Static calculation	**Rev. :** 0 **Date:** 19-03-2013	**Initials:** Mateusz Bylinowski	[redacted] Chimney E□ 62, Lillebæltsvej DK-6715 Esbjerg N Telephon□ 22 Telefax +45 75 14 01 22 E-mail : steelcon@steelcon.com
	Rev.: A **Date:** 7-10-2013	**Page:** 1/44	
Subject: Steel Chimney	**Project:** Bjugn		
Manufactur□ Steelcon Chimney A **Manufactur□** .: 58981	**Client:** □ **Client Order No.:**		

Main Dimensions of Steel Chimney

H = 80.00 m
Shell D= 2500 mm
Liner d= 2250 mm

Revision	By	Date	Description
0	Mateusz B□	19-03-2013	First iss □
A	Mateusz B□	07-10-2013	Calculations acc. to NS-EN 1993-3-2:2006/NA:2009

[redacted]

[redacted]

[redacted]

1 Calculation based on:

EN 1993-1-1:2005 ....□ ....□ es.and rules for buildings.
EN 1991-1-4:2005 ....□ ....□ ns....
EN 1993-3-2:2006 ....□ ....□ ..... neys
NS-EN 1993- p□ A:2009 ..□ ....□ NA.for Norway)
EN 1993-1-6:2007 Annex D ....□ ....□ d stability of shell structures.
EN 1993-1-8:2005 ....□ ....□ oints.
EN 1993-1-9:2005 ....□ ....□ .....
NS EN 1991-K□ ....□ ....□ ns.:.National Annex for Norway

The chimney is calculated for 2 cases of load:
* L 1 - □ wind (static)
* L 2 - □ s (dynamic)

L1. This case is mainly static and is acting in the wind direction. The design wind speed and the static pressure is statistically determined. These sizes are stated in EN 1991-1-4: 2005. This wind load together with the dead load of the chimne□ sent the case – Static load.

L2. This case is mainly dynamic and is acting cross to the wind direction. □ ign wind speed and the corresponding transverse motion de□□ ural freU □ ney along with damping of the chimney. The calculation is made acc. to EN 1991-1-4: 2005 Approach 1.
This load represents the load case – **dynamic load**

The chimney is freestanding and self-supporting.
To reduce the effect of cross to wind oscillation a hydraulic damper is mounted at the chimney □ e oscillation damper is tested in full scale and in wind tunnel.

[redacted]

2 Design parameters

2.1 Dimensions:

Chimney h□ ase plate - chimney top) ....□ .00 m
Outer diameter of structural shell ....□ ....□ 00 mm

2.2 Materials:

Structural steel...........□ ....□ ....□ 2.....
Anchors in foundation.....................□ ....□ N.ISO 898-1
Bolt quality.............□ ....□ ....□ galv.

2.3 Safety factors:

Reliability class ....□ ....□ ....□ rmal chimneys
Execution class............□...............□ ....□ .....
Concerned Actions........................□ ....□ d-load “+” Wind) ea
Design temperature of shell............□ ....□ ....

Factor type	Designation	Value	Referencing norm
Safety on wind loa□	γ_Q	1.50	NS-EN 1993□
Safety on dead load	γ_{Gk}	1.20	NS-EN 1993□
Safety on vortex shedding loads	$\gamma_{F,f}$	1.0	NS-EN1993-3-2 for reliability class 2
Safety on materials	γ_m	1.05	NS-EN 1993□
Safety on materials	γ_{mf}	1.35	NS-EN 1993□
Safety on bolts	$\gamma_{m,b}$	1.25	NS-EN1993-3-2 for reliability class 2/ EN 1993-1-8
Safety on buckling	γ_{M1}	1.1	NS-EN1993-3-2 for reliability class 2/ EN 1993-1-6

2.4 Plate thickness in shell:

From	To	Plate	Steel	Shell reinforcements
0,00	2500,00	18	S355J2	No
2500,00	10000,00	16	S355J2	No
10000,00	30000,00	14	S355J2	No
30000,00	37200,00	12	S235JR	No
37200,00	46200,00	10	S235JR	No
46200,00	57000,00	8	S235JR	Yes
57000,00	80000,00	6	S235JR	Yes
mm	**mm**	**mm**	**-**	**-**

If "yes" reinforcement acc. to page.32 is nessesary.
The thicknesses include an allowance of corrosion of 0.5 mm

2.5 Liners:

No	Ø	Plate	Steel	Insulation
1	2250	3,0	1,4301	30
-	**mm**	**mm**	**-**	**mm**

2.6 Surface treatment

Sandblast SA 2 ½
2 x Epoxy Primer..........□..............□ ....□ .....
1 x Polyurethane Finish...................□ ....□ .....
Thickness of layers ....□ ....□ y.....
Allowanc□ ....□ ....□ .....

2.7 *Allowable stresses under static load*

Design temperature........□..............□ ....□ ree.Celsius.

Reducing factor at design temperat□
- yield stress ....□ ....□ 000..
- modulus of elasticity..................□ ....□ 000..

Structural steel...........□ ....□ ....□ 2.....
Anchor bolts..............□ ....□ ....□ G...

Allowabl□ 35JRG2
Yield stress.............□ ....□ ....□ 235.0 N/mm^2
Allowabl□ aterial ....□ ....□ = 223.8 N/mm^2
- □ d, K-weld ....□ ....□ 223.8 N/mm^2
- □ ld ....□ ..et.we......□ 207.8 N/mm^2

Allowabl□ 55J2
Yield stress.............□ ....□ ....□ 355.0 N/mm^2
Allowabl□ aterial ....□ ....□ = 338.1 N/mm^2
- □ d, K-weld ....□ ....□ 304.3 N/mm^2
- □ ld ....□ ..et.we......□ 241.2 N/mm^2

Anchors, 8.8, 20°C...............□ ....□ ...Eyd = 554.1 N/mm^2 .....
................□ ....□ = 576.0 N/mm2
(Inclusive notch factor 1/0,9 acc to EN 1991-1-8: 2005 Table 3.

Modulus of□ ....□ ....□ 210000 N/mm^2

2.8 *Allowable stresses under dynamic loads:*

Acc. to EN1991-1-4:
Load oscillation number acc. to p□ ....□ 66670000
Max. load oscillation number in formula (B.3) ......□...............□ 5000000
Reference number for σa ....□ ....□ =.2000000
Stress amplitude acc.□ B.3) ....□ ....□ ..$_c$ * (Na/N)$^{1/3}$ N/mm^2 = Δσ

For temperatures 100°C ≤ t ≤ 500°C Allowable stresses are factored according following for□

$$\square \qquad \square \qquad {}_{RT} = \frac{1300 - T}{1200} * \Delta\sigma_R \qquad \square$$

If the chimney is □ ed with an allowanc□ corrosion, the corroded parts will fall 1 not□ The corrosion will be differentia□ een outside and inside corrosion. The shell will fall to notc □ atter on which side the corrosion allowance is applied. On the other hand flanges will only fall to a lower notch case if there is corrosion allowance on the outside of the chimney.

Fault line uncorroded	Fault line corroded	Description	$\Delta\sigma_R$ N/mm^2
125	112	Base materials, machine flame cut.	61.128
90	80	Parts with holes that are subjected to normal forces or bending moments (baseplate)	43.663
71	63	Cross welded plates (K-welds at fins agais□ ase plate)	34.384
63	56	Flanges without fins	30.564
50	45	Welded longitudinal plates (fin-shell, fin-ring)	24.560
45	40	Welds end to end with crossing plate (shell-flange, shell-base plate)	21.831
36	36	(Fin-shell without ring over fins, corroded plates)	19.648
50*	50*	Bolts subj□ with rolled threads.(all bolts)	27.289
36*	36*	Bolts subj□ with cut□ se plate)	19.648

2.9 Buckle certification for shell

For the sake of convenience the buckle certification will be carried out for the outer selfsupporting shell acc. to, EN 1993-1-6: 2007 appendix D, for □ inder. When the necessity of reinforcement is to be determined, the sections with varying thickness are calculated with BC 2 - BC 2.

Ideal buckle stress: σ_{xRc} = 0.605□ $_x$ * E * t/r

Length parameter $\omega_x = \dfrac{\ell}{\sqrt{rt}}$

$\omega_x \le 1{,}7$ $\qquad C_x = 1{,}36 - \dfrac{1{,}83}{\omega_x} + \dfrac{2{,}07}{\omega_x^2}$

$1{,}7 < \omega_x \le 0{,}5\dfrac{r}{t}$ $\qquad C_x = 1$

$0{,}5\dfrac{r}{t} < \omega_x$ $\qquad C_x = 1 + \dfrac{0{,}2}{C_{xb}}\left[1 - 2\omega_x \dfrac{t}{r}\right] \quad (C_x \ge 0{,}6)$

Where $C_{xb} = 1$ for□

Modus of e□ E = 210000
Effective wall thickness t = t - 0.5 mm
Mean radius r = (Da - t)/2 mm

Relative shell slenderness $\bar{\lambda}_x = \sqrt{f_{y,k} / \sigma_{xRc}}$

Squash limit slenderness $\bar{\lambda}_{x0} = 0{,}20$

Plastic limit relative slenderness $\bar{\lambda}_{xp} = \sqrt{\dfrac{\alpha_x}{1-\beta_x}}$

Plastic ra□ $\beta_x = 0{,}60$
Interaction eksponent $\eta_x = 1{,}0$

Characteristic inperfection amplitude $\Delta wk = \dfrac{1}{Q_x}\sqrt{\dfrac{r}{t}}t$

Fabrication quality parameter $Q_x = 25$

Meridional elastic inperfection factor $\alpha_x = \dfrac{0{,}62}{1 + 1{,}91(\Delta wk / t)^{1{,}44}}$

Safety factor $\gamma_{M1} = 1.1$

Reduction factor χ_x:

$\bar{\lambda}_x \le \bar{\lambda}_{x0}$ $\qquad \chi_x = 1$

$\bar{\lambda}_{x0} < \bar{\lambda}_x < \bar{\lambda}_{xp}$ $\qquad \chi_x = 1 - \beta_x \left(\dfrac{\bar{\lambda}_x - \bar{\lambda}_{x0}}{\bar{\lambda}_{xp} - \bar{\lambda}_{x0}}\right)^{\eta_x}$

$\bar{\lambda}_{xp} \le \bar{\lambda}_x$ $\qquad \chi_x = \dfrac{\alpha_x}{\bar{\lambda}_x^2}$

Reduced, allowable buckle stress: □ $_{xRd} = \chi_x * f_{y,k} / \gamma_{M1}$

Steel	t	r	ℓ	C_x	σ_{xRc}	χ_ξ	σ_{xRd}
S355J2	17,5	1241,3	22500	0,600	1074,7	0,742	232,7
S355J2	15,5	1242,3	22500	0,600	951,1	0,706	227,8
S355J2	13,5	1243,3	21900	0,600	827,8	0,668	215,6
S235JR	11,5	1244,3	21900	0,600	704,6	0,718	153,3
S235JR	9,5	1245,3	21900	0,600	581,6	0,664	141,8
S235JR	7,5	1246,3	21600	0,665	508,1	0,613	131,0
S235JR	5,5	1247,3	21600	0,742	415,4	0,525	112,3
S235JR	5,5	1247,3	14000	0,903	505,8	0,586	125,2
-	**mm**	**mm**	**mm**	**-**	**N/mm²**	**-**	**N/mm²**

2.10 *Allowable buckle stresses (shear)*

The buckle certification will be carried out□ uter self-supporting shell acc. to, EN 1993-1-6: 2007 Annex D, for a circular cylinder with a length defined by stack section lengths. The sections with varying thickness are calculated with BC 2 □

Ideal buckle stress $\tau_{Rc} = 0{,}75 * E * C_t * \sqrt{\frac{1}{\omega_\tau}} * \frac{1}{r}$

Length parameter $\omega_\tau = \frac{\ell}{\sqrt{rt}} =$

Coefficient $C_\tau = \sqrt{1 + \frac{42}{\omega_\tau^3}}$

Shear elastic imperfection factor $\alpha_\tau = 0{,}65$

Pressure limit slenderness $\bar{\lambda}_{\tau 0} = 0{,}40$

Plastic limit slenderness $\bar{\lambda}_{\tau p} = \sqrt{\frac{\alpha_\tau}{1 - \beta_\tau}}$

Plastic ra□ $\beta_\tau = 0{,}60$

Interaction exponent $\eta_\tau = 1{,}0$

Modulus of□ E □210000

Effective plate thickness t = t - 0.5 mm

Mean radius r = (Da - t)/2 m□

Relative slenderness $\bar{\lambda}_\tau = \sqrt{\frac{f_{y,k}}{\sqrt{3} * \tau_{Rc}}}$

Safety factor $\gamma_{M1} = 1.1$

Reduction factor χ_τ:

$\bar{\lambda}_\tau \leq \bar{\lambda}_{\tau 0}$ $\chi_\tau = 1$

$\bar{\lambda}_{\tau 0} < \bar{\lambda}_\tau < \bar{\lambda}_{\tau p}$ $\chi_\tau = 1 - \beta\left(\frac{\bar{\lambda}_\tau - \bar{\lambda}_{\tau 0}}{\bar{\lambda}_{\tau p} - \bar{\lambda}_{\tau 0}}\right)^\eta$

$\bar{\lambda}_{\tau p} \leq \bar{\lambda}_\tau$ $\chi_\tau = \frac{\alpha_\tau}{\bar{\lambda}_\tau^2}$

[redacted]

Allowabl□ g stresses: $\tau_{xRd} = \chi_{\tau} * f_{y,k} / \left(\sqrt{3} * \gamma_{M1}\right)$

Steel	t	r	ℓ	C_τ	τ_{Rc}	χ	τ_{xRd}
S355J2	17,5	1241,3	22500	1,000	178,8	0,550	99,7
S355J2	15,5	1242,3	22500	1,000	153,6	0,482	89,8
S355J2	13,5	1243,3	21900	1,000	129,2	0,411	76,5
S235JR	11,5	1244,3	21900	1,000	105,8	0,498	61,4
S235JR	9,5	1245,3	21900	1,000	83,3	0,399	49,2
S235JR	7,5	1246,3	21600	1,000	62,0	0,297	36,6
S235JR	5,5	1247,3	21600	1,000	42,1	0,202	24,9
S235JR	5,5	1247,3	14000	1,000	42,1	0,202	24,9
-	mm	mm	mm	-	N/mm^2	-	N/mm^2

2.11 Weight of sections:

No	Length	From	To	Weight
1	22,50	0,00	22,50	31874
2	21,90	22,50	44,40	22458
3	21,60	44,40	66,00	15475
4	14,00	66,00	80,00	11293
-	m	m	m	kg

Foundation loads
(Self-supporting Chimney)

Rev. : 0
Date: 19-03-2013

Initials: Mateusz Bylinowski

Rev.: A
Date: 7-10-2013

Page: 10/44

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Manufactur□ Steelcon Chimney A

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Client:
□
Client Order No.:

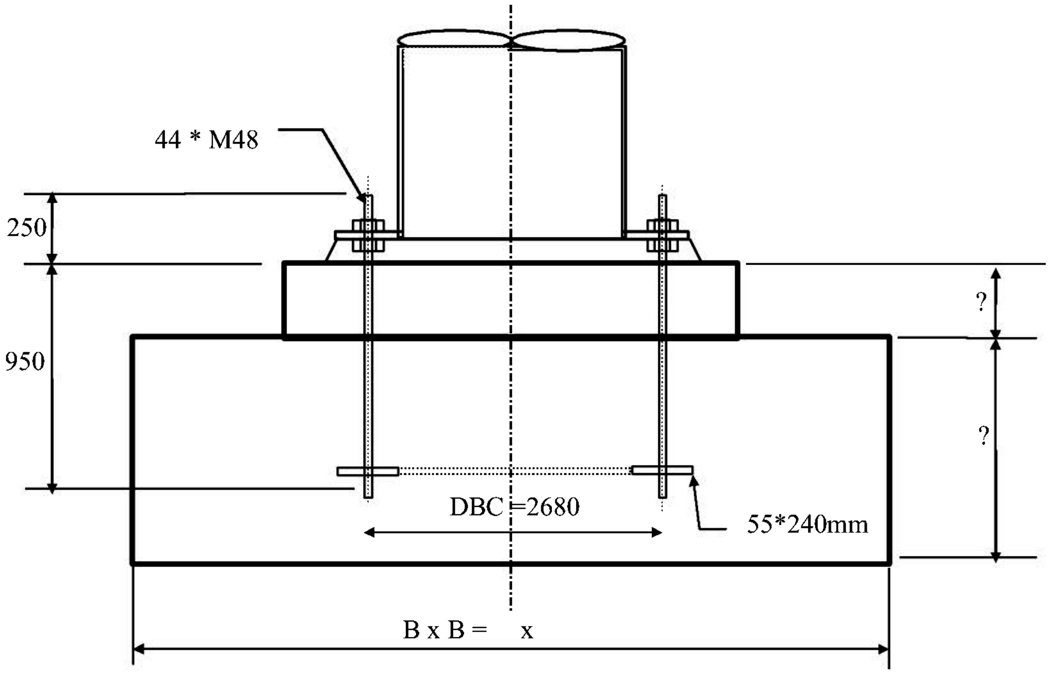
Values without safet□ tors! acc. to. EN 1993-3-2: 2006

Chimney: H =□ m, Du = 2500 mm

Reactions

Dead load (Weight of the chimney):	N=	819.38	kN
Maximum wind load, shear force at base:	Qs=	258.28	kN
Maximum wind load, bending moment at bas	Ms=	11220.96	kNm
Cross to : shear force at base:	Qd=	3.36	kN
Cross to : bending □ :	Md=	182.21	kNm

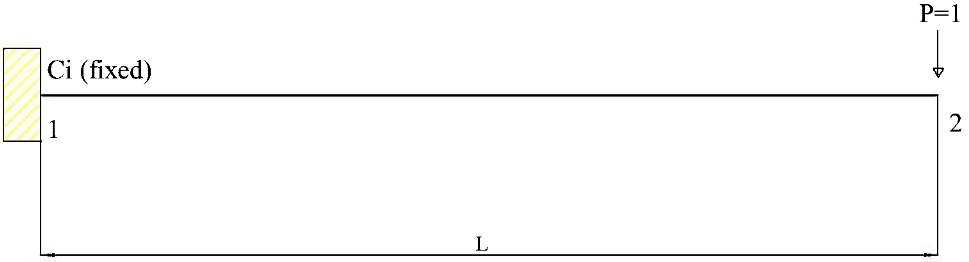
The foundation shall be dimensioned acc to the characteristic loads above.



3 Natural frequency

The chimney is considered fixed in the foundation.

The natural frequency is calculated as for an oscillating one-mass system with elasticity of horizontal deflection C N/m at top and mass of oscillation M kg.
Elasticity at top i□ ined by calculating the deflection at top caused by a horizontal unit force P = 1:



Deflection caused by bending of part 1 - 2:

$$Ue = \int M0(x) * M1(x) * dx / EIx$$

Where:
Mo(x) = x
M1(x) = x
x = Afstand fra pkt. 2
Ix = $\pi/8 * Dm^3 * t$
Dm = Middeldiameter

In sections with constant plate thickness t:

$$Ue = \left| \frac{x^3}{3 * EIx} \right|$$

x1	x2	t	$Ix*10^6$	$Ue*10^{-6}$	$\Sigma Ue*10^{-6}$
0	23000	6	36551,102	528,375	528,375
23000	33800	8	48617,652	863,475	1391,850
33800	42800	10	60625,863	1041,734	2433,584
42800	50000	12	72575,869	1019,125	3452,709
50000	70000	14	84467,818	4096,611	7549,319
70000	77500	16	96301,851	2018,856	9568,175
77500	80000	18	108078,105	683,157	10251,333
mm	**mm**	**mm**	**mm^4**	**mm**	**mm**

Total deflection at top: ....□ ....□ 0251 * 10^{-6} mm => 1
Elasticity at top: □ ....□ ....□ 97548 N/m
Addition □ ....□ ....□ 12631 N/m

Total elasticity at top:.....................□ ....□ ..... ΣC = 110179 N/m

With assumed curve of deflection Φ(n,p) the mass of oscillation is:

$$M = \int \xi^2 * g(x) * dx$$

Where:
ξ = $(4*p*n + 2*n^2 - 4*n^3/3 + n^4/3) / (1 + 4*p)$
ξ = deflection with constant moment of inertia and load.
n = x/L (rel. coordinate measured from point 1)
p = Factor for elasticity at point 1
p = 0 for fixed base (point 1)
g(x) = Load of shell + 5% + load of liner(s)
Liner(s) = 192.5 kg/m

[redacted]

In sections with constant plate thickness:

$$M = \frac{16 * g(x) * L}{(1+4*p)^2} * \left(\frac{n^9}{1296} - \frac{n^8}{144} + \frac{7*n^7}{252} + \frac{(p-2)*n^6}{36} - \frac{(8*p-3)*n^5}{60} + \frac{p*n^4}{4} + \frac{p^2*n^3}{3} \right)$$

x1	x2	t	g(x)	M	ΣM
0	2500	18	1371,5	0,0	0,0
2500	10000	16	1241,3	2,1	2,1
10000	30000	14	1110,9	343,2	345,3
30000	37200	12	980,4	500,6	845,9
37200	46200	10	849,6	1113,5	1959,4
46200	57000	8	718,6	2218,4	4177,7
57000	80000	6	587,4	9000,9	13178,7
mm	**mm**	**mm**	**kg/m**	**kg**	**kg**

Mass of oscillation□ ....□ ....□ =..13860.0 kg
Additional mass at top: ....□ ....□ .=.2273.0 kg
Total mass of oscillation: ....□ ....□ ..... ΣM = 16133.0 kg

Reduced mass per meter.

$$\Sigma m = \frac{\Sigma M}{\int \xi^2 dn} = \Sigma M/(0.2568*H)$$

Σm = 785.□

With elasticity and mass of oscillation kno□

$$n_1 = \frac{1}{2\pi} * \sqrt{\frac{\Sigma C}{\Sigma M}} = 0.4159 \text{ Hz}$$

4 Static windload (dynamic response):

Acc. to EN 1991-1-4: 2005 section 6.2 shal□ ys be calculated with dynamic respons, by determining of the value of $c_s c_d$. The s d per meter shell wi□ be (with safety factor):

$$F_w(z) = \gamma_f * q_{max}(z) * b(z) * C_f * c_s c_d \text{ kN/m}$$

Partial factor γ_f = 1.50

Wind pressure q(z):□

With basic wind speed of 29.0 m/s the 10 minute mean wind speed in height Z_{ref} acc to.□ x EN 1991-1-4(wind chosen by user) is then:

Height to base of chimney z_{fod} = 0.00

Reference height z_{ref} = 48000.00 mm

$V(z_{ref})$ = 29.0 □ $_t$ * $\ln(z_{ref}/z_0)$

Terrain parameters: z_0 = 0.01 m

k_t = 0.17

Mean wind pressure acc. to. EN 1991-1-4: 2005

$$q_m(z) = ½ * 1{,}25 * Vz^2$$

Max wind pressure acc. to. EN 1991-1-4: 2005

$$q_{max}(z) = ((1+2*k_p I_v(z))*q_m(z)$$

Special for $z = z_{ref}$ V = 56.38

$q_{max}(z_{ref})$ = 1.987 kN/m^2

Width cross to wind, b(z):

From	To	b(z)
0	80000	2500
mm	**mm**	**mm**

Pressure coefficient, C_f:

Acc. to. EN 1991-1-4: 2005 section 7.9.2: $C_f = \psi_\lambda * C_{fo}$

Reduction for free flow over top:

Slendernessratio λ = 22.40

for $1 \leq H/D \leq 10$ $\psi = 0{,}6+0{,}1*\log(\lambda)$

for $10 < H/D \leq 100$ $\psi = 0{,}7+0{,}125*\log(\lambda/10)$

for $100 < H/D$ $\psi = 1$

H = 80.00 m og D = 2.500 m => ψ = 0.787□

Pressure for a infinite cylinder: C_{fo} iht. EN 1991-1-4: 2005, Figure 7.28

Reynold number: $Re = V_p * D/15*10^{-6}$

For instence in 80.00 m height:

b(z) = 2.500 m and V(z) = 59.01 m/s => Re = 9834917.39

Replacement roughness: k = 0.2000 mm

Pressure for a infinite cylinder: C_{f0} = 0.8010

Pressure coefficient: C_f = 0.6308

Increasing factor for outer ladder: Fl = 1.0000

Axis distance to neighbour chimneys:

a ≈ ∞

a/d - ratio a/d > 30

Increasing factor Fs = 1.0000

Structural factor, $c_s c_d$:

Construction factor

$$c_s c_d = \frac{1+2*k_p*I_v\sqrt{B^2+R^2}}{1+7I_v(z_{ref})}$$

Reference height z_t = 200 m

Reference length scale L_t = 300 m

Turbulence length scale $L(z_{ref}) = L_t\left(\frac{z_{ref}}{z_t}\right)^{\alpha}$

Where $\alpha = 0.4397$

$L(z_{ref}) = 160.1675$

Background response $$B^2 = \frac{1}{1+\frac{3}{2}\sqrt{\left(\frac{b}{L(z_{ref})}\right)^2+\left(\frac{h}{L(z_{ref})}\right)^2+\left(\frac{b}{L(z_{ref})}\frac{h}{L(z_{ref})}\right)^2}}$$

$B^2 = 0.5715$□

Non-dimensional frequency $f_L(z,n_1) = \frac{n_1 L(z_{ref})}{v_m(z_{ref})}$

$f_L(z, n_1) = 1.5964$

Non-dimensional power spectral density function $S_L(z, n_1) = \frac{6{,}8 f_L(z,n_1)}{(1+10{,}2 f_L(z,n_1))^{5/3}}$

$S_L(z, n_1) = 0.0940$

Horizontal constant $\phi_y = \frac{c_y b n_1}{v_m(z_{ref})}$ (c_y=11.5)

$\phi_y = 0.2866$

Vertical constant $\phi_z = \frac{c_z h n_1}{v_m(z_{ref})}$ (c_z=11.5)

$\phi_z = 9.1699$

Horizontal response constant G_y = 0,5 [EN 1991-1-4: 2005 Annex C, Table C.1]
Vertical response constant G_z = 5/18 [EN 1991-1-4: 2005 Annex C, Table C.1]
Size reduction fact□

frequency-turbulence interaction $$K_s = \frac{1}{1+\sqrt{(G_y\phi_y)^2+(G_z\phi_z)^2+\left(\frac{2}{\pi}G_y\phi_y G_z\phi_z\right)^2}}$$

$K_s = 0.2808$□

Reference mass per unit of area $$\mu_{ref} = \frac{\int_0^h\int_0^b \mu(y,z)\xi^2(y,z)dydz}{\int_0^h\int_0^b \xi^2(y,z)dydz}$$

$\mu_{ref} = 785.3192$

Where:

μ Structure mass per unit of area
ξ Deflection mode shape

Aerodynamic dampin□ $\delta_a = \frac{c_f \rho v_m(z_{ref})}{2 n_1 \mu_{ref}}$

$\delta_a = 0.1344$

[redacted]

Structural damping acc. to EN 1991-1-4: 2005 Annex F, Table F2

Chimney type	**δ_s**
Unlined welded steel stack without insulation	0,012
Unlined welded steel stack with external insulation	0,020
Steel stack with one liner with external insul□ h/b<18 □ □ □ □ □ □	0,020 0,040 0,014
Steel stack with two or more liner with external insulation h/b<18 □ □ □ □ □ □	0,020 0,040 0,025
Steel stack with internal brick liner	0,070
Steel stack with external gunite	0,030
Coupled chimneys without liners□ e)	0,015
Guyed Chimney witho liner and insulation	0,040
Chimney with oscillation damper	Variable

δ_s = 0.1650

Factor for turbulen□ sonance with the chimney $R^2 = \frac{\pi^2}{2(\delta_s + \delta_a)} R_v(z_{ref}, n_1) K_s(n_1)$

R^2 = 0.4348□

Zero-upcrossing frequency $v = n_1 \sqrt{\frac{R^2}{B^2 + R^2}}$

v = 0.2734

Peak-factor $k_p = \sqrt{2\ln(vT)} + \frac{0,577}{\sqrt{2\ln(vT)}}$

where

T Averagi□ r the reference wind velocity, T=600 sec.

k_p = 3.3816

Topography factor (hills and ensharpments) c_t = 1

Turbulence intensity $I_v = \frac{1}{c_t(z)} \frac{1}{\ln(z_{ref}/z_0)}$

I_v = 0.1180

Structural factor $c_s c_d$ = 0.9861□

Discrete ancillaries:

From height	**To height**	**Discrete components**	**C_f**	**Area**	**Weight**
20000	21000	1x(Platform 1200)	2,000	1287602	500
78500	79500	1x(Platform 800)	2,000	915602	400
mm	**mm**	**-**	**-**	**mm^2**	**kg**

Linear ancillaries:

From height	**To height**	**Linear components**	**C_f**	**Area**	**Weight**
0	20000	Outside ladder with backsupport	2,000	201022	42
20000	80000	SF ladder	2,000	40000	10
mm	**mm**	**-**	**-**	**mm^2**	**kg/m**

[redacted]

Calculation of wind load variation over the chimney height□ he following table:

$F_{w,ch}(z)$ = $1.4791 * q_{max}(z) * b(z) * C_f$ kN/m

Static windload from discrete ancillaries:

$F_{w,1}(z)$ = $1.4791 * q_{max}(z) * b_1(z) * C_{f,1}$ kN/m

Static windload from Linear ancillaries:

$F_{w,2}(z)$ = $1.4791 * q_{max}(z) * b_2(z) * C_{f,2}$ kN/m

Total static windload:

$F_{w,Tot}(z)$ = $F_{w,ch}(z) + F_{w,1}(z) + F_{w,2}(z)$ kN/m

Plate	**Height =z**	**$\gamma_f * C_d$**	**$q_{max}(z)$**	**b(z)**	**$C_f(z)$**	**$F_{w,ch}(z)$**	**$F_{w,1}(z)$**	**$F_{w,2}(z)$**	**$F_{w,Tot}(z)$**
1	2500	1,479	1,047	2500	0,616	2,385	0,000	0,623	3,008
2	5000	1,479	1,244	2500	0,619	2,850	0,000	0,740	3,589
3	7500	1,479	1,366	2500	0,622	3,139	0,000	0,812	3,951
4	10000	1,479	1,455	2500	0,623	3,351	0,000	0,865	4,216
5	12500	1,479	1,526	2500	0,624	3,520	0,000	0,908	4,428
6	15000	1,479	1,586	2500	0,624	3,662	0,000	0,943	4,604
7	17500	1,479	1,636	2500	0,625	3,783	0,000	0,973	4,756
8	20000	1,479	1,681	2500	0,626	3,889	0,000	1,000	4,889
9	21000	1,479	1,697	2500	0,626	3,929	6,466	0,201	10,595
9	22500	1,479	1,721	2500	0,626	3,985	0,000	0,204	4,188
10	25000	1,479	1,757	2500	0,627	4,071	0,000	0,208	4,279
11	27500	1,479	1,790	2500	0,627	4,149	0,000	0,212	4,361
12	30000	1,479	1,820	2500	0,627	4,221	0,000	0,215	4,437
13	31800	1,479	1,840	2500	0,627	4,270	0,000	0,218	4,488
14	33600	1,479	1,860	2500	0,628	4,316	0,000	0,220	4,536
15	35400	1,479	1,878	2500	0,628	4,361	0,000	0,222	4,583
16	37200	1,479	1,895	2500	0,628	4,403	0,000	0,224	4,627
17	39000	1,479	1,912	2500	0,628	4,443	0,000	0,226	4,669
18	40800	1,479	1,929	2500	0,628	4,482	0,000	0,228	4,710
19	42600	1,479	1,944	2500	0,629	4,519	0,000	0,230	4,749
20	44400	1,479	1,959	2500	0,629	4,554	0,000	0,232	4,786
21	46200	1,479	1,973	2500	0,629	4,589	0,000	0,234	4,822
22	48000	1,479	1,987	2500	0,629	4,622	0,000	0,235	4,857
23	49800	1,479	2,000	2500	0,629	4,654	0,000	0,237	4,891
24	51600	1,479	2,013	2500	0,629	4,685	0,000	0,238	4,923
25	53400	1,479	2,026	2500	0,629	4,715	0,000	0,240	4,955
26	55200	1,479	2,038	2500	0,630	4,744	0,000	0,241	4,986
27	57000	1,479	2,050	2500	0,630	4,773	0,000	0,243	5,015
28	58800	1,479	2,061	2500	0,630	4,800	0,000	0,244	5,044
29	60600	1,479	2,072	2500	0,630	4,827	0,000	0,245	5,072
30	62400	1,479	2,083	2500	0,630	4,853	0,000	0,247	5,100

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31	64200	1,479	2,094	2500	0,630	4,878	0,000	0,248	5,126
32	66000	1,479	2,104	2500	0,630	4,903	0,000	0,249	5,152
33	67800	1,479	2,114	2500	0,630	4,927	0,000	0,250	5,177
34	69600	1,479	2,124	2500	0,630	4,951	0,000	0,251	5,202
35	71400	1,479	2,134	2500	0,630	4,974	0,000	0,252	5,226
36	73200	1,479	2,143	2500	0,631	4,996	0,000	0,254	5,250
37	75000	1,479	2,152	2500	0,631	5,018	0,000	0,255	5,273
38	76800	1,479	2,161	2500	0,631	5,040	0,000	0,256	5,295
39	78500	1,479	2,169	2500	0,631	5,060	0,000	0,257	5,316
39	78600	1,479	2,170	2500	0,631	5,061	5,877	0,257	11,194
40	79500	1,479	2,174	2500	0,631	5,071	5,888	0,257	11,217
40	80000	1,479	2,176	2500	0,631	5,077	0,000	0,257	5,334
-	**mm**	**-**	**kN/m²**	**mm**	**-**	**kN/m**	**kN/m**	**kN/m**	**kN/m**

4.1 Data for cross-section, cutting forces, static

For each plate-section calculation are carried out as:

$A(t)$ $= \pi * D * t$(area)

$W(t)$ $= \frac{\pi}{4} * Dm^2 * t$ (mom of resistance)

N(z) = Normal force z meter above base, incl. $\gamma_f = 1.20$

Q(z) = Shear force z meter above base, incl. $\gamma_f = 1.50$

M(z) = Bending moment z me □ cl. $\gamma_f = 1.50$

Where t = corroded thickness of plate

Dm(z) = mea□ r at considered height z.

II. order moment M" $= (1 + \eta^2/8) * M =$□ 1993-3-2: 2006]

where η $= \sqrt{H * N(0)/(E * I)} = 0.4485$

Plate	Height =z	t	A(t)	W(t)	N(z)	Q(z)	M(z)	M"(z)
1	0	17,5	136,483	84,704	693,97	387,42	16418,60	16831,44
2	2500	15,5	120,982	75,145	657,36	379,90	15459,45	15848,17
3	5000	15,5	120,982	75,145	624,66	370,93	14520,92	14886,04
4	7500	15,5	120,982	75,145	591,96	361,05	13605,94	13948,06
5	10000	13,5	105,456	65,554	559,26	350,51	12716,49	13036,24
6	12500	13,5	105,456	65,554	530,47	339,44	11854,06	12152,12
7	15000	13,5	105,456	65,554	501,67	327,93	11019,85	11296,94
8	17500	13,5	105,456	65,554	472,88	316,04	10214,89	10471,74
9	20000	13,5	105,456	65,554	444,09	303,82	9440,07	9677,44
9	21000	13,5	105,456	65,554	427,07	293,22	9141,56	9371,42
10	22500	13,5	105,456	65,554	410,36	286,94	8706,44	8925,36
11	25000	13,5	105,456	65,554	382,51	276,24	8002,46	8203,68
12	27500	13,5	105,456	65,554	354,66	265,34	7325,49	7509,68
13	30000	11,5	89,905	55,932	326,81	254,25	6676,00	6843,87
14	31800	11,5	89,905	55,932	309,58	246,17	6225,63	6382,17
15	33600	11,5	89,905	55,932	292,35	238,00	5789,87	5935,46
16	35400	11,5	89,905	55,932	275,12	229,75	5368,89	5503,89

[redacted]

17	37200	9,5	74,329	46,279	257,89	221,43	4962,83	5087,61
18	39000	9,5	74,329	46,279	243,49	213,02	4571,82	4686,78
19	40800	9,5	74,329	46,279	229,08	204,54	4196,02	4301,52
20	42600	9,5	74,329	46,279	214,68	196,00	3835,53	3931,97
21	44400	9,5	74,329	46,279	200,27	187,38	3490,49	3578,26
22	46200	7,5	58,728	36,595	185,86	178,70	3161,02	3240,50
23	48000	7,5	58,728	36,595	174,29	169,96	2847,22	2918,82
24	49800	7,5	58,728	36,595	162,71	161,15	2549,22	2613,32
25	51600	7,5	58,728	36,595	151,14	152,29	2267,12	2324,13
26	53400	7,5	58,728	36,595	139,56	143,37	2001,02	2051,34
27	55200	7,5	58,728	36,595	127,98	134,40	1751,03	1795,06
28	57000	5,5	43,102	26,879	116,41	125,37	1517,24	1555,39
29	58800	5,5	43,102	26,879	107,67	116,29	1299,74	1332,42
30	60600	5,5	43,102	26,879	98,93	107,16	1098,63	1126,25
31	62400	5,5	43,102	26,879	90,18	97,98	914,00	936,98
32	64200	5,5	43,102	26,879	81,44	88,76	745,94	764,69
33	66000	5,5	43,102	26,879	72,70	79,48	594,52	609,47
34	67800	5,5	43,102	26,879	63,96	70,16	459,84	471,41
35	69600	5,5	43,102	26,879	55,22	60,80	341,98	350,58
36	71400	5,5	43,102	26,879	46,47	51,39	241,01	247,07
37	73200	5,5	43,102	26,879	37,73	41,94	157,01	160,96
38	75000	5,5	43,102	26,879	28,99	32,45	90,06	92,32
39	76800	5,5	43,102	26,879	20,25	22,92	40,22	41,23
39	78500	5,5	43,102	26,879	11,99	13,88	8,94	9,17
40	78600	5,5	43,102	26,879	11,04	12,76	7,61	7,80
40	79500	5,5	43,102	26,879	2,43	2,67	0,67	0,68
Factor:			**x 10^3**	**x 10^6**				
-	**mm**	**mm**	**mm^2**	**mm^3**	**kN**	**kN**	**kNm**	**kNm**

[redacted]

4.2 *Stresses in shell under static load*

Normal- and bending stresses, incl. safety factor :

σ_d = N(z) □ z) / W(t)

Allowabl□ ds..............□ $_{wRd}$· σ

Allowabl□ : ....□ $_{xRd}$·

Shear stresses:

τ = Q(z)/π*r*t_{corr}

Allowabl□ (shear)........□ $_{xRd}$

Interaction check f□ bined membrane stresses: $=(\frac{\sigma}{\sigma_{xRd}})^{1,25}+(\frac{\tau}{\tau_{xRd}})^{2}\le 1$

Plate	Height =z	t	σ_d	τ	σ_{wRd}	σ_{xRd}	τ_{xRd}	Interaction
1	0	17,5	203,8	5,7	295,7	232,7	99,7	0.851<=1
2	2500	15,5	216,3	6,3	295,7	227,8	89,8	0.942<=1
3	5000	15,5	203,3	6,1	295,7	227,8	89,8	0.872<=1
4	7500	15,5	190,5	6,0	295,7	227,8	89,8	0.804<=1
5	10000	13,5	204,2	6,6	304,3	215,6	76,5	0.942<=1
6	12500	13,5	190,4	6,4	304,3	215,6	76,5	0.863<=1
7	15000	13,5	177,1	6,2	304,3	215,6	76,5	0.788<=1
8	17500	13,5	164,2	6,0	304,3	215,6	76,5	0.718<=1
9	20000	13,5	151,8	5,8	304,3	215,6	76,5	0.651<=1
9	21000	13,5	147,0	5,6	-	215,6	76,5	0.625<=1
10	22500	13,5	140,0	5,4	304,3	215,6	76,5	0.588<=1
11	25000	13,5	128,8	5,2	304,3	215,6	76,5	0.530<=1
12	27500	13,5	117,9	5,0	304,3	215,6	76,5	0.475<=1
13	30000	11,5	126,0	5,7	223,8	153,3	61,4	0.791<=1
14	31800	11,5	117,5	5,5	223,8	153,3	61,4	0.725<=1
15	33600	11,5	109,4	5,3	223,8	153,3	61,4	0.663<=1
16	35400	11,5	101,5	5,1	223,8	153,3	61,4	0.604<=1
017	37200	9,5	113,4	6,0	223,8	141,8	49,2	0.771<=1
18	39000	9,5	104,5	5,7	223,8	141,8	49,2	0.697<=1
19	40800	9,5	96,0	5,5	223,8	141,8	49,2	0.627<=1
20	42600	9,5	87,9	5,3	223,8	141,8	49,2	0.561<=1
21	44400	9,5	80,0	5,0	223,8	141,8	49,2	0.499<=1
22	46200	7,5	91,7	6,1	223,8	131,0	36,6	0.668<=1
23	48000	7,5	82,7	5,8	223,8	131,0	36,6	0.588<=1
24	49800	7,5	74,2	5,5	223,8	131,0	36,6	0.514<=1
25	51600	7,5	66,1	5,2	223,8	131,0	36,6	0.445<=1
26	53400	7,5	58,4	4,9	223,8	131,0	36,6	0.382<=1
27	55200	7,5	51,2	4,6	223,8	131,0	36,6	0.325<=1
28	57000	5,5	60,6	5,8	223,8	112,3	24,9	0.517<=1
29	58800	5,5	52,1	5,4	223,8	112,3	24,9	0.430<=1
30	60600	5,5	44,2	5,0	223,8	112,3	24,9	0.352<=1
31	62400	5,5	37,0	4,5	223,8	112,3	24,9	0.283<=1
32	64200	5,5	30,3	4,1	223,8	112,3	24,9	0.222<=1
33	66000	5,5	24,4	3,7	223,8	112,3	24,9	0.170<=1

[redacted]

34	67800	5,5	19,0	3,3	223,8	125,2	24,9	0.112<=1
35	69600	5,5	14,3	2,8	223,8	125,2	24,9	0.079<=1
36	71400	5,5	10,3	2,4	223,8	125,2	24,9	0.053<=1
37	73200	5,5	6,9	1,9	223,8	125,2	24,9	0.033<=1
38	75000	5,5	4,1	1,5	223,8	125,2	24,9	0.018<=1
39	76800	5,5	2,0	1,1	223,8	125,2	24,9	0.008<=1
39	78500	5,5	0,6	0,6	-	125,2	24,9	0.002<=1
40	78600	5,5	0,5	0,6	223,8	125,2	24,9	0.002<=1
40	79500	5,5	0,1	0,1	-	125,2	24,9	0.000<=1
40	80000	5,5	0,0	0,0	-	110,4	24,9	0.000<=1
-	**mm**	**mm**	**N/mm^2**	**N/mm^2**	**N/mm^2**	**N/mm^2**	**N/mm^2**	**-**

5 Wind-excited oscillations:

At the r□ n a free wind flow a von Karman vortex shedding will cause a cross-to-wind action on the chimney.
If the frequency of vortex-shedding is equal to the natural frequency of the chimney a case of resonance will occur.

Critical wind speed acc. to EN 1991-1-4: 2005 Annex E, section E.1.2:

$Vr = n_1 * d / St$ m/s

Where:
n_1 = natural frequency acc. to page 11
$n_1 = 0.4159$ Hz
$d = 2.500$ m
St = St□ rl for a cylinder:
$St = 0.1800$

Strouhals number for cylinder is varying acc. to axis distance to neighbor chimneys, a:
$a \approx \infty$
a / d - ratio $a/d > 15$

$Vr = 5.78$ m/s

Calculation of cutting forces
Maximum forces of in□ a per meter:

$$w(h) = m(h) * (2 * \pi * f)^2 * \Phi(n,p) * \max y \ \text{N/m}$$

Oscillating mass, m(h) is calculated as mass of shell + 5% + liner(s): Identical with g(x) in the table at page 13.
Assumed curve of deflection, $\Phi(n,p)$: (See point 4)

$$\Phi(n,p) = (4*p*n + 2*n^2 - 4*n^3/3 + n^4/3) / (1 + 4*p)$$

$n = h/H$ rel. coordinat measur□
p = 0 for fixed base

Maximum oscillation amplitude of the chimney, max y:
Acc. to (E.1.5.2.1) the result is:

$$\max y/d = K_w * K * C_{lat} * 1/S^2 * 1/Sc$$

Operating length factor, Kw:
$\max y/d = 0.0088$ (assumed) =>
□ $L/d = 6.0000$
□ Factor $\theta = (L/d) /$ $= 6.0000 / 32.00$
$= 0.1875$
$Kw = 3 * \theta * [1 - \theta + \theta^2/3]$
$= 0.4636$

Coefficient of oscillation form, K
□ $\phi(n,p) = (4*p*n + 2*n^2 - 4*n^3/3 + n^4/3) / (1 + 4*p)$

$$K = \frac{1}{4\pi} * \frac{\int \phi(n,p)\,dn}{\int \phi(n,p)^2\,dn} \Rightarrow$$

$K = 0.1234$

Transverse force coefficient, Clat
Reynolds number $Re = 2/3 * d * Vcrit * 10^{-5} = 9.628 * 10^{-5}$ =>
Fig. E.2 and table E.3: $Clat = 0.2000$

Axis distance $a \approx \infty$

Increasing factor = 1.0000 =>
Clat = 0.2000
Scruton number, Sc = 2 * ∑m * δ / g * d2
Reduced mass per unit length: ∑m = □ g/m
Logarithmic damping decrement:
□ δ = 0.2000
Density of air g = 1.25 kg/m^3
Scruton number Sc = 40.2083
□ max y/d = 0.4636 * □1234 * 0.2000 / 0.1800^2 / 40.2083
= 0.0088
Maximum forces of in□ a per meter:
w(h) = m(h) * (2 * π * f)^2 * Φ(n,p) * max y :
w(h) = 0.1500 * m(h) * Φ(n,p) N/m

Calculation of wind load variation over the chimney height□ he following table.

5.1 Maximum forces of inertia per meter:

Plate	From height	To height	t	Factor	M(h)	ϕ(n,p)	W(h)
1	0	2500	17.5	0.1500	1371.467	0.00048	0.0001
2	2500	5000	15.5	0.1500	1241.311	0.00426	0.0008
3	5000	7500	15.5	0.1500	1241.311	0.01158	0.0022
4	7500	10000	15.5	0.1500	1241.311	0.02223	0.0041
5	10000	12500	13.5	0.1500	1110.945	0.03597	0.0060
6	12500	15000	13.5	0.1500	1110.945	0.05260	0.0088
7	15000	17500	13.5	0.1500	1110.945	0.07191	0.0120
8	17500	20000	13.5	0.1500	1110.945	0.09370	0.0156
9	20000	21000	13.5	0.1500	1110.945	0.11033	0.0184
10	21000	22500	13.5	0.1500	1110.945	0.12286	0.0205
11	22500	25000	13.5	0.1500	1110.945	0.14397	0.0240
12	25000	27500	13.5	0.1500	1110.945	0.17209	0.0287
13	27500	30000	13.5	0.1500	1110.945	0.20198	0.0337
14	30000	31800	11.5	0.1500	980.367	0.22896	0.0337
15	31800	33600	11.5	0.1500	980.367	0.25240	0.0371
16	33600	35400	11.5	0.1500	980.367	0.27655	0.0407
17	35400	37200	11.5	0.1500	980.367	0.30135	0.0443
18	37200	39000	9.5	0.1500	849.578	0.32675	0.0416
19	39000	40800	9.5	0.1500	849.578	0.35271	0.0449
20	40800	42600	9.5	0.1500	849.578	0.37918	0.0483
21	42600	44400	9.5	0.1500	849.578	0.40611	0.0517
22	44400	46200	9.5	0.1500	849.578	0.43347	0.0552
23	46200	48000	7.5	0.1500	718.578	0.46120	0.0497
24	48000	49800	7.5	0.1500	718.578	0.48928	0.0527
25	49800	51600	7.5	0.1500	718.578	0.51766	0.0558
26	51600	53400	7.5	0.1500	718.578	0.54632	0.0589
27	53400	55200	7.5	0.1500	718.578	0.57522	0.0620
28	55200	57000	7.5	0.1500	718.578	0.60432	0.0651
29	57000	58800	5.5	0.1500	587.367	0.63361	0.0558
30	58800	60600	5.5	0.1500	587.367	0.66305	0.0584
31	60600	62400	5.5	0.1500	587.367	0.69262	0.0610
32	62400	64200	5.5	0.1500	587.367	0.72230	0.0636
33	64200	66000	5.5	0.1500	587.367	0.75207	0.0663
34	66000	67800	5.5	0.1500	587.367	0.78191	0.0689
35	67800	69600	5.5	0.1500	587.367	0.81180	0.0715
36	69600	71400	5.5	0.1500	587.367	0.84173	0.0742
37	71400	73200	5.5	0.1500	587.367	0.87170	0.0768
38	73200	75000	5.5	0.1500	587.367	0.90168	0.0794
39	75000	76800	5.5	0.1500	587.367	0.93167	0.0821
40	76800	78500	5.5	0.1500	587.367	0.96083	0.0846
41	78500	78600	5.5	0.1500	587.367	0.97583	0.0860

42	78600	79500	5.5	0.1500	587.367	0.98417	0.0867
43	79500	80000	5.5	0.1500	587.367	0.99583	0.0877
44	80000	80000	5.5	0.1500	587.367	1.00000	0.0881
-	mm	mm	mm	-	kg/m	-	kN/m

5.2 *Data for cross-section, cutting forces, dynamic*

Plate	Height	t	W(t)	M(h)
1	0	17.5	84.7045	182.21
2	2500	15.5	75.1449	173.81
3	5000	15.5	75.1449	165.40
4	7500	15.5	75.1449	157.01
5	10000	13.5	65.5542	148.63
6	12500	13.5	65.5542	140.29
7	15000	13.5	65.5542	131.99
8	17500	13.5	65.5542	123.76
9	20000	13.5	65.5542	115.61
10	21000	13.5	65.5542	112.38
11	22500	13.5	65.5542	107.57
12	25000	13.5	65.5542	99.67
13	27500	13.5	65.5542	91.94
14	30000	11.5	55.9323	84.40
15	31800	11.5	55.9323	79.10
16	33600	11.5	55.9323	73.91
17	35400	11.5	55.9323	68.86
18	37200	9.5	46.2793	63.93
19	39000	9.5	46.2793	59.15
20	40800	9.5	46.2793	54.51
21	42600	9.5	46.2793	50.02
22	44400	9.5	46.2793	45.69
23	46200	7.5	36.5950	41.54
24	48000	7.5	36.5950	37.55
25	49800	7.5	36.5950	33.74
26	51600	7.5	36.5950	30.09
27	53400	7.5	36.5950	26.64
28	55200	7.5	36.5950	23.37
29	57000	5.5	26.8794	20.32
30	58800	5.5	26.8794	17.46
31	60600	5.5	26.8794	14.79
32	62400	5.5	26.8794	12.30
33	64200	5.5	26.8794	10.03
34	66000	5.5	26.8794	7.96
35	67800	5.5	26.8794	6.11
36	69600	5.5	26.8794	4.49
37	71400	5.5	26.8794	3.10
38	73200	5.5	26.8794	1.96
39	75000	5.5	26.8794	1.07
40	76800	5.5	26.8794	0.44
41	78500	5.5	26.8794	0.10
42	78600	5.5	26.8794	0.09
43	79500	5.5	26.8794	0.01
44	80000	5.5	26.8794	0.00
Factor			* 10^6	
-	m	mm	mm^3	kNm

Where W(t) = $\pi/4 * Dm^2 * t$
□ M(h) = Dynamic moment h met□
□ t = Plate thickness.
□ Dm = Mean diameter.

5.3 *Stresses in shell, Dynamic*

Bending stresses; $\Delta\sigma$ = +/- M(h) / W(t)
must be smaller than allowable stress amplitude in butt weld ($\sigma_{a,R,w}$) or allowable stre□ basic material ($\sigma_{a,R}$):

Plate	Height	t	$\Delta\sigma$	$\Delta\sigma_{a,R,w}$	$\sigma_{a,R}$
1	0	17.5	2.2	49.1	-
2	2500	15.5	2.3	49.1	-
3	5000	15.5	2.2	49.1	-
4	7500	15.5	2.1	49.1	-
5	10000	13.5	2.3	49.1	-
6	12500	13.5	2.1	49.1	-
7	15000	13.5	2.0	49.1	-
8	17500	13.5	1.9	49.1	-
9	20000	13.5	1.8	49.1	-
10	21000	13.5	1.7	-	76.4
11	22500	13.5	1.6	49.1	-
12	25000	13.5	1.5	49.1	-
13	27500	13.5	1.4	49.1	-
14	30000	11.5	1.5	49.1	-
15	31800	11.5	1.4	49.1	-
16	33600	11.5	1.3	49.1	-
17	35400	11.5	1.2	49.1	-
18	37200	9.5	1.4	49.1	-
19	39000	9.5	1.3	49.1	-
20	40800	9.5	1.2	49.1	-
21	42600	9.5	1.1	49.1	-
22	44400	9.5	1.0	49.1	-
23	46200	7.5	1.1	49.1	-
24	48000	7.5	1.0	49.1	-
25	49800	7.5	0.9	49.1	-
26	51600	7.5	0.8	49.1	-
27	53400	7.5	0.7	49.1	-
28	55200	7.5	0.6	49.1	-
29	57000	5.5	0.8	49.1	-
30	58800	5.5	0.6	49.1	-
31	60600	5.5	0.6	49.1	-
32	62400	5.5	0.5	49.1	-
33	64200	5.5	0.4	49.1	-
34	66000	5.5	0.3	49.1	-
35	67800	5.5	0.2	49.1	-
36	69600	5.5	0.2	49.1	-
37	71400	5.5	0.1	49.1	-
38	73200	5.5	0.1	49.1	-
39	75000	5.5	0.0	49.1	-
40	76800	5.5	0.0	49.1	-
41	78500	5.5	0.0	-	76.4
42	78600	5.5	0.0	49.1	-
43	79500	5.5	0.0	-	76.4
44	80000	5.5	0.0	-	76.4
-	m	mm	N/mm^2	N/mm^2	N/mm^2

5.4 *Load alternating number*

Fatigue life expectancy: ....□ ....□ ears
Natural frequency: ....□ ....□ ..=.0.4159
Critical wind speed: ....□ ....□ ...= 5.78 m/s
Reference wind speed (20% of Vm(H))..............□...............□ = 8.85 m/s
Load alternating number ....□ ....□ ...= $2*T*f*\varepsilon_0*(Vcr/V)^2 *exp(-(Vcr/V)^2)$
N = 66670000

6 Reinforcement in foundation

Anchor basket:

Number of anchors..............□ ....□ .....
Size of anchors.....................□ ....□ .....
Quality of anchors...............□ ....□ N.ISO 898-1
Diameter of anchor basket.........□ ....□ 2680 mm
Area of anchors...................□ ....□ 1470.0mm^2

The bolts are calculated to transfe□ e tension side to the foundation whereas the pressure is supposed to be transferred by the grout between the foundation and the base plate. Total area n * □ g with diameter Dc and width:

$$t = \frac{n * As}{\pi * Dc} = \ 7.682 \text{ mm}$$

Moment of resistance: $Wc = \frac{\pi}{4} * Dc^2 * t = \ 43335600 \text{ mm}^3$

6.1 Maximum forces in shell per bolt, static:

Tension P,t,st,d = 4*Mst,d/n/D - N,k/n□ 172
Pressure P,p,st,d = 4*Mst,d/n/D + N,k/n = 586716

6.2 Maximum force and stress in bolt, static:

Anchor force Pb,t,st,d =P,t,st,d = 555172
σt,d = Pb,t,st,d/As = 377.7 N/mm^2 < 576.0 N/mm^2

6.3 Maximum forces in shell per bolt, dynamic:

Tension P,t,dy,d = 4*Mst,d/n/D - N,k/n = -12026
Pressure P,p,dy,d = 4*Mst,d/n/D - N,k/n □ 18

6.4 Maximum force and stress in bolt, dynamic:

Anchor force Pb,t,dy,d = P,t,dy,d = -12026 N
$\sigma_{p,dy}$ = N,k/(n*As) = 10.7 N/mm^2
$\sigma_{t,dy}$ = P,t, m^2
$\Delta\sigma_{dy} = \sigma_{p,dy} + \sigma_{p,dy} = 2.5 \leq$ ^{2}

7 Baseplate

Between each anchor, a fin is mounted to reinforce the base plate. The base plate between two fins is considered a continuous□ ed to a vertical force from the anc e is divided upon fin and shell wi□ line dependent factor.

Distribution of forces between fin and shell

Tension static Fin: Pr,t,st,d =f * Pb,st,d = 0.7403 * Pb,st,d
Shell: Pm,t,st,d = (1 - f) * □ Pb

Pressure static Fin: Pr,t,st,d =f * P,p,st,d = 0.7403 * P,p,st,d
Shell: Pm,t,st,d = (1 - f) * □ P,p,st,d

Dynamic Δσ Fin: Pr, Δσ,dy,d =f * $\Delta\sigma_{dy}$ = 0.7403 * $\Delta\sigma_{dy}$
Shell: Pm, Δσ,dy,d □ 1 - f) * □ $_{dy}$ = 0.2597 * $\Delta\sigma_{dy}$

Resulting forces

Static: Pr,t,st,d =□10979 N
Pm,t,st,d = 144193 N

Dynamic Δσ Fin: Pr, Δσ,dy,d =2773 N
Shell: Pm, Δσ,dy,d □ 73 N

Hole in base plate................□ ....□ =.56 mm
Width of Baseplate..............□ ....□ =.180
Distance between anchors/fins.............□ ....□ = π * Dc / n =>
l =191.4 mm
Thicknes□ plate ....□ ....□ =50.- 0.0 mm
Baseplate material...............□ ....□ =S355J2
Moment o□ nce at h□ ....□ ..=.1/6 * 124.0 * t^2 =>
Wf = 51667 mm^3

7.1 Stress in baseplate, static:

Bending moment in base plate...........□ .... Mf,st,d = 1/8 * Pr,t,st,d.* l =9.8302 kNm =>
σst,d = □ .3 $N/mm^2 < 319.0\ N/mm^2$

7.2 Baseplate, dynamic:

Bending moment in base plate...........□ .... Mf,dy,d = 1/8 * Pr□Δσ,dy,d * l =9.8302 kNm =>
...............□ ....□ .... Δσ,dy,d = Mf,dy,d / Wf = 0.0 $N/mm^2 < 34.384\ N/mm^2$

Notch case: 71

7.3 Fins at base

The fins are calculated for the reduced fin force Pr:

Fin dimensions
Fin thickness.........................□ ....□ mm.
Fin width ....□ ....□ 65.mm
Fin heig ....□ ....□ 00.mm
Fin radi ....□ ....□ mm.
Fin mate□ ....□ ....□ 355J2

The fin itself has to be able to take up the tension and pressure without□ ing. It does not matter if the fin should buckle a little under pressure because that will just transfer the forces directly in to the shell through the baseplate. The part of the fin that will be subjected to the highest stresses is the part where the □ baseplate.

Stress area of fin ....□ ....□ =.ft*(fw-fr) =>
Afin = 1725 mm^2

[redacted]

Stress in fin static: $\sigma,st,d = Pr,p.st,d / Afin = 251.8 N/mm^2 \leq 338.1\ \pi \quad {}^2$

Stress in fin dynamic: $\Delta\sigma,dy,d = Pr,\Delta\sigma. \quad N/mm^2 \leq 34.384\ N/mm^2$
Notch case: 71

7.4 Fillet weld between fin and base plate:

$a1 = 8\ mm \Rightarrow$
$Aw = 2 * a1 * 115 = 1840\ mm^2$

Stresses in fillet w□ tic:

$\sigma st,d = Pr,p,st,d / Aw = 236.0 N/mm^2 < 241.2\ N/mm^2$

Filletweld, dynamic:

$\Delta\sigma,dy,d = Pr,\Delta\sigma. \quad /mm^2 \leq 19.648\ N/mm^2$

Notch case: 36*

7.5 Fillet weld between shell and base plate:

$a2 = 3\ mm \Rightarrow Aw = 2 * a2 * \pi * D / n = 1071\ mm^2/bolt$

Stresses in fillet w□ tic:

$\sigma st,d = Pm,p,st,d / Aw = 142.3\ N/mm^2 < 241.2\ N/mm^2$

Filletweld, dynamic:

$\Delta\sigma,dy,d = Pr,\Delta\sigma. \quad /mm^2 \leq 21.831\ N/mm^2$

Notch case: 45

7.6 Fillet weld between fin and shell:

$a3 = 5\ mm \Rightarrow Aw = 2 * a3 * 350 = 3500 mm^2 \Rightarrow$
$Ww = 1/6$ □ ${}^2 = 204167\ mm^3$

Stresses in fillet w□ tic:

$\tau,d = Pr,p,st.d / Aw = 124.1\ N/mm^2$
$\sigma,d = 90 * Pr,p,st,d / Ww = 181.2\ N/mm^2$
$\Sigma\sigma^2 = \sigma^2 + \tau^2 \Rightarrow$
$\Sigma\sigma,d = 228.2\ N/mm^2 < 241.2\ N/mm^2$

Fillet weld, dynamic:

$\Sigma\Delta\sigma,d = 2.9\ N/mm^2 < 19.648\ N/mm^2$

Notch case: 36*

7.7 Ring over fins:

In order t□ izontal load of the shell because of the eccentricity of the anchors, a pl 15x135 mm ring is welded on top of the fins.

Number of fins............□................□ ....□ pcs
Distance between anchors/fins ....□ ....□ .. $\pi * Dc / n \Rightarrow$
l =191.4 mm
Heigth of fin ....□ ....□ ....□ 0..mm
Distance shell – bolt........................□ ....□ mm
Ring size........□ ....□ ....□ 5mm

$Pr,p,st,d = 410979\ N$

$Po,d = Pr,p,st,d*e/h = 92470\ N$

$k = 12-31,592/n^2-39,904/n^4 = 11.98$□

[redacted]

Bending moment in reinforcement ring

Mring = Po,d * l /k = 1377367 KNm

W_{ring}= 1/6*t*b^2 = 30375 mm^3

σ = Mring/Wring =□ .3 N/mm^2 <= 319.0N/mm^2

[redacted]

[redacted]

8 Reinforcement at flue gas inlet(s), access door(s) etc.

At flue gas inlets, access doors etc. it is necessary to reinforce the shell. The dimensions of the reinforcements are determined, so that the moment of resistance□ reinforced section at minimum is equal to a :□ in the unweakened cylinder.

Flat-iron frames are named type 1 and welded circular frames type 2.

i = 0 means reinforcement at access door.

8.1 *Assumptions:*

No	Type	Height	Shell: t	Width: B	Projection	Reinfor.thickn.: T	Reinfor.: H
2	2	6000,0	16,0	800,0	100,0	40,0	222,1
3	1	7000,0	16,0	2100,0	100,0	40,0	671,8
-	**-**	**mm**	**mm**	**mm**	**mm**	**mm**	**mm**

Moment of inertia for part of shell:

$$\mathrm{Im} = \mathrm{Rm}^3 * \mathrm{t} * \left(\pi - \mathrm{u} - \sin(\mathrm{u})\cos(u) - \frac{2 * \sin^2(u)}{\pi - u} \right)$$

Moment of inertia for reinforcement:

$$\mathrm{Iv} = 2 * (1/12 * \mathrm{T} * \mathrm{H}^3 + \mathrm{T} * \mathrm{H}\square^2 + 1/12 * \mathrm{B} * \mathrm{T}^3 + \mathrm{B} * \mathrm{T} * \mathrm{e2}^2)$$

Moment of resistance for reinforced section:

$$\mathrm{Wf} = (\mathrm{Im} + \mathrm{Am} * (e_{tot} - e_{ma})^2 + \mathrm{Iv} + \mathrm{Av}(e_{tot} - e_{ver})^2)/(\mathrm{proj} + \mathrm{dia} - e_{tot})$$

8.2 *Data of cross sections*

i	u	e_{ma}	e_{ver}	e_{tot}	Im x 10^6	Iv x 10^6	Wf
2	0,360	1091,834	2488,945	1284,209	72277,508	73,049	77716064
3	0,983	768,271	2264,116	1342,079	31846,474	2020,993	85847152
-	**rad**	**mm**	**mm**	**mm**	**mm^4**	**mm^4**	**mm^3**

8.3 *Calculation of shell opposite reinforcement.*

$$\square \quad = M_I / W_{I,shell}$$

$$\square \quad {}_{I,shell\,\square} \quad = \sum I / e_{tot}$$

i	e_{tot}	$\sum$I x 10^6	$W_{I\ shell}$	σ	$\sigma_{xS.R.d}$
3	1342,079	107988,926	80463904,000	181,552	225,874
-	**Mm**	**mm^4**	**mm^3**	**N/mm^2**	**N/mm^2**

8.4 Calculation of shell at bottom reinforcement

□ = MIII /WIII,shell
□ $_{\text{till}}$ = 0,9* $\sigma_{xS,R,d}$

i	Σ	0,9* $\sigma_{xS,R,d}$	Flange
1	189,942	211,239	No
3	175,082	211,239	No
-	N/mm^2	N/mm^2	

8.5 Calculation of column:

BR = 0,78*(r*t)½
A_r = bR*t+br*tr
I_r = 1/12*tr*br^3
Sk = Hrein□
N_{st} = σI*AR
$N_{pl,d}$ = AR*fyd
$N_{ki,d}$ = π^2*E*Ir/Sk^2*γm

$$\eta\chi = \sqrt{\frac{N_{pl,d}}{N_{ki,d}}} \Rightarrow \chi$$

$$\frac{Nst}{\chi * Npl,d} <= 1$$

i	b_r	A_r	I_r x 10^6	Sk	N_{st}	$N_{pl,d}$	$N_{ki,d}$	ηχ	χ	$N_{st}/(N_{pl,d}{*}\chi)$
1	116,6	6535,9	1,021	165,0	1200,5	2085,3	74023,7	1,0	0,5	0,576
3	110,0	28630,0	1010,496	3570,0	4871,9	9134,3	156505,0	0,9	0,5	0,603
-	mm	mm	mm^4	mm	kN	kN	kN	factor	factor	

8.6 Calculation of Buckling:

$$\sigma e = \frac{\pi^2 * E}{12(1-\mu^2)} * \left(\frac{t_r}{b}\right)^2$$

σπ = σe*0,43

$$\lambda = \sqrt{\frac{f_{y,k}}{\sigma_\pi}}$$

$$\kappa = \frac{1}{\lambda^2 + 0{,}51}$$

$\sigma_{p,R,d}$ = κ*fy,k/γm

Allowabl□ $_I / \sigma_{p,R,d} < 1$

i	σe	σπ	λ	κ	$\sigma_{p,R,d}$	Proof
1	327116,2	140660,0	0,0	1,0	319,0	0,576
3	672,9	289,4	1,1	0,6	191,3	0,889
-	N/mm^2	N/mm^2	-	-	N/mm^2	-

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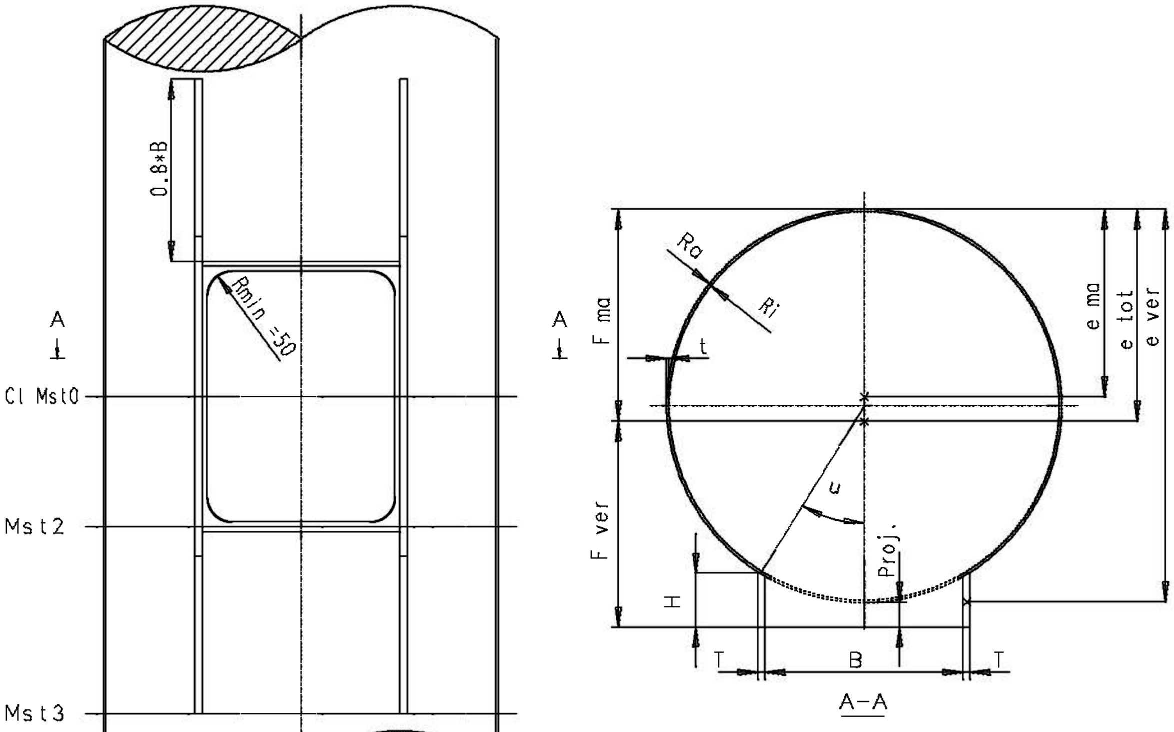

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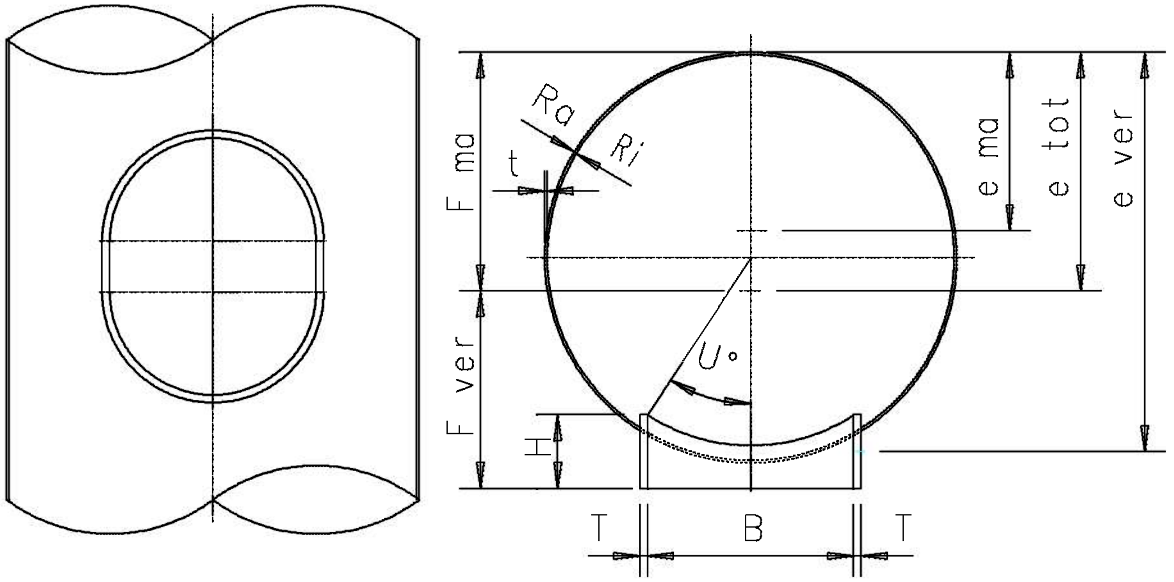
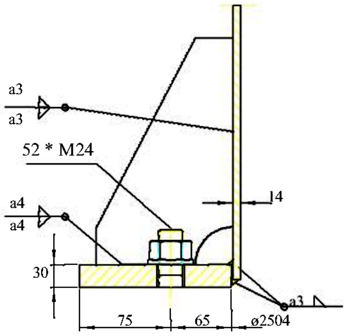


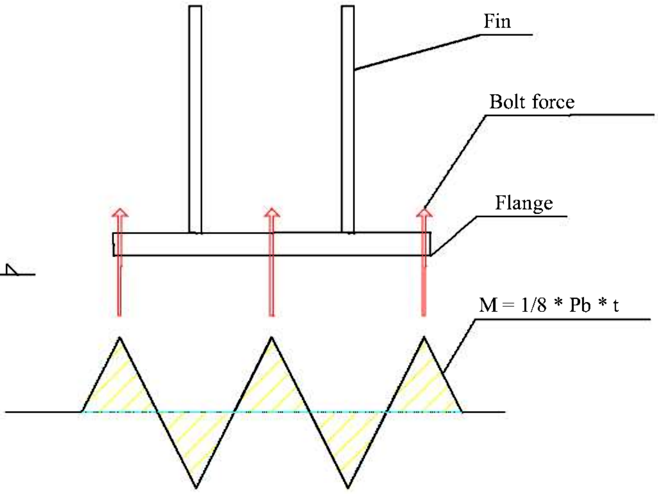
9 Flange in shell No. 1

Outer flange with fin reinforcement.

9.1 *Assumptions:*

Height above base to flange	z	= 22.50 m
Static moment, II-order	Ms	= 8925.36 kNm
Number of bolts	n	= 52 pcs.
Size of bolts	b_d	= M 24
Holes in flange for bolts	d	= 26.0 mm
Area of bolts	As	= 353 mm^2
Quality of bolts		= 10.9.
Preload moment,		
MoS2 oiled□	Mt	= 800 Nm (Garniture)
Thickness of flange	t	= 30.0 mm
Diameter of flange	Di	= 2504 mm
	Da	= 2784 mm
Diameter for bolts in flange	Dc	= 2634 mm
Distance, bolts - shell	b	= 65 mm
Width of flange	B	= 140 mm
Flange material	Flmat	= S355J2
Distance between bolts	lc	= 159,1 mm





The tota □ As is assumed to be equal to a ring with diameter Dc and width:

t = n * As / π / Dc = 2.3889 mm

Moment of resistance is then: Wc = π/4 * Dc^2 * t = 12087426 mm^3

9.2 *Stress in bolts, static:*

σst,d = □ .04 N/mm^2 < 720

Max. force in bolt,□ Pb,st,d= Pm,t,st,d = 234709 N

9.3 *Bolt, dynamic:*

Δσdy,d = Pm,t,dy,d/As = 0.0 N/mm^2 < 27.3

Max. force in bolt,□ ic Pb,dy,d= Pm,t,dy,d = 0 N

Notch case: 50*

9.4 Flange:

Between two bolts, a fin is mounted to reinforce the flange. The flange□ med to be a continuous beam submitted to a loa □ rce in the bolts. This force is divided upon fin and shell wit□ ndent factor:

Fin: Pr = f * pb= 0,744781855 * Pb
Shell: Pm = (1 - f) * Pb = 0,255218145 * Pb

With force in bolt□ :

Static: Pr = 188253,89 N
Pm = 64509,91 N
Dynamic: Pr = 0,00 N
Pm = 0,00 N

Moment of resistance at hole:

Wf = 1/ □ - d) * t□ 16800 mm3

Stresses in flange, static:

Moment: Mf = 1/8 * Pr * lc = 3744693,45 Nm =>
σf = Mf / Wf = 222,90 N/mm2 < 328.6

Stresses in flange, dynamic:

Moment: Mf = 1/8 * Pr * lc = 0,00 kNm =>
σf = Mf / Wf = 0,00 N/mm2 < 34.4

9.5 Fin welds

The welds are calculated for the reduced force of the bolts:

Static: Pr = 188253,89 N
Pm = 64509,91 N
Dynamic: Pr = 0,00 N
Pm = 0,00 N

Fin dimensions:

T	8	mm
B	125	mm
H	400	mm
R	50	mm

9.6 Fillet weld between fin and flange:

a1 = 4 mm
Aw = 2 * a1 *(125-50) 600 mm^2

Stresses in fillet w□ tic:

σ = Pr / Aw = 313,76 N/mm^2 < 338.1

Stresses in fillet w□ amic:

σ = Pr / Aw = 0,00 N/mm^2 < 21.8

9.7 Fillet weld between shell and flange:

a2 = 4 mm

Aw = 2 * a2 * π * D / n□ 1345,57 mm^2/bolt

Stresses in fillet w□ tic:

σ = Pm / Aw = 47,94 N/mm^2 $<$ 241.2

Stresses in fillet w□ amic:

σ = Pm / Aw = 0,00 N/mm^2 $<$ 24.6

9.8 Fillet weld between fin and shell

a3 = 3 mm

Aw = 2 * a3 * Lw 2100 mm^2

Ww = 1/6 * 2 * a3 * Lw^2 122500 mm^3

Stresses in fillet w□ tic:

τ = = Pr / Aw = 89,64 N/mm^2

σ = = b * Pr / Ww = 99,89 N/mm^2

$\Sigma\sigma^2$ = $s^2 + t^2$ =>

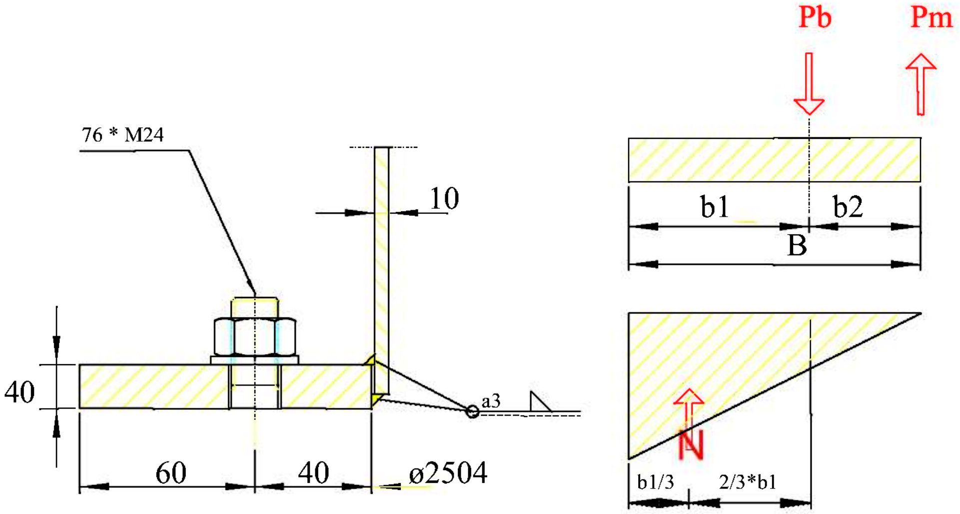
$\Sigma\sigma$ = 134,22 N/mm^2 $<$ 241.2

10 Flange in shell No. 2

Outer flange without fin reinforcement.

10.1 Assumptions:

Height above base to flange	z	= 44.40 m
Static moment, II-order	Ms	= 3578.26 kNm
Number of bolts	n	= 76 pcs.
Size of bolts	b_d	= M 24
Holes in flange for bolts	d	= 26.0 mm
Area of bolts	As	= 353 mm^2
Quality of bolts		= 10.9.
Preload moment,		
MoS2 oiled□	Mt	= 800 Nm (Garniture)
Thickness of flange	t	= 36.0 mm
Diameter of flange	Di	= 2504 mm
	Da	= 2704 mm
Diameter for bolts in flange	Dc	= 2584 mm
Distance, bolts - shell	b	= 40 mm
Width of flange	B	= 100 mm
Flange material	Flmat	= S355J2
Distance between bolts	lc	= 106.8 mm



10.2 Max. force in shell per bolt static:

Tension: Pm,t,st,d= 4 * Mst,d / n / D – N,k/n = 72576 N (static)

Pressure: Pm,p,st,d= 4 * Mst,d / n / D + N,k/n = 77846 N□ atic)

With an assumed stress distribution as shown in sketch above the bolt force will be:

Static: Pb,t,st,d $= Pm,t,st,d(1+\frac{b*1,5}{B-b})$ = 145152 N (static)

10.3 Max. force in shell per bolt dynamic:

Tension: Pm,t,dy,d= 4 * Mdy□ / D – N, tatic)

Pressure: Pm,p,dy,d= 4 * Mdy,d / n / D + N,k/n = 3595 N (static)

Δ force: Pm,Δ,dy,d= Pm,t,dy,d+ Pm,p,dy,d = 1920 N (static)

With an assumed stress distribution as shown in sketch above the bolt force will be:

Dynamic: Pb,t,dy,d $= Pm,t,dy,d(1+\frac{b*1{,}5}{B-b})$ = 0 N (dynamic)

10.4 Stresses in Bolts:

Static: σb,st,d = Pb,t,st,d / As = 411.2 N/mm^2 < 720 N/mm^2
Dynamic: Δσb,dy,d = Pb,t,dy,d / As = 0.0 N/mm^2 < 27.3 N/mm^2
Notch case: 50*

10.5 Stresses in Flange:

Moment per□ Mf = b * Pm,t,d
Moment of resistance per bolt Wf = 1/6 * (Dc*π/n – 26) * 40.0^2 =>
Wf = 21550 mm^3
Statical stresses: σf ,st,d= Mf,st,d / Wf =>
σf,st,d = 134.7 N/mm^2 < 328.6 N/mm^2
Dynamic stresses: Δσf ,dy,d= Mf,dy,d / Wf =>
Δσf,dy,d = 0.0 N ^{2} < 34.4 N/□ ^{2}
Notch case: 63

10.6 Fillet weld between shell and flange:

a = 3 mm => Aw = 2 * a * D * π / n = 828 mm^2/bolt
Stress in fillet weld, static: σst,d = Pm,p,st,d / Aw = 87.8 N/mm^2 < 241.2 N/mm^2
Dynamic: Δσst,d = Pm,Δ,dy,d /□ .4 N/mm^2 < 21.8 N/mm^2
Notch case: 45

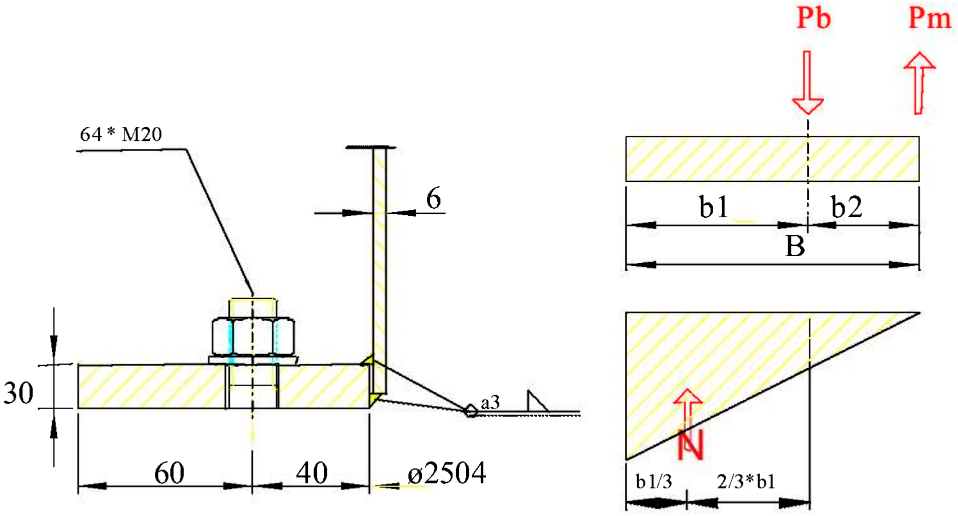
[redacted]

11 Flange in shell No. 3

Outer flange without fin reinforcement.

11.1 Assumptions:

Height above base to flange	z	= 66.00 m
Static moment, II-order	Ms	= 609.47 kNm
Number of bolts	n	= 64 pcs.
Size of bolts	b_d	= M 20
Holes in flange for bolts	d	= 22.0 mm
Area of bolts	As	= 245 mm^2
Quality of bolts		= 10.9.
Preload moment,		
MoS2 oiled□	Mt	= 450 Nm (Garniture)
Thickness of flange	t	= 30.0 mm
Diameter of flange	Di	= 2504 mm
	Da	= 2704 mm
Diameter for bolts in flange	Dc	= 2584 mm
Distance, bolts - shell	b	= 40 mm
Width of flange	B	= 100 mm
Flange material	Flmat	= S355J2
Distance between bolts	lc	= 126.8 mm



11.2 Max. force in shell per bolt static:

Tension: Pm,t,st,d= 4 * Mst,d / n / D – N,k/n = 14101 N (static)

Pressure: Pm,p,st,d= 4 * Mst,d / n / D + N,k/n = 16373 N□ atic)

With an assumed stress distribution as shown in sketch above the bolt force will be:

Static: Pb,t,st,d $= Pm,t,st,d(1+\frac{b*1{,}5}{B-b})$ = 28202 N (static)

11.3 Max. force in shell per bolt dynamic:

Tension: Pm,t,dy,d= 4 * Mdy□ / D – N, tic)

Pressure: Pm,p,dy,d= 4 * Mdy,d / n / D + N,k/n = 1335 N (static)

Δ force: Pm,Δ,dy,d= Pm,t,dy,d+ Pm,p,dy,d = 398 N (static)

With an assumed stress distribution as shown in sketch above the bolt force will be:

Dynamic: Pb,t,dy,d $= Pm,t,dy,d(1+\frac{b*1{,}5}{B-b})$ = 0 N (dynamic)

11.4 Stresses in Bolts:

Static: $\sigma b,st,d = Pb,t,st,d / As$ $= 115.1\ N/mm^2 < 720\ N/mm^2$
Dynamic: $\Delta\sigma b,dy,d = Pb,t,dy,d / As$ $= 0.0\ N/mm^2 < 27.3\ N/mm^2$
Notch case: 50*

11.5 Stresses in Flange:

Moment per□ $Mf = b * Pm,t,d$
Moment of resistance per bolt $Wf = 1/6 * (Dc*\pi/n – 22$ □ ^{2} =>
$Wf = 15726\ mm^3$
Statical stresses: $\sigma f ,st,d= Mf,st,d / Wf$ =>
$\sigma f,st,d = 35.9\ N/mm^2 < 328.6\ N/mm^2$
Dynamic stresses: $\Delta\sigma f ,dy,d= Mf,dy,d / Wf$ =>
$\Delta\sigma f,dy,d = 0.0\ N$ $^2 < 34.4\ N/$□ ^{2}
Notch case: 63

11.6 Fillet weld between shell and flange:

$a = 4\ mm$ => $Aw = 2 * a * D * \pi / n = 983\ mm^2/bolt$
Stress in fillet weld, static: $\sigma st,d = Pm,p,st,d / Aw = 14.4\ N/mm^2 < 241.2\ N/mm^2$
Dynamic: $\Delta\sigma st,d = Pm,\Delta,dy,d /$□ $.2\ N/mm^2 < 21.8\ N/mm^2$
Notch case: 45

[redacted]

12 Shell reinforcement

Acc. to EN13084-1:2007 a bending moment per meter will arise in the shell due to uneven pressure distribution:

$$Mst,d(h) = +- c_M * qst,d(z) * b^2 \text{ kNm}$$

Where □ qst,d(z) = Wind pressure acc to part 4 [kN/m^2]
b = diameter of the chimney shell [m]

The factor c_M is dependent on Reynolds No.

Reynolds No.	c_M
>1E7	0.095
≤1E7	0.125

Reynolds No. at top of chimney: ....□ ....□ 17
c_M...............□ ....□ ....□ .....

Moment of resistance per meter shell:

$$W(t) = 1/6 * 1000 * t^2 \text{ mm}^3$$

Stress in shell:

$$\sigma_{m,d} = Mst,d / W \text{ N/mm}^2$$

If σ_m > Fyd reinforcement is necessary.

i	t	z	qst,d(z)	Mst,d(z)	W(t)	σ_{md}	F_{yd}	Reinforce□
1	17,5	2,500	1,047	0,818	51041,7	24,0	328,6	No
2	15,5	5,000	1,244	0,972	40041,7	36,4	328,6	No
3	15,5	7,500	1,366	1,067	40041,7	40,0	328,6	No
4	15,5	10,000	1,455	1,137	40041,7	42,6	328,6	No
5	13,5	12,500	1,526	1,192	30375,0	58,9	338,1	No
6	13,5	15,000	1,586	1,239	30375,0	61,2	338,1	No
7	13,5	17,500	1,636	1,278	30375,0	63,1	338,1	No
8	13,5	20,000	1,681	1,313	30375,0	64,9	338,1	No
9	13,5	21,000	1,697	1,326	30375,0	65,5	338,1	No
10	13,5	22,500	1,721	1,344	30375,0	66,4	338,1	No
11	13,5	25,000	1,757	1,373	30375,0	67,8	338,1	No
12	13,5	27,500	1,790	1,398	30375,0	69,0	338,1	No
13	13,5	30,000	1,820	1,422	30375,0	70,2	338,1	No
14	11,5	31,800	1,840	1,438	22041,7	97,8	223,8	No
15	11,5	33,600	1,860	1,453	22041,7	98,9	223,8	No
16	11,5	35,400	1,878	1,467	22041,7	99,8	223,8	No
17	11,5	37,200	1,896	1,481	22041,7	100,8	223,8	No
18	9,5	39,000	1,912	1,494	15041,7	149,0	223,8	No
19	9,5	40,800	1,928	1,507	15041,7	150,2	223,8	No
20	9,5	42,600	1,944	1,519	15041,7	151,5	223,8	No
21	9,5	44,400	1,959	1,530	15041,7	152,6	223,8	No
22	9,5	46,200	1,973	1,542	15041,7	153,7	223,8	No
23	7,5	48,000	1,987	1,552	9375,0	248,4	223,8	Yes
24	7,5	49,800	2,000	1,563	9375,0	250,1	223,8	Yes

25	7,5	51,600	2,013	1,573	9375,0	251,7	223,8	Yes
26	7,5	53,400	2,026	1,583	9375,0	253,2	223,8	Yes
27	7,5	55,200	2,038	1,592	9375,0	254,8	223,8	Yes
28	7,5	57,000	2,050	1,601	9375,0	256,2	223,8	Yes
29	5,5	58,800	2,061	1,610	5041,7	479,1	223,8	Yes
30	5,5	60,600	2,072	1,619	5041,7	481,7	223,8	Yes
31	5,5	62,400	2,083	1,628	5041,7	484,2	223,8	Yes
32	5,5	64,200	2,094	1,636	5041,7	486,7	223,8	Yes
33	5,5	66,000	2,104	1,644	5041,7	489,1	223,8	Yes
34	5,5	67,800	2,114	1,652	5041,7	491,4	223,8	Yes
35	5,5	69,600	2,124	1,659	5041,7	493,7	223,8	Yes
36	5,5	71,400	2,133	1,667	5041,7	495,9	223,8	Yes
37	5,5	73,200	2,143	1,674	5041,7	498,1	223,8	Yes
38	5,5	75,000	2,152	1,681	5041,7	500,2	223,8	Yes
39	5,5	76,800	2,161	1,688	5041,7	502,3	223,8	Yes
40	5,5	78,500	2,169	1,695	5041,7	504,2	223,8	Yes
41	5,5	78,600	2,170	1,695	5041,7	504,3	223,8	Yes
42	5,5	79,500	2,174	1,698	5041,7	505,3	223,8	Yes
43	5,5	80,000	2,176	1,700	5041,7	505,9	223,8	Yes
-	**mm**	**m**	**kN/m^2**	**kNm**	**mm^3**	**N/mm^2**	**N/mm^2**	**-**

In addition to the static influence a resonance instance may occur in connection with the wind passage, which may cause chimney oscillations. For a circular cylinder with plate thickness t and diameter D the ovalling frequency is acc. to "Dynamic wind influence on structures" (H. Ruscheweyh):

$$fr = 0.492 * \sqrt{\frac{t^3 * E}{\mu_s * (1 - v^2) * b^4}} \quad Hz$$

The corresponding □ l wind speed:

$$Vcr = \frac{fr * b}{S * 2} m / s$$

where: S = 0.1800 (Strouhal-number)
D = 2500 mm
□ b = 2.500 m

In case of critical wind speed (Vcr) below the 10 min. mean wind speed □ = 29.0 * Kt * ln(z/zo), the chimney is to be supplied with reinforcements with intervals of min.:

$$a = 8 * D \quad \text{(acc.CICIND)}$$

Plate	Shell: t	Height	fr	Vcr	Vlim	Shell reinforcements	
1	17,5	2500	7,5	51,9	55,30	Yes	20,00
2	15,5	5000	6,6	45,9	55,30	Yes	20,00
3	15,5	7500	6,6	45,9	55,30	Yes	20,00
4	15,5	10000	6,6	45,9	55,30	Yes	20,00

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5	13,5	12500	5,8	40	55,30	Yes	20,00
6	13,5	15000	5,8	40	55,30	Yes	20,00
7	13,5	17500	5,8	40	55,30	Yes	20,00
8	13,5	20000	5,8	40	55,30	Yes	20,00
9	13,5	21000	5,8	40	55,30	Yes	20,00
10	13,5	22500	5,8	40	55,30	Yes	20,00
11	13,5	25000	5,8	40	55,30	Yes	20,00
12	13,5	27500	5,8	40	55,30	Yes	20,00
13	13,5	30000	5,8	40	55,30	Yes	20,00
14	11,5	31800	4,9	34,1	55,30	Yes	20,00
15	11,5	33600	4,9	34,1	55,30	Yes	20,00
16	11,5	35400	4,9	34,1	55,30	Yes	20,00
17	11,5	37200	4,9	34,1	55,30	Yes	20,00
18	9,5	39000	4,1	28,2	55,30	Yes	20,00
19	9,5	40800	4,1	28,2	55,30	Yes	20,00
20	9,5	42600	4,1	28,2	55,30	Yes	20,00
21	9,5	44400	4,1	28,2	55,30	Yes	20,00
22	9,5	46200	4,1	28,2	55,30	Yes	20,00
23	7,5	48000	3,2	22,2	55,30	Yes	20,00
24	7,5	49800	3,2	22,2	55,30	Yes	20,00
25	7,5	51600	3,2	22,2	55,30	Yes	20,00
26	7,5	53400	3,2	22,2	55,30	Yes	20,00
27	7,5	55200	3,2	22,2	55,30	Yes	20,00
28	7,5	57000	3,2	22,2	55,30	Yes	20,00
29	5,5	58800	2,3	16,3	55,30	Yes	20,00
30	5,5	60600	2,3	16,3	55,30	Yes	20,00
31	5,5	62400	2,3	16,3	55,30	Yes	20,00
32	5,5	64200	2,3	16,3	55,30	Yes	20,00
33	5,5	66000	2,3	16,3	55,30	Yes	20,00
34	5,5	67800	2,3	16,3	55,30	Yes	20,00
35	5,5	69600	2,3	16,3	55,30	Yes	20,00
36	5,5	71400	2,3	16,3	55,30	Yes	20,00
37	5,5	73200	2,3	16,3	55,30	Yes	20,00
38	5,5	75000	2,3	16,3	55,30	Yes	20,00
39	5,5	76800	2,3	16,3	55,30	Yes	20,00
40	5,5	78500	2,3	16,3	55,30	Yes	20,00
41	5,5	78600	2,3	16,3	55,30	Yes	20,00
42	5,5	79500	2,3	16,3	55,30	Yes	20,00
43	5,5	80000	2,3	16,3	55,30	Yes	20,00
-	**mm**	**m**	**Hz**	**m/s**	**m/s**	**-**	**m**

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12.1 Suggestions for reinforcements:

The reinforcements must be designed for th□ ng moment:

$$M(z) = c_M * q(z) * b^2 \text{ Nm} \Rightarrow$$
$$M = 2.5504 * a \text{ kNm}$$

If reinforcements are profiles or flange reinforcements, an effective part of 15 x shell plate thickness is included as reinforcement.

Profile	Shell diameter	Shell part	W	Max. M	Max. a	a
25.0*140	2500	13.5*202.5	142772,9688	46,9111	18,39	7,50
36.0*100	2500	9.5*142.5	91733,4375	30,1410	11,82	7,50
30.0*100	2500	5.5*82.5	63197,59375	20,7649	8,14	7,50
10.0*60	2500	7.5*112.5	11732,08691	3,9666	1,56	1,56
10.0*100	2500	7.5*112.5	28947,39063	9,7870	3,84	3,84
12.0*110	2500	7.5*112.5	39938,44922	13,5030	5,29	5,29
15.0*50	2500	7.5*112.5	12143,00977	4,1055	1,61	1,61
15.0*90	2500	7.5*112.5	33712,77734	11,3981	4,47	4,47
30.0*100	2500	7.5*112.5	71304,13281	23,4285	9,19	9,19
30.0*140	2500	7.5*112.5	129776,4688	42,6408	16,72	15,00
10.0*60	2500	5.5*82.5	10390,70801	3,5130	1,38	1,38
10.0*100	2500	5.5*82.5	25622,40625	8,6628	3,40	3,40
12.0*110	2500	5.5*82.5	35232,82813	11,9121	4,67	4,67
15.0*50	2500	5.5*82.5	10577,98828	3,5764	1,40	1,40
15.0*90	2500	5.5*82.5	29585,27539	10,0026	3,92	3,92
30.0*100	2500	5.5*82.5	63197,59375	20,7649	8,14	8,14
30.0*140	2500	5.5*82.5	117111,2969	38,4794	15,09	15,00
UNP50	2500	7.5*112.5	13021,26953	4,4024	1,73	1,73
UNP65	2500	7.5*112.5	18908,78906	6,3930	2,51	2,51
UNP80	2500	7.5*112.5	25213,58008	8,5246	3,34	3,34
UNP100	2500	7.5*112.5	34868,55469	11,7889	4,62	4,62
UNP120	2500	7.5*112.5	49429,16797	16,7118	6,55	6,55
UNP140	2500	7.5*112.5	63721,72656	21,5440	8,45	8,45
UNP160	2500	7.5*112.5	81720,94531	27,6295	10,83	10,83
UNP50	2500	5.5*82.5	13021,26953	4,4024	1,73	1,73
UNP65	2500	5.5*82.5	18908,78906	6,3930	2,51	2,51
UNP80	2500	5.5*82.5	25213,58008	8,5246	3,34	3,34
UNP100	2500	5.5*82.5	34868,55469	11,7889	4,62	4,62
UNP120	2500	5.5*82.5	49429,16797	16,7118	6,55	6,55
UNP140	2500	5.5*82.5	63721,72656	21,5440	8,45	8,45
UNP160	2500	5.5*82.5	81720,94531	27,6295	10,83	10,83
	mm	**mm**	**mm^3**	**kNm**	**m**	**m**
Disk	-	-	-	-	-	16,14

13 Deflection of shell

With a horizontal unit force P=1 placed h mm above base t□ r static□ eplacement load:

$$u = \int M0(x)*M1(x)*dx/EI(x)$$

Where
M0(x) = S□ c bending moment.
Ms = Acc to part
Md = Maximum dynamic bending moment □ dynamic ”destruction”
M1(x) = x + h – H for x > H - h
= 0 for x < H - h
x = Distance from chimney top.

With a linear moment variation between x1 and x2 the result becomes:

$$u = \frac{\frac{(x2\text{-}x3)}{3} * \frac{(M0(x1)*M1(x1) + M0(x2)*M1(x2) + (M0(x1)*M1(x2) + M0(x2)*M1(x1))}{2}}{EI(x)}$$

No	x1	x2	Shell: t	Ms	Md	u stat	u dyn
1	0	2500	18,0	11220,959	110,43	0	0
2	2500	5000	16,0	10565,447	105,34	1,51	0
3	5000	7500	16,0	9924,025	100,24	6,11	0,01
4	7500	10000	16,0	9298,706	95,16	13,78	0,01
5	10000	12500	14,0	8690,829	90,08	24,32	0,03
6	12500	15000	14,0	8101,415	85,02	37,74	0,04
7	15000	17500	14,0	7531,291	79,99	54	0,06
8	17500	20000	14,0	6981,16	75	72,93	0,08
9	20000	21000	14,0	6451,627	70,07	94,31	0,1
10	21000	22500	14,0	6247,611	68,11	103,51	0,11
11	22500	25000	14,0	5950,237	65,2	117,97	0,13
12	25000	27500	14,0	5469,121	60,41	143,72	0,16
13	27500	30000	14,0	5006,455	55,72	171,41	0,19
14	30000	31800	12,0	4562,578	51,15	200,86	0,23
15	31800	33600	12,0	4254,779	47,94	223,13	0,25
16	33600	35400	12,0	3956,97	44,8	246,31	0,28
17	35400	37200	12,0	3669,258	41,73	270,33	0,31
18	37200	39000	10,0	3391,743	38,75	295,14	0,34
19	39000	40800	10,0	3124,52	35,85	320,73	0,37
20	40800	42600	10,0	2867,682	33,04	347,12	0,4
21	42600	44400	10,0	2621,315	30,32	374,23	0,44
22	44400	46200	10,0	2385,505	27,69	402,02	0,47
23	46200	48000	8,0	2160,333	25,18	430,41	0,51
24	48000	49800	8,0	1945,878	22,76	459,42	0,55
25	49800	51600	8,0	1742,215	20,45	489,05	0,59
26	51600	53400	8,0	1549,418	18,24	519,23	0,63
27	53400	55200	8,0	1367,559	16,14	549,9	0,67
28	55200	57000	8,0	1196,705	14,17	581,01	0,71
29	57000	58800	6,0	1036,924	12,31	612,5	0,75

30	58800	60600	6,0	888,28	10,58	644,37	0,8
31	60600	62400	6.0	750,836	8,96	676,61	0,84
32	62400	64200	6.0	624,655	7,46	709,18	0,89
33	64200	66000	6,0	509,795	6.08	742	0,93
34	66000	67800	6.0	406,314	4,82	775,05	0,98
35	67800	69600	6,0	314,27	3,7	808,26	1,03
36	69600	71400	6.0	233,718	2,72	841,61	1,07
37	71400	73200	6,0	164,712	1,88	875,06	1,12
38	73200	75000	6.0	107,304	1,19	908,58	1,17
39	75000	76800	6.0	61,546	0,65	942,14	1,22
40	76800	78500	6,0	27,489	0,27	975,73	1,27
41	78500	78600	6,0	6,111	0.06	1007,47	1,31
42	78600	79500	6.0	5,201	0,05	1009,34	1,31
43	79500	80000	6,0	0,456	0,01	1026,14	1,34
-	**mm**	**mm**	**mm**	**kNm**	**kNm**	**mm**	**mm**

Max. deflection at chimney top under dynamic load:
(Total system chimney/damper):
y_{max} = 13 mm

Steelcon
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Esbjerg the 07-10-2013_Rev_A

Mateusz Bylinowski