base pressures

$q_1 = F_{dz} * (1 - 6 * e_x / L_x - 6 * e_y / L_y) / (L_x * L_y) =$ **87.5** kN/m^2

$q_2 = F_{dz} * (1 - 6 * e_x / L_x + 6 * e_y / L_y) / (L_x * L_y) =$ **87.5** kN/m^2

$q_3 = F_{dz} * (1 + 6 * e_x / L_x - 6 * e_y / L_y) / (L_x * L_y) =$ **125** kN/m^2

$q_4 = F_{dz} * (1 + 6 * e_x / L_x + 6 * e_y / L_y) / (L_x * L_y) =$ **125** kN/m^2

Minimum base pressure; $q_{min} = \min(q_1, q_2, q_3, q_4) =$ **87.5** kN/m^2

Maximum base pressure; $q_{max} = \max(q_1, q_2, q_3, q_4) =$ **125** kN/m^2

Presumed bearing capacity

Presumed bearing capacity; $P_{bearing} =$ **150.0** kN/m^2

PASS - Presumed bearing capacity exceeds design base pressure

Design approach 1

Partial factors on actions - Combination1

Partial factor set; A1

Permanent unfavourable action - Table A.3; $\gamma_G =$ **1.35**

Permanent favourable action - Table A.3; $\gamma_{Gf} =$ **1.00**

Variable unfavourable action - Table A.3; $\gamma_Q =$ **1.50**

Variable favourable action - Table A.3; $\gamma_{Qf} =$ **0.00**

Partial factors for spread foundations - Combination1

Resistance factor set; R1

Bearing - Table A.5; $\gamma_{R.v} =$ **1.00**

Sliding - Table A.5; $\gamma_{R.h} =$ **1.00**

Forces on foundation

Force in z-axis; $F_{dz} = \gamma_G * (A * (F_{swt} + F_{soil}) + F_{Gz1}) + \gamma_Q * F_{Qz1} =$ **598.6** kN

Moments on foundation

Moment in x-axis; $M_{dx} = \gamma_G * (A * (F_{swt} + F_{soil}) * L_x / 2 + F_{Gz1} * x_1) + \gamma_G * M_{Gx1} + \gamma_Q * F_{Qz1} * x_1 + \gamma_Q * M_{Qx1} =$ **633.9** kNm

Moment in y-axis; $M_{dy} = \gamma_G * (A * (F_{swt} + F_{soil}) * L_y / 2 + F_{Gz1} * y_1) + \gamma_Q * F_{Qz1} * y_1 =$ **598.6** kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-axis; $e_x = M_{dx} / F_{dz} - L_x / 2 =$ **59** mm

Eccentricity of base reaction in y-axis; $e_y = M_{dy} / F_{dz} - L_y / 2 =$ **0** mm

Effective area of base

Effective length; $L'_x = L_x - 2 * e_x =$ **1882** mm

Effective width; $L'_y = L_y - 2 * e_y =$ **2000** mm

Effective area; $A' = L'_x \times L'_y =$ **3.764** m^2

Pad base pressure

Design base pressure; $f_{dz} = F_{dz} / A' = \mathbf{159}$ kN/m^2

Design approach 1

Partial factors on actions - Combination2

Partial factor set; A2

Permanent unfavourable action - Table A.3; $\gamma_G = \mathbf{1.00}$

Permanent favourable action - Table A.3; $\gamma_{Gf} = \mathbf{1.00}$

Variable unfavourable action - Table A.3; $\gamma_Q = \mathbf{1.30}$

Variable favourable action - Table A.3; $\gamma_{Qf} = \mathbf{0.00}$

Partial factors for spread foundations - Combination2

Resistance factor set; R1

Bearing - Table A.5; $\gamma_{R.v} = \mathbf{1.00}$

Sliding - Table A.5; $\gamma_{R.h} = \mathbf{1.00}$

Forces on foundation

Force in z-axis; $F_{dz} = \gamma_G * (A * (F_{swt} + F_{soil}) + F_{Gz1}) + \gamma_Q * F_{Qz1} = \mathbf{474.6}$ kN

Moments on foundation

Moment in x-axis; $M_{dx} = \gamma_G * (A * (F_{swt} + F_{soil}) * L_x / 2 + F_{Gz1} * x_1) + \gamma_G * M_{Gx1} + \gamma_Q * F_{Qz1} * x_1 + \gamma_Q * M_{Qx1} = \mathbf{502.6}$ kNm

Moment in y-axis; $M_{dy} = \gamma_G * (A * (F_{swt} + F_{soil}) * L_y / 2 + F_{Gz1} * y_1) + \gamma_Q * F_{Qz1} * y_1 = \mathbf{474.6}$ kNm

Eccentricity of base reaction

Eccentricity of base reaction in x-axis; $e_x = M_{dx} / F_{dz} - L_x / 2 = \mathbf{59}$ mm

Eccentricity of base reaction in y-axis; $e_y = M_{dy} / F_{dz} - L_y / 2 = \mathbf{0}$ mm

Effective area of base

Effective length; $L'_x = L_x - 2 * e_x = \mathbf{1882}$ mm

Effective width; $L'_y = L_y - 2 * e_y = \mathbf{2000}$ mm

Effective area; $A' = L'_x \times L'_y = \mathbf{3.764}$ m^2

Pad base pressure

Design base pressure; $f_{dz} = F_{dz} / A' = \mathbf{126.1}$ kN/m^2

Conclusion

Structure capacity is sufficient with the proposed steel post sections under wind and snow loadings. Steel posts have to be embedded in the proposed pad foundation.