Rev.	Date	Designer	Checker	Description
0	**28.08.2025**	**Aleksandra Czech**	**Dawid Tabor**	**First issue**
1	**01.09.2025**	**Aleksandra Czech**	**Dawid Tabor**	**New address**
2	**04.09.2025**	**Aleksandra Czech**	**Dawid Tabor**	**Correct slenderness**

Static calculation

Main dimensions of Steel Chimney

Height of the chimney H = 13,50 m
Outside shell diameter D = 1422 mm

Order No.: 441

Revision: 2

Project: Northern Combustion Systems

Esbjerg, 01.09.2025

jeremias®
ABGASTECHNIK

01623 889219 info@jeremias.com www.jeremias.UK

Unit 2 Longstoop Way, Crown Farm Industrial Estate, Forest Town, Mansfield, Notts NG19 0FQ

1 Calculation basis:

EN 1993-1-1:2005 .... General rules and rules for buildings.
EN 1991-1-4:2005 .... Wind actions.
BS EN 1991-1-4/NA .... Wind actions. National Annex
EN 1993-3-2:2006 .... Chimneys.
EN 1993-1-6:2007 Annex D .... Strength and stability of shell structures.
EN 1993-1-8:2005 .... Design of joints.
EN 1993-1-9:2005 .... Fatigue.

The chimney is calculated for the following load cases:

L1. **Max. pressure of wind**. 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 chimney represent the case – **Static load**.

- ..... No information was provided on the nearest circular object affecting wind impact on the chimney. Therefore, the axis distance to the nearest circular cross-section object was assumed to be ∞ m.
- ..... The corroded shell is calculated as corroded for strength and uncorroded for weight.
- ..... The structural and the smoke leading function are separated in an outer self-supporting shell and an inner insulated flue. Heating and corrosive attack on structural steel is excluded.
- ..... The chimney is calculated from top to threat cut in anchor bolts. Transferring the forces from the bolts to the foundation is up to the engineer that calculates the foundation.
- ..... The chimney is freestanding and self-supporting.

Design lifetime assumed to 25 years.

2 Classes and safety factors

The safety system for a chimney is covered by the reliability classes defined in EN 1993-3-2. These classes are in direct relation to the consequence class system in EN1090.

2.1 Reliabity Class

Differentiation as follows

Reliability Class	
3	Chimneys erected in strategic locations, such as nuclear power plants or in densely populated urban locations. Major chimneys in manned industrial sites where the economic and social consequences of their failure would be very high.
2	All normal chimneys at industrial sites or other locations that cannot be defined as Class 1 or Class 3.
1	Chimneys built in open countryside whose failure would not cause injury. Chimneys less than 16m high in unmanned sites.

The chosen reliability class for this chimney is: 2

Reliability class 2
Loads.. (Dead load "+" wind load)
Design temperature for shell .... 50 °C

2.2 Partial Factors

Factor type	Designation	Value	Referencing norm
Safety on wind load	γ_Q	1,4	EN 1993-3-2 for selected reliability class
Safety on dead load	γ_{Gk}	1,1	EN 1993-3-2 for selected reliability class
Safety on vortex shedding loads	$\gamma_{F,f}$	1,0	EN 1993-3-2 for selected reliability class
Safety on materials	γ_m	1,0	EN 1993-3-2 for selected reliability class
Safety on buckling	γ_{M1}	1,1	EN 1993-3-2 for selected reliability class/ EN 1993-1-6
Safety on bolts	$\gamma_{m,b}$	1,25	EN 1993-3-2 for selected reliability class/ EN 1993-1-8
Safety on materials fatigue	γ_{mf}	1,15	EN1993-1-9 Safe life low consequence

2.3 Execution class

The execution class chosen for this project is: EXC3

3 Calculation parameters

3.1 Dimensions:

Foundation level above ground h_0 .... h_0 = 0,00 m
Chimney height (upper base plate - chimney top)................................ H = 13,50 m
Chimney top level .... H_{tot} = 13,50 m
Outer diameter of structural shell .... D = 1422 mm

3.2 Materials:

Structural steel... S235JR
Anchors in foundation 8.8

Plate thickness in shell:

From	To	Pl.	Steel	Type
0.000	13500	8	S235JR	plate
mm	mm	mm	-	-

The thicknesses include an allowance of corrosion 0,35 mm.
Flues:

No.	Internal diameter	Pl.	Steel	Insulation
1	1100	2	1.4301	50
-	mm	mm	-	mm

3.3 Surface Treatment

Internal surface:
Internal corrosion allowance .... 0,35 mm

External surface:

- C4 Paint System according to contract

External corrosion allowance .... 0 mm

3.4 Allowable stresses under static load

Design temperature .... 50 degree Celsius.
Reducing factor at design temperature:

- yield stress .... Ft =1.0000
- modulus of elasticity .... Ft =1.0000

Structural steel S235JR
Anchor bolts 8.8

Allowable stresses:
t<=16mm .... Fyd = 355.0 N/mm2
16<t<=40mm .... Fyd = 345.0 N/mm2
40<t<=63mm .... Fyd = 335.0 N/mm2
- - butt weld, K-weld .... Fyd = Fyd [N/mm2] of weaker part
- - fillet weld .... Fyd = 241.2 N/mm2

Allowable stresses:
Yield stress .... Fyk = 235.0 N/mm2
Allowable stress, basic material .... Fyd = 235.0 N/mm2
- - butt weld, K-weld .... Fyd = Fyd [N/mm2] of weaker part
- - fillet weld .... Fyd = 207.8 N/mm2

Anchors, 8.8, 20°C .... Fyd = 576 N/mm2
Modulus of elasticity .... E = 210000 N/mm2

3.5 Allowable stress for fatigue

First mode:
acc. E.1.5.2.6 .... N = 10000
Cut off limit in formula (B.3) .... N = 5000000
Reference number σa .... On = 2000000
Stress amplitude acc. to (B.3) .... σ =$\Delta c*(Na/N)^{1/3}$ N/mm2

For temperature 100°C ≤ t ≤ 500°C allowable stress are as follow:

$$\Delta\,\sigma_{RT} = \frac{1300 - T}{1200} * \Delta\sigma_R$$

If the chimney is calculated with an allowance for corrosion, the corroded parts will fall 1 notch case. The corrosion will be differentiated between outside and inside corrosion. The shell will fall to notch case 71/50 no matter 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	ΔσR N/mm2
125	112	Base materials, machine flame cut.	352,5
90	80	Parts with holes that are subjected to normal forces or bending moments (baseplate)	352,5
71	63	Cross welded plates (K-welds at fins against flange/base plate)	352,5
63	56	Flanges without fins	327,5
50	45	Welded longitudinal plates (fin-shell, fin-ring)	263,2
45	40	Welds end to end with crossing plate (shell-flange, shell-base plate)	233,9
36	36	(Fin-shell without ring over fins, corroded plates, bolts)	210,5
50	50	Rolled or cut thread bolts in tension (all bolts)	292,4

3.6 Meridonal Buckle certification for shell

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

Ideal buckle stress: $\sigma_{xRc} = 0.605 * C_x * E * t/r$

Length parameter $\omega_x =$

	$\omega_x \leq 1{,}7$	$C_x = 1{,}36 - \frac{1{,}83}{\omega_x} + \frac{2{,}07}{\omega_x^2}$
$1{,}7 <$	$\omega_x \leq 0{,}5\,\frac{r}{t}$	$C_x = 1$
$0{,}5\frac{r}{t} <$	ω_x	$C_x = (C1 + \frac{0{,}2}{C_{xb}}\left[1 - 2\omega_x \frac{t}{r}\right]_x$ $(C_x \geq 0{,}6)$

where $C_{xb} = 1$ for BC2-BC2

Modulus of elasticity E
Effective wall thickness t = t – corrosion 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 $\bar{\lambda}_{xp} = \sqrt{\frac{\alpha_x}{1-\beta_x}}$
Plastic range factor $\beta_x = 0{,}60$
Interaction exponent $\eta_x = 1{,}0$
Characteristic imperfection amplitude $\Delta wk = \frac{1}{Qx}\sqrt{\frac{r}{t}}\,t$
Fabrication quality parameter $Q_x = 25$
Meridional elastic imperfection factor $\alpha_x = \frac{0{,}62}{1+1{,}91(\frac{\Delta wk}{t})^{1{,}44}}$
Safety factor $\gamma_{M1} = 1{,}1$

Reduction factor χ_x:

	$\bar{\lambda}_x \leq \bar{\lambda}_{x0}$	$\chi_x = 1$
$\bar{\lambda}_{x0} <$	$\bar{\lambda}_x < \bar{\lambda}_{xp}$	$\chi_x = 1 - \beta_x \left(\frac{\bar{\lambda}_x - \bar{\lambda}_{x0}}{\bar{\lambda}_{xp} - \bar{\lambda}_{x0}}\right)^{\eta_x}$
$\bar{\lambda}_{xp} \leq$	$\bar{\lambda}_x$	$\chi_x = \frac{\alpha_x}{\bar{\lambda}_x^2}$

Reduced, allowable buckle tension: $\sigma_{xRd} = \chi_x * f_{y,k} / \gamma_{M1}$

Steel	t	r	ℓ	0,5 r/t	ω_x	C_x	Δwk	α_x	$\bar{\lambda}_x$	$\bar{\lambda}_{xp}$	σ_{xRc}	χ_x	σ_{xRd}
S235JR	7,65	707,175	13500	46,22	183,54	0,600	2,94	0,42	0,53	1,02	824,6	0,76	161,6
-	mm	mm	mm	-	-	-	-	-	-	-	N/mm²	-	N/mm²

3.7 Allowable buckle stresses (shear)

The buckle certification will be carried out for the outer 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 - BC 2.

Ideal buckling tension	τ_{Rc}	$= 0{,}75 \cdot E \cdot C_t \cdot \sqrt{\frac{1}{\omega_\tau}} \cdot \frac{1}{r}$
Length parameter	ω_τ	$= \frac{l}{\sqrt{rt}}$
Coefficient	C_τ	$= \sqrt{1 + \frac{42}{\omega_\tau^3}}$
Shear elastic imperfection factor	α_τ	$= 0{,}65$
Pressure limit slenderness	$\bar{\lambda}_{\tau 0}$	$= 0{,}40$
Plastic limit slenderness	$\bar{\lambda}_{\tau p}$	$= \sqrt{\frac{\alpha_\tau}{1-\beta_\tau}}$
Plastic range factor	β_τ	$= 0{,}60$
Interaction exponent	η_τ	$= 1{,}0$
Modulus of elasticity	E	
Effective plate thickness	t	= t - corrosion mm
Mean radius	r	= (Da - t)/2 mm
Relative slenderness	$\bar{\lambda}_\tau$	$= \sqrt{\frac{f_{y,k}}{\sqrt{3} * \tau_{Rc}}}$
Safety factor	γ_{M1}	$= 1{,}1$

Reduction factor χ_τ:

	$\bar{\lambda}_\tau \leq \bar{\lambda}_{\tau 0}$	$\chi_\tau = 1$
$\bar{\lambda}_{\tau 0} <$	$\bar{\lambda}_\tau < \bar{\lambda}_{\tau p}$	$\chi_\tau = 1 - \beta \left(\frac{\bar{\lambda}_\tau - \bar{\lambda}_{\tau 0}}{\bar{\lambda}_{\tau p} - \bar{\lambda}_{\tau 0}}\right)^\eta$
$\bar{\lambda}_{\tau p} \leq$	$\bar{\lambda}_\tau$	$\chi_\tau = \frac{\alpha_\tau}{\bar{\lambda}_\tau^2}$

Allowable design buckling stresses: $\tau_{xRd} = \chi_\tau * f_{y,k} / (\sqrt{3} * \gamma_{M1})$

Steel	t	r	ℓ	ω_τ	C_τ	$\bar{\lambda}_{\tau p}$	$\bar{\lambda}_\tau$	τ_{Rc}	χ_τ	τ_{xRd}
S235JR	7,65	707,18	13500	183,54	1,00	1,27	1,04	125,76	0,56	69,31
-	mm	mm	mm	-	-	-	-	N/mm²	-	N/mm²

3.8 Weight of sections:

No.	Length	Hi -	Hj	Weight
1	13,50	0,00-	13,50	7800
-	m	m -	m	kg

4 Static wind load

According to BS EN 1991-1-4 the static wind load per meter of outer sheath (with safety factor):

Calculations acc. to NA to BS EN 1991-1-4:2005

The fundamental basic wind velocity before applying the altitude

	Acc. to Figure NA.1	10 minutes mean	$V_{b,map}$ =	**25,50**	m/s

The altitude factor

$$\boxed{\begin{aligned} c_{alt} &= 1 + 0{,}001 \cdot A ....for..z \le 10m \\ c_{alt} &= 1 + 0{,}001 \cdot A \cdot (10/z)^{0,2} ....for..z > 10m \end{aligned}}$$

Site data

Site altitude above mean sea level		**200**	m
Distance to sea		**40**	km
Height of the chimney base:	H_0 =	**0,00**	m
Chimney hieght	H=	**13,50**	m
Chimney diamenter	D=	**1422,00**	mm
Surface roughness:	k =	**0,0002**	m
Axis distance to neighbour chimneys:	a =	**999,00**	m
Total logarithmic decrement for gust deflection	δGust=	**0,0046**	
Logarithmic damping decrement:	δ =	**0,0246**	
Natural frequency	$n_{1,x}$ =	**6,5342**	Hz
Reference height	$z = z_s = 0{,}6 \cdot H + H_0$		
Then the reference height become	z_s=	**8,1**	m
Altitude factor	c_{alt}=	**1,209**	

The basic wind velocity acc. to NA.1

$$\boxed{v_{b,0} = v_{b,map} \cdot c_{alt}}$$

10 minutes mean	vb,0=	**30,82**	m/s

Peak velocity pressure:

N.A 2.18	Airdensity:	**1,226**	kg/m³
	q_b =	**0,58**	kN/m²
For an unsignificant oragraphy the exposure factor Figure NA.7	Ce=	**2,36**	at z_s
	$q_{p,zs}$ =	**1,38**	kN/m²

Peak wind velocity at zs:

V =	**47,39**	m/s

Pressure coefficient, C_f:

Acc to EN 1991-1-4:2005, (7.19)	$C_f =$	$C_{f,0} \times \psi_l$
Force coefficient:	$C_{f,0} =$	Figure 7.28
Reynolds number acc. 7.9.1:	Re =	v x b/υ

For instence in 8,1 **m height:**

Air density:	ρ =	**1,226**	kg/m^3
Kinematic viscocity	υ =	**1,50E-05**	m^2/s
For an unsignificant oragraphy the exposure factor Figure NA.7	Ce=	**2,66**	at top
Peak wind velocity	V(m) =	**50,23**	m/s
b(h) = m , v(**8,1**m) = **47,39** m/s	Re =	**4762156**	
Surface roughness:	k =	**0,0002**	m
Force coefficient	$C_{f,0} =$	**0,796**	
End-effect factor (7.13)	$\psi_\lambda =$	7.13	
Solidity ratio	φ =	1,00	
Slenderness	λ =	**h/b**	
	λ =	**9,49**	<70
	$\psi_\lambda =$	**0,6977**	
Pressure coefficient at top:	$C_f =$	**0,556**	
Axis distance to neighbour chimneys:	a =	**999,00**	m
a/d - ratio	a/d =	**702,53**	
Increasing factor	Fs =	**1,0000**	

Structural factor CsCd (Procedure 1 Annex B):

$$\boxed{c_s c_d = \frac{1 + 2 \cdot k_p \cdot I_v(z_s) \cdot \sqrt{B^2 + R^2}}{1 + 7 \cdot I_v(z_s)}}$$

Refence height	z_s=	**8,1**	m

According to EN 1991-1-4:2005 section 4.4

The peak factor can be found as:

$$\boxed{I_v = \frac{k_l}{c_o(z) \cdot \ln\left(\frac{z}{z_0}\right)} \quad for\ z_{min} \le z \le z_{max}}$$

The tubulence factor as recommended	k_l=	**1,0**
The orography factor	c_o=	**1,0**
Then:	$I_{v,zs}$=	**0,274**

Calculation of the background factor B^2

$$\boxed{B^2 = \frac{1}{1 + 0,9 \left(\frac{b + h}{L(ze)} \right)^{0,63}}}$$

The turbulence length

$$L(z_s) = L_t \cdot \left(\frac{z}{z_t}\right)^{\alpha}$$

Where:

$$\alpha = 0{,}67 + 0{,}05\ln(z_0)$$

For country terrain zo is taken as 0,05

	α=	**0,520**	
The reference scale	L_t=	**300**	m
The reference height	z_t=	**200**	m
	L(z)=	**56,58**	m

The background factor becomes: B^2= **0,7201**

Calculation of the tubulence response factor R^2

$$R^2 = \frac{\pi^2}{2.\delta} \cdot S_L(z_s, n_{1,x}) \cdot R_h(\eta_h) R_b(\eta_b)$$

Total logarithmic decrement for gust deflection δ= **0,0246**

The power density function

$$S_L(z,n) = \frac{6{,}8 \cdot f_L(z,n)}{(1 + 10{,}2 \cdot f_L(z,n))^{5/3}}$$

The non-dimensional frequency

$$f_L(z_s, n_{1,x}) = \frac{n_{1,x}.L(z)}{v_m(z)}$$

Figure NA.3 Values of $c_r(z_s)$	c_r=	**0,999**
	$v_m(z_s)$=	**30,79**
	$f_L(z_s, n_{1,x})$=	**12,009**
Spectral density becomes	$S_L(z_s, n_{1,x})$=	**0,027**

The size reduction function

$$R_s(h) = \frac{1}{\eta_h} - \frac{1}{2.\eta_h^2}(1 - e^{-2\eta_h})$$

$$R_s(b) = \frac{1}{\eta_b} - \frac{1}{2.\eta_b^2}(1 - e^{-2\eta_b})$$

Where:

$$\eta_h = \frac{4{,}6.h}{L(z_s)} \cdot f_L(z_s, n_{1,x})$$

= **13,179**

$$\eta_b = \frac{4{,}6.b}{L(z_s)} \cdot f_L(z_s, n_{1,x})$$

= **1,388**

	Rh=	**0,073**
	Rb=	**0,48**
According to EN 1991-1-4:2005 Annex E expression B.6	R^2=	**0,186**

The peak factor K_p

$$\boxed{K_p = \sqrt{2 \cdot \ln(\nu \cdot T)} + \frac{0,6}{\sqrt{2 \cdot \ln(\nu \cdot T)}}}$$

T= **600** sec

The up-crossing frequency

$$\boxed{\nu = n_{1,x} \cdot \sqrt{\frac{R^2}{B^2 + R^2}}}$$

	υ=	**0,386**
	K_p=	**3,48**
The structural factor	**c_sc_d=**	**0,965**

Discrete ancillaries

From	To	Discrete Components	$C_{f.D}$	$Area_{.D}$	Weight
-	-	-	-	-	-
mm	mm	-	-	mm2	kg

Linear ancillaries

From	To	Linear Components	$C_{f.L}$	$Area_{.L}$	Weight
-	-	-	-	-	-
mm	mm	-	-	mm2	kg/m

Wind load is composed of 3 components

Static wind load from chimney shaft :

$$Fw_{ch}(h) = 1{,}35 * qp(h) * b(h) * C_f \text{ kN/m}$$

Static wind load from discrete ancillaries:

$$Fw_1(h) = 1{,}35 * qp(h) * C_{f.D} * Area_{.D} \text{ kN/m}$$

Static wind load from Linear ancillaries:

$$Fw_2(h) = 1{,}35 * qp(h) * C_{f.L} * Area_{.L} \text{ kN/m}$$

Total static wind load:

$$Fw_{tot}(h) = Fw_{ch}(h) + Fw_1(h) + Fw_2(h)$$

No.	From	To	CsCd * γ_Q	qp(h)	b(h)	Cf	$Fw_{,ch}(z)$	$Fw_{,1}(z)$	$Fw_{,2}(z)$	$Fw_{,Tot}(z)$
1	0	150	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
2	150	350	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
3	350	500	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
4	500	1200	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
5	1200	1800	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
6	1800	2000	1,35	0,796	1422	0,542	0,83	0,00	0,00	0,83
7	2000	3000	1,35	0,953	1422	0,546	1,00	0,00	0,00	1,00
8	3000	3600	1,35	1,064	1422	0,548	1,12	0,00	0,00	1,12
9	3600	3850	1,35	1,064	1422	0,548	1,12	0,00	0,00	1,12
10	3850	4000	1,35	1,064	1422	0,548	1,12	0,00	0,00	1,12
11	4000	4800	1,35	1,150	1422	0,550	1,21	0,00	0,00	1,21
12	4800	5000	1,35	1,150	1422	0,550	1,21	0,00	0,00	1,21
13	5000	5400	1,35	1,220	1422	0,551	1,29	0,00	0,00	1,29
14	5400	5500	1,35	1,220	1422	0,551	1,29	0,00	0,00	1,29
15	5500	5800	1,35	1,220	1422	0,551	1,29	0,00	0,00	1,29
16	5800	6000	1,35	1,220	1422	0,551	1,29	0,00	0,00	1,29
17	6000	6500	1,35	1,279	1422	0,552	1,36	0,00	0,00	1,36
18	6500	6800	1,35	1,279	1422	0,552	1,36	0,00	0,00	1,36
19	6800	7000	1,35	1,279	1422	0,552	1,36	0,00	0,00	1,36
20	7000	7200	1,35	1,331	1422	0,553	1,41	0,00	0,00	1,41
21	7200	7600	1,35	1,331	1422	0,553	1,41	0,00	0,00	1,41
22	7600	8000	1,35	1,331	1422	0,553	1,41	0,00	0,00	1,41
23	8000	8500	1,35	1,376	1422	0,553	1,46	0,00	0,00	1,46
24	8500	9000	1,35	1,376	1422	0,553	1,46	0,00	0,00	1,46
25	9000	9500	1,35	1,417	1422	0,554	1,51	0,00	0,00	1,51
26	9500	10000	1,35	1,417	1422	0,554	1,51	0,00	0,00	1,51
27	10000	11000	1,35	1,454	1422	0,554	1,55	0,00	0,00	1,55
28	11000	12000	1,35	1,487	1422	0,555	1,59	0,00	0,00	1,59
29	12000	13500	1,35	1,547	1422	0,556	1,65	0,00	0,00	1,65
30	13500	13500	1,35	1,547	1422	0,556	1,65	0,00	0,00	1,65
-	mm	mm	-	kN/m2	mm	-	kN/m	kN/m	kN/m	kN/m

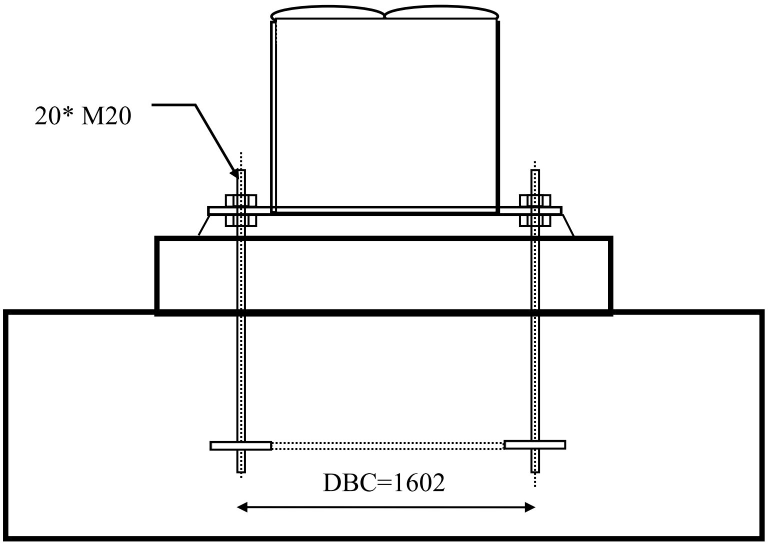
AVANTEA STEEL SOLUTIONS	**5 Foundation Loads** **(free-standing chimney)**	**Order No:** 441 **Project:** Northern Combustion Systems **Date:** 01.09.2025 **Sign:** Aleksandra Czech

Characteristic values, without safety factors! Acc. EN 1993-3-2:2006

Chimney: H = 13,50 m, Do = 1422 mm

Reactions:

Dead load:	N=	77,19	kN
Max. wind, lateral force at the base:	Qs=	12,60	kN
Max. wind, bending moment at base:	Ms=	95,04	kNm



6 Data for cross-section, cutting forces, static Wind

For each plate-section calculation are carried out as:

	$A(t)$	$= \pi * D * t(\text{area})$
	$W(t)$	$= \frac{\pi}{4} * Dm^2 * t(\text{moment of resistance})$
	N(h)	= Normal force z meter above base. γf = 1,1
	Q(h)	= Shear force z meter above base, incl. γf = 1,4
	M(h)	= Bending moment z meter above base incl γf = 1,4
Where	t	= corroded thickness of plate
	Dm(h)	= mean diameter at considered height h.

II. Moment of order	M "	= (1 + e2/8) * M = 1,0011* M
Where	ε	$= H * \sqrt{N(0)/(E * I)}$ = 0,0931

No.	From	To	t	A(t)	W(t)	N(z)	Q(z)	M(z)	M"(z)
1	0	150	7,65	33,991	12,019	84,91	17,64	132,92	133,06
2	150	350	7,65	33,991	12,019	84,08	17,51	130,28	130,42
3	350	500	7,65	33,991	12,019	82,97	17,35	126,80	126,93
4	500	1200	7,65	33,991	12,019	82,13	17,22	124,20	124,34
5	1200	1800	7,65	33,991	12,019	78,24	16,64	112,35	112,47
6	1800	2000	7,65	33,991	12,019	74,91	16,15	102,51	102,62
7	2000	3000	7,65	33,991	12,019	63,92	15,98	99,30	99,41
8	3000	3600	7,65	33,991	12,019	58,36	14,98	83,82	83,91
9	3600	3850	7,65	33,991	12,019	55,03	14,31	75,03	75,12
10	3850	4000	7,65	33,991	12,019	53,64	14,03	71,49	71,57
11	4000	4800	7,65	33,991	12,019	52,80	13,86	69,40	69,48
12	4800	5000	7,65	33,991	12,019	48,36	12,89	58,70	58,76
13	5000	5400	7,65	33,991	12,019	47,25	12,65	56,15	56,21
14	5400	5500	7,65	33,991	12,019	45,02	12,13	51,19	51,25
15	5500	5800	7,65	33,991	12,019	44,47	12,00	49,99	50,04
16	5800	6000	7,65	33,991	12,019	42,80	11,61	46,44	46,50
17	6000	6500	7,65	33,991	12,019	41,69	11,35	44,15	44,20
18	6500	6800	7,65	33,991	12,019	38,91	10,68	38,64	38,68
19	6800	7000	7,65	33,991	12,019	37,24	10,27	35,50	35,54
20	7000	7200	7,65	33,991	12,019	36,13	10,00	33,47	33,51
21	7200	7600	7,65	33,991	12,019	35,02	9,71	31,50	31,54
22	7600	8000	7,65	33,991	12,019	32,79	9,15	27,73	27,76
23	8000	8500	7,65	33,991	12,019	30,57	8,58	24,18	24,21
24	8500	9000	7,65	33,991	12,019	27,79	7,85	20,07	20,10
25	9000	9500	7,65	33,991	12,019	25,01	7,12	16,33	16,35
26	9500	10000	7,65	33,991	12,019	22,23	6,37	12,96	12,97
27	10000	11000	7,65	33,991	12,019	19,45	5,61	9,97	9,98
28	11000	12000	7,65	33,991	12,019	13,90	4,06	5,13	5,13
29	12000	13500	7,65	33,991	12,019	8,34	2,48	1,86	1,86
30	13500	13500	7,65	33,991	12,019	0,00	0,00	0,00	0,00
Faktor				x 10^3	x 10^6				
-	mm	mm	mm	mm2	mm3	kN	kN	kNm	kNm

7 Stresses in shell under static load Wind

Normal- and bending stresses, incl. safety factor :

$\sigma d = N(h) / A(t) + M''(h) / W(t)$

Allowable stresses in welds: .... $\sigma_{w,R,d}$.

Allowable buckle stresses: .... $\sigma_{xS,R,d}$.

Shear stresses: .... $\tau = Q(h)/\pi * r * t_{corr}$

Allowable buckle stresses (shear) .... $\tau_{S,R,D}$

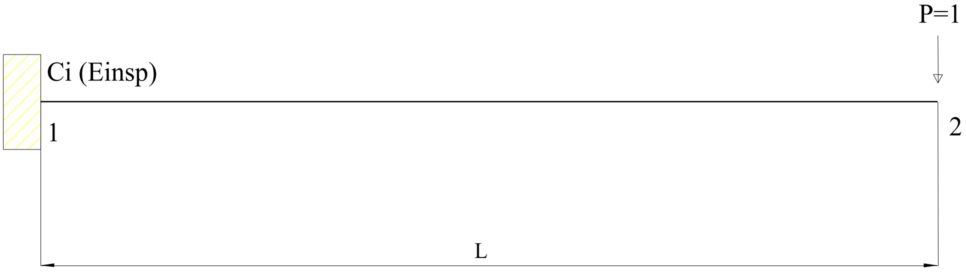
Proof check for combined membrane stresses $= (\frac{\sigma}{\sigma_{S,R,D}})^{1,25} + (\frac{\tau}{\tau_{s,R,D}})^2 \leq 1$

No.	From	To	t	σ	τ	σw,R,d	σxS,R,d	τS,R,D	Utilisation
1	0	150	7,65	13,6	1,03	207,8	161,61	69,31	0,045
2	150	350	7,65	13,3	1,02	207,8	161,61	69,31	0,044
3	350	500	7,65	13,0	1,02	207,8	161,61	69,31	0,043
4	500	1200	7,65	12,8	1,01	207,8	161,61	69,31	0,042
5	1200	1800	7,65	11,7	0,97	207,8	161,61	69,31	0,038
6	1800	2000	7,65	10,7	0,94	207,8	161,61	69,31	0,034
7	2000	3000	7,65	10,2	0,94	207,8	161,61	69,31	0,032
8	3000	3600	7,65	8,7	0,88	207,8	161,61	69,31	0,026
9	3600	3850	7,65	7,9	0,84	207,8	161,61	69,31	0,023
10	3850	4000	7,65	7,5	0,82	207,8	161,61	69,31	0,022
11	4000	4800	7,65	7,3	0,81	207,8	161,61	69,31	0,021
12	4800	5000	7,65	6,3	0,75	207,8	161,61	69,31	0,017
13	5000	5400	7,65	6,1	0,74	207,8	161,61	69,31	0,017
14	5400	5500	7,65	5,6	0,71	207,8	161,61	69,31	0,015
15	5500	5800	7,65	5,5	0,70	207,8	161,61	69,31	0,015
16	5800	6000	7,65	5,1	0,68	207,8	161,61	69,31	0,013
17	6000	6500	7,65	4,9	0,66	207,8	161,61	69,31	0,013
18	6500	6800	7,65	4,4	0,62	207,8	161,61	69,31	0,011
19	6800	7000	7,65	4,1	0,60	207,8	161,61	69,31	0,010
20	7000	7200	7,65	3,9	0,59	207,8	161,61	69,31	0,009
21	7200	7600	7,65	3,7	0,57	207,8	161,61	69,31	0,009
22	7600	8000	7,65	3,3	0,54	207,8	161,61	69,31	0,008
23	8000	8500	7,65	2,9	0,50	207,8	161,61	69,31	0,007
24	8500	9000	7,65	2,5	0,46	207,8	161,61	69,31	0,005
25	9000	9500	7,65	2,1	0,42	207,8	161,61	69,31	0,004
26	9500	10000	7,65	1,7	0,37	207,8	161,61	69,31	0,003
27	10000	11000	7,65	1,4	0,33	207,8	161,61	69,31	0,003
28	11000	12000	7,65	0,8	0,24	207,8	161,61	69,31	0,001
29	12000	13500	7,65	0,4	0,14	207,8	161,61	69,31	0,001
30	13500	13500	7,65	0,0	0,00	207,8	161,61	69,31	0,000
-	mm	mm	mm	N/mm2	N/mm2	N/mm2	N/mm2	N/mm2	-

8 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 is determined 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 = distance from point 2
Ix = π/8 * Dm^3 * t
Dm = mean diameter

In sections with constant plate thickness t:

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

x1 [mm]	x2 [mm]	t [mm]	Jx *10^6[mm4]	Ue *10^-6[mm]	Σue *10^-6 [mm]
0	13500	8	292919460,083	459,469	459,469

Total deflection: ....U = 459,47 * 10^{-6} mm =>
Elasticity at top:..C = 2176426,2 N/m
Addition for liner(s): ....C = 0 N/m

Elasticity at top:..ΣC = 2176426,2 N/m

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

$$M = \int \Phi(n,p)^2 * g(x) * dx$$

Where:

Φ(n,p) = (4*p*n + 2*n^2 – 4*n^3/3 + n^4/3) / (1 + 4*p)
Φ(n,p) = Assumed curve of deflection.
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) = 79,6 kg/m

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 [mm]	x2 [mm]	t [mm]	g(x) [kg/m]	M [kg]	ΣM [kg]
0	13500	8	372,48	1291,20	1291,20

Mass of oscillation: .... M = 1291,2 kg
Additional mass at top:.. m = 0,0 kg
Total mass of oscillation: .... ΣM = 1291,2 kg

Reduced mass per meter.

$$\Sigma m = \frac{\Sigma M}{\int \Phi(n, p)^2 \, dn} = \Sigma M / (0.2568 * H)$$

$$\Sigma m = 372{,}45 \text{ kg/m}$$

With elasticity and mass of oscillation known:

$$f = \frac{1}{2\pi} * \sqrt{\frac{\Sigma C}{\Sigma M}} = 6{,}5342 \text{ Hz}$$

9 Wind-excited oscillations:

9.1 Calculation of 1st mode:

At the rear of a cylinder in 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:

$$V_{cr} = f * d / S \text{ m/s}$$

Where:	f	= natural frequency of number i mode
	f	= 6,5342 Hz
	d	= 1,42 m
	S	= Strouhal's number for cylinders:
	S	= 0,180

Strouhals number for cylinder is varying acc. to axis distance to neighbour chimnys, a:

	a	≈ 999,00 m
a / d - ratio	a/d	= 702,53

Vcrit = 51,62 m/s > 1.25 * $v_{m.Lj}$
1.25 * $v_{m.Lj}$ = 36,56 m/s

According to (E.1.2) EN 1991-1-4 examination of cross-to-wind oscillation is not necessary.

10 Foundation anchoring

Anchor basket:

Number of bolts .... n = 20
Size of bolts.. M20
Quality of bolts... 8.8
Diameter for bolts in flange .... Dc = 1602 mm
Cross section of bolt... As = 245 mm2

The reinforcement is considered as a group of bolts under action of bending moment
Total area n*As is equal to a ring with diameter Dc and width:

$$t = \frac{n * As}{\pi * Dc} = \ 0{,}97 \text{ mm}$$

Moment of resistance is then: $$Wc = \frac{\pi}{4} * Dc^2 * t = \ 1962450 \text{ mm}^3$$

10.1 Stresses in bolt, static:

σ = M(0)/Wc – N/(n*As) = 52,05 N/mm2 < 576,0 N/mm2

Max. force in bolt, static Pb = σ * As = 12752,48 N

11 Baseplate

Between each anchor, a gusset is mounted to reinforce the base plate. The base plate between two gussets is considered a continuous beam submitted to a vertical force from the anchor bolt.

Static: Pb = 8810,06 N

Hole in baseplate	d	= 24 mm
Width of base plate	b	= 178 mm
Distance between anchors/fins	l	$= \pi * Dc / n =>$
	l	= 251,6 mm
Thickness of base plate	t	= 15 mm
Moment of resistance at hole	Wf	$= 1/6 * 154 * t^2 =>$
	Wf	$= 5850,00\ mm^3$

11.1 Stress in baseplate, static:

Bending moment of baseplate	Mf	= 1/8 * Pb * l =277,12 kNm =>
	σ	$= Mf / Wf = 47,37\ N/mm^2 < 355 N/mm^2$

11.2 Gussets at baseplate

The gussets are calculated for the reduced force in the anchors Pr and Pm. The forces were determined by multiplying the forces in the anchors by a correction factor:

Gusset: Pr = f * Pb = 0,691 *Pb
Shell: Pm = (1 - f) * Pb = 0,309 *Pb

For anchor bolt force:

Static: Pr = 8810,06 N
Pm = 3942,42 N

Thickness of gusset: t = 8 mm

11.3 Weld between gusset and baseplate – fillet weld:

a1 = 3 mm =>
$Aw = 2 * a1 * 115 = 690\ mm^2$

Stress in fillet welds, static:

$\sigma = Pr / Aw = 12,77\ N/mm^2 < 207,8\ N/mm^2$

11.4 Weld between shell and baseplate – fillet weld:

$a2 = 3\ mm => Aw = 2 * a2 * \pi * D/n = 1343,97\ mm^2$/Anchor

Stresses in fillet welds, static:

$\sigma = Pm/Aw = 2,93\ N/mm^2 < 207,8\ N/mm^2$

11.5 Weld between gusset and shell – fillet weld:

$a3 = 3\ mm => Aw = 2 * a3 * 350 = 2100\ mm^2 =>$
$Ww = 1/6 * 2 * a3 * 350^2 = 122500,00\ mm^3$

Stresses in fillet welds, static:

$\tau = Pr / Aw = 4,20\ N/mm^2$
$\sigma = 90 * Pr / Ww = 6,47\ N/mm^2$
$\Sigma\sigma^2 = \sigma^2 + \tau^2 =>$
$\Sigma\sigma = 7,71\ N/mm^2 < 207,8\ N/mm^2$

11.6 Ring over fins

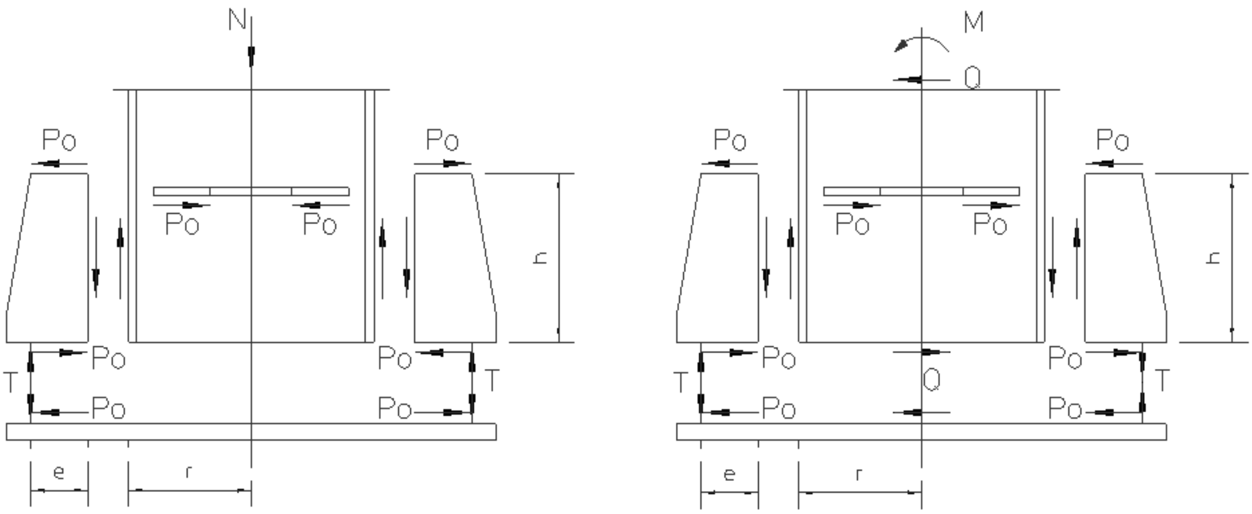
In order to reduce the horizontal load of the shell because of the eccentricity of the anchors, a pl 10x135 mm ring is welded on top of the fins.

Number of ribs .... n = 20 pcs
Distance between anchors/ribs .... l = π * Dc / n =>
l =223 mm
Height of fin .... h = 400 mm
Distance shell – bolt .... e =90 mm
Ring Size .... 10x135 mm

Pr =	= 20850,69 N
Po= Pr*e/h	= 4691,41 N
K = 12-31,592/N2-39,904/n4	= 11,92

Bending moment in reinforcement ring

M_{ring} = po * l/k	= 0,09 kNm
W_{ring} = 1/6*t*b2	= 30375 mm^3
$\sigma = M_{ring}/W_{ring}$	= 2,89 N/mm^2 <= 275 N/mm^2



.

12 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 of the reinforced section at minimum is equal to a section in the unweakened cylinder.
Flat-iron frames are named type 1 and welded circular frames type 2.
i = 0 means reinforcement at access door.

12.1 Assumptions

i	Type	Height	Shell t	Width B	Projection	Frame
1	1	3000	7,65	1260	100	20 x 481
2	1	1200	7,65	400	100	20 x 129
-	-	mm	mm	mm	mm	mm mm

Moment of inertia for part of shell:

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

$$\mathrm{Rm} = R_a - 0{,}5 * t$$

Moment of inertia for reinforcement:

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

Moment of resistance for reinforced section:

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

Am = cross section area of shell (with opening)
Av = cross section area of reinforcement
Proj = projection
dia = outside shell diameter
R_a = external shell radius

12.2 Data of cross section

i	u	e_{ma}	e_{ver}	e_{tot}	I_m x 10^{-6}	I_v x 10^{-6}	W_f
1	1,15	413	1281	812	2101530337,80	371928317,50	14531982,31
2	0,31	645	1458	760	6669065034,10	7107314,90	12590988,85
-	rad	mm	mm	mm	mm^4	mm^4	mm^3

12.3 Calculation IVS103

IVS 103 4.1.2. Calculation of shell opposite reinforcement.

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

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

i	e_{tot}	$\sum I$ x 10^{-6}	$W_{I\ shell}$	σ	$\sigma_{xS.R.d}$
1	812	10316,1	12702799,72	8,00	149,31
2	760	9596,2	12629172,26	11,06	149,31
-	mm	mm^4	mm^3	N/mm^2	N/mm^2

IVS 103 4.1.3. Calculation of shell at buttom reinforcement.

$\sigma \quad = MIII / WIII,shell$
$\sigma allowable \quad = 0{,}9 * \sigma_{xS,R,d}$

i	σ	$0,9^* \sigma_{xS,R,d}$	Flange
1	8,7	134,4	NO
2	11,7	134,4	NO
-	N/mm^2	N/mm^2	

IVS 103 5.1.1 Calculation of column

$B_R = 0,78^*(R_a^*t)^{0,5}$
$A_r = H^*T+B_R^*t$
$I_r = 1/12^*T^*H^3$
$S_k = Hr^*½^*B$
$N_{st} = \sigma_I^*A_r$
$N_{pl,d} = A_r^*f_{yd}$
$N_{ki,d} = \pi^2{}^*E^*I_r/S_k{}^2{}^*\gamma_m$

$$\bar{\lambda}_K = \sqrt{\frac{N_{pl,d}}{N_{ki,d}}} \Rightarrow \kappa$$

$\gamma_m = 1,1$

$$\frac{N_{st}}{\kappa * N_{pl,d}} <= 1$$

i	b_r	A_r	I_r x 10^{-6}	Sk	N_{st}	$N_{pl,d}$	$N_{ki,d}$	$\bar{\lambda}_K$	κ	$N_{st}/(N_{pl,d}{*}\kappa)$
1	481,4	10068,53	185,964	2030	72160	3157857	85028306	0,19	0,517	0,023
2	128,7	3014,25	3,554	800	33408	643953	10462174	0,25	0,543	0,053
-	mm	mm	mm^4	mm	N	N	N	factor	factor	

B_R = proportional shell part
A_r = cross-sectional area of frame
H = frame width
T = frame thickness
R_a = external shell radius
t = shell thickness
Hr = height between plates (opening height)
B = width of reinforcement
S_k = buckling length
σ_I = Stress in the extreme fiber

IVS 103 5.1.2 Calculation of Buckling

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

$$\sigma\pi = \sigma e * 0,43$$

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

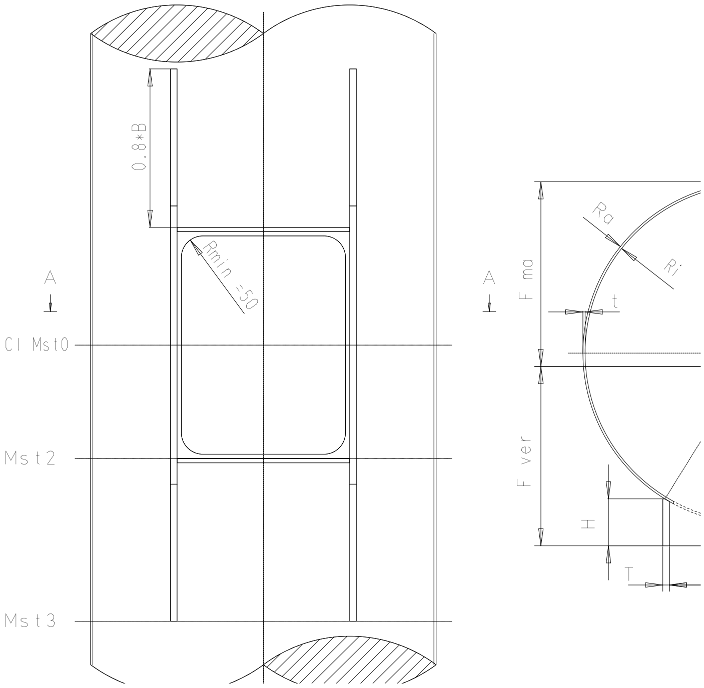
$$\kappa = \frac{1}{\lambda^2 + 0,51}$$

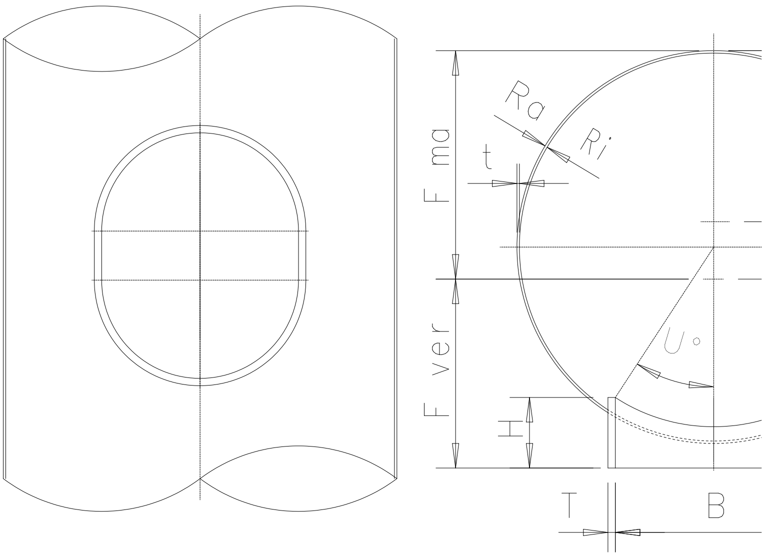
$$\sigma_{p,R,d} = \kappa * fy,k/\gamma m$$

Allowable Buckling: $\sigma_I / \sigma_{p,R,d} < 1$

i	σe	$\sigma\pi$	λ	κ	$\sigma_{p,R,d}$	$\sigma_I / \sigma_{p,R,d}$
1	327,57	140,85	1,57	0,338	105,98	0,07
2	4582,88	1970,64	0,35	1,589	339,51	0,03
-	N/mm^2	N/mm^2	-	-	N/mm^2	-

IVS calculations . Guidelines met - (OK)





13 Shell reinforcement

According to 13084-1:2007, the cylindrical sheath is affected by a static, bill-wise torque that per meter of mantle is:

Mst,d(h) = +- c_M * qst,d(z) * b^2 kNm

Where qst,d(z) = windshield pressure [kN/m^2]
b = cutting diameter [m]

The factor c_M depends on the Reynolds number.

Reynolds speech	c_M
>1E7	0.095
≤1E7	0.125

Reynolds number at the chimney top 2486576
c_M..0,1232

Resistance torque for the coat per meter:

W(t) = 1/6 * 1000 * t^2 mm^3

Tensions in the shell:

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

If σm > Fyd the shell must be reinforced.

No.	From	To	t	q(s) x CsCd	M(z)	W(z)	σ(z)	fyd	
1	0	150	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
2	150	350	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
3	350	500	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
4	500	1200	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
5	1200	1800	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
6	1800	2000	7,65	0,877154	0,310038186	9753,75	31,79	235	No.
7	2000	3000	7,65	1,049454	0,370939133	9753,75	38,03	235	No.
8	3000	3600	7,65	1,171703	0,414149043	9753,75	42,46	235	No.
9	3600	3850	7,65	1,171703	0,414149043	9753,75	42,46	235	No.
10	3850	4000	7,65	1,171703	0,414041921	9753,75	42,45	235	No.
11	4000	4800	7,65	1,266526	0,446734835	9753,75	45,80	235	No.
12	4800	5000	7,65	1,266526	0,44654916	9753,75	45,78	235	No.
13	5000	5400	7,65	1,344002	0,473490642	9753,75	48,54	235	No.
14	5400	5500	7,65	1,344002	0,473400555	9753,75	48,54	235	No.
15	5500	5800	7,65	1,344002	0,473138311	9753,75	48,51	235	No.
16	5800	6000	7,65	1,344002	0,472969743	9753,75	48,49	235	No.
17	6000	6500	7,65	1,409508	0,495600604	9753,75	50,81	235	No.
18	6500	6800	7,65	1,409508	0,495360775	9753,75	50,79	235	No.
19	6800	7000	7,65	1,409508	0,495205781	9753,75	50,77	235	No.
20	7000	7200	7,65	1,466251	0,514984137	9753,75	52,80	235	No.
21	7200	7600	7,65	1,466251	0,514680033	9753,75	52,77	235	No.
22	7600	8000	7,65	1,466251	0,514389089	9753,75	52,74	235	No.
23	8000	8500	7,65	1,516302	0,531589185	9753,75	54,50	235	No.
24	8500	9000	7,65	1,516302	0,531247687	9753,75	54,47	235	No.
25	9000	9500	7,65	1,561075	0,546598446	9753,75	56,04	235	No.
26	9500	10000	7,65	1,561075	0,546277428	9753,75	56,01	235	No.
27	10000	11000	7,65	1,601576	0,559831179	9753,75	57,40	235	No.
28	11000	12000	7,65	1,638551	0,572168942	9753,75	58,66	235	No.
29	12000	13500	7,65	1,704056	0,594203116	9753,75	60,92	235	No.

30	13500	13500	7,65	1,704056	0,594203116	9753,75	60,92	235	No.
-	mm		mm	kN/m2	kNm	mm3	N/mm2	N/mm2	-

In addition to the static impact, the wind when crossing around the cylinder will bring the circular cross-section into ring oscillations. The own frequency according to EN 1991-1-4 for a ring with the thickness t and diameter D is:

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

and the critical wind speed corresponding to this is:

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

where: St = 0,180 (Strouhal number)
b = 1422,00 mm

For critical wind speeds Less than 10-min. medium wind speed V(z) = * Kt * ln(z/zo), the shell is reinforced with intervals of min.:

a = 8*d (CICIND commentaries 2010 C3.5.24)

No.	t	Diameter	Height	ms	N1	Vkrit	1,25*Vm	Reinforcement	a
-	m	m	m	kg/m2	Hz	m/s	m/s	-	m
1	0,00765	1,422	0,00	60,0525	10,0921	39,86	9,27	No	-
2	0,00765	1,422	0,15	60,0525	10,0921	39,86	15,32	No	-
3	0,00765	1,422	0,35	60,0525	10,0921	39,86	17,86	No	-
4	0,00765	1,422	0,50	60,0525	10,0921	39,86	24,11	No	-
5	0,00765	1,422	1,20	60,0525	10,0921	39,86	27,00	No	-
6	0,00765	1,422	1,80	60,0525	10,0921	39,86	27,76	No	-
7	0,00765	1,422	2,00	60,0525	10,0921	39,86	30,65	No	-
8	0,00765	1,422	3,00	60,0525	10,0921	39,86	31,95	No	-
9	0,00765	1,422	3,60	60,0525	10,0921	39,86	32,43	No	-
10	0,00765	1,422	3,85	60,0525	10,0921	39,86	32,70	No	-
11	0,00765	1,422	4,00	60,0525	10,0921	39,86	34,00	No	-
12	0,00765	1,422	4,80	60,0525	10,0921	39,86	34,29	No	-
13	0,00765	1,422	5,00	60,0525	10,0921	39,86	34,84	No	-
14	0,00765	1,422	5,40	60,0525	10,0921	39,86	34,97	No	-
15	0,00765	1,422	5,50	60,0525	10,0921	39,86	35,35	No	-
16	0,00765	1,422	5,80	60,0525	10,0921	39,86	35,59	No	-
17	0,00765	1,422	6,00	60,0525	10,0921	39,86	36,17	No	-
18	0,00765	1,422	6,50	60,0525	10,0921	39,86	36,49	No	-
19	0,00765	1,422	6,80	60,0525	10,0921	39,86	36,69	No	-
20	0,00765	1,422	7,00	60,0525	10,0921	39,86	36,89	No	-
21	0,00765	1,422	7,20	60,0525	10,0921	39,86	37,28	No	-
22	0,00765	1,422	7,60	60,0525	10,0921	39,86	37,65	No	-
23	0,00765	1,422	8,00	60,0525	10,0921	39,86	38,08	No	-
24	0,00765	1,422	8,50	60,0525	10,0921	39,86	38,49	No	-
25	0,00765	1,422	9,00	60,0525	10,0921	39,86	38,87	No	-
26	0,00765	1,422	9,50	60,0525	10,0921	39,86	39,24	No	-
27	0,00765	1,422	10,00	60,0525	10,0921	39,86	39,92	Yes	6,85
28	0,00765	1,422	11,00	60,0525	10,0921	39,86	40,54	Yes	6,85
29	0,00765	1,422	12,00	60,0525	10,0921	39,86	41,38	Yes	6,85
30	0,00765	1,422	13,50	60,0525	10,0921	39,86	41,38	Yes	6,85

14 Deflection of shell

With a horizontal unit force P=1 placed h mm above base the deflection under static wind pressure or replacement load:

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

Where M0(x) = static or dynamic moment

Mstat = acc. point 4.

Mdyn = Calculated for replacement loads

plat = Clat * 1.25/2 * $Vcrit^2$ * D [N/m]

(Operating length Lj = 6.0 * D

M1(x) = x + h – H for x > H – h

= 0 for x < H – h

x = Distance from chimney bottom.

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	t	Mstat	Ustat
1	13500	13500	8	0,00	2,5
2	12000	13500	8	1,33	2,1
3	11000	12000	8	3,67	1,9
4	10000	11000	8	7,13	1,7
5	9500	10000	8	9,27	1,5
6	9000	9500	8	11,68	1,4
7	8500	9000	8	14,35	1,3
8	8000	8500	8	17,29	1,2
9	7600	8000	8	19,83	1,1
10	7200	7600	8	22,53	1,0
11	7000	7200	8	23,94	0,9
12	6800	7000	8	25,38	0,9
13	6500	6800	8	27,63	0,8
14	6000	6500	8	31,57	0,7
15	5800	6000	8	33,21	0,7
16	5500	5800	8	35,74	0,6
17	5400	5500	8	36,61	0,6
18	5000	5400	8	40,15	0,5
19	4800	5000	8	41,97	0,5
20	4000	4800	8	49,63	0,4
21	3850	4000	8	51,12	0,3
22	3600	3850	8	53,65	0,3
23	3000	3600	8	59,94	0,0
24	2000	3000	8	71,01	0,0
25	1800	2000	8	73,30	0,0
26	1200	1800	8	80,34	0,0
27	500	1200	8	88,81	0,0

28	350	500	8	90,67	0,0
29	150	350	8	93,16	0,0
30	0	150	8	95,04	0,0
-	mm	mm	mm	kNm	mm

Max. allowable deflection at chimney top under static load:
(total system chimney/damper system):
Max. y = H/50 => y = 270,0 mm

Esbjerg, 04.09.2025

Aleksandra Czech