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EN 1993-3-2 (2006) (English): Eurocode 3: Design of steel structures - Part 3-2: Towers, masts and chimneys – Chimneys [Authority: The European Union Per Regulation 305/2011, Directive 98/34/EC, Directive 2004/18/EC]

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Eurocode 3 - Design of steel structures - Part 3-2: Towers, masts and chimneys - Chimneys

Eurocode 3 - Calcul des structures en acier - Partie 3-2: Tours, mâts et cheminées - Cheminées

Eurocode 3 - Bemessung und Konstruktion von Stahlbauten - Teil 3-2: Türme, Maste und Schornsteine - Schornsteine

This European Standard was approved by CEN on 13 January 2006.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Central Secretariat has the same status as the official versions.

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Contents

Foreword

This European Standard EN 1993-3-2, Eurocode 3: Design of steel structures: Part 3-2 Towers, masts and chimneys – Chimneys, has been prepared by Technical Committee CEN/TC250 « Structural Eurocodes », the Secretariat of which is held by BSI. CEN/TC250 is responsible for all Structural Eurocodes.

This European Standard shall be given the status of a National Standard, either by publication of an identical text or by endorsement, at the latest by April 2007 and conflicting National Standards shall be withdrawn at latest by March 2010.

This Eurocode supersedes ENV 1993-3-2.

According to the CEN-CENELEC Internal Regulations, the National Standard Organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

National Annex for EN 1993-3-2

This standard gives alternative procedures, values and recommendations for classes with notes indicating where national choices may have to be made. Therefore the National Standard implementing EN 1993-3-2 should have a National Annex containing all Nationally Determined Parameters to be used for the design of steel structures to be constructed in the relevant country.

National choice is allowed in EN 1993-3-2 through paragraphs:

- 2.3.3.1(1)
- 2.3.3.5(1)
- 2.6(1)
- 4.2(1)
- 5.1(1)
- 5.2.1(3)
- 6.1(1)P
- 6.2.1(6)
- 6.4.1(1)
- 6.4.2(1)
- 6.4.3(2)
- 7.2(1)
- 7.2(2)
- 9.1(3)
- 9.1(4)
- 9.5(1)
- A.1(1)
- A.2(1) (2 places)
- C.2(1)

1 General

1.1 Scope

(1) This Part 3.2 of EN 1993 applies to the structural design of vertical steel chimneys of circular or conical section. It covers chimneys that are cantilevered, supported at intermediate levels or guyed.

(2) The provisions in this Part supplement those given in Part 1.1 of EN 1993.

(3) This Part 3.2 is concerned only with the requirement for resistance (strength, stability and fatigue) of steel chimneys.

NOTE: In this context (i.e. resistance) the term chimney refers to:

a) chimney structures

b) the steel cylindrical elements of towers

c) the steel cylindrical shafts of guyed masts

(4) For provisions concerning aspects, such as chemical attack, thermo-dynamical performance or thermal insulation see EN 13084-1. For the design of liners see EN 13084-6.

(5) Foundations in reinforced concrete for steel chimneys are covered in EN 1992 and EN 1997. See also 4.7 and 5.4 of EN 13084-1.

(6) Wind loads are specified in EN 1991-1-4.

NOTE: Procedures for the wind response of guyed chimneys are given in annex B of EN 1993-3-1.

(7) This Part does not cover special provisions for seismic design, which are given in EN 1998-6. See also 5.2.4.1 of EN 13084-1.

(8) Provisions for the guys and their attachments are given in EN 1993-3-1 and EN 1993-1-11.

(9) For the execution of steel chimneys, reference should be made to EN 1090, Part 2 and EN 13084-1.

NOTE: Execution is covered to the extent that is necessary to indicate the quality of the construction materials and products that should be used and the standard of workmanship on site needed to comply with the assumptions of the design rules.

(10) The following subjects are dealt with in EN 1993-3-2:

Section 1: General

Section 2: Basis of design

Section 3: Materials

Section 4: Durability

Section 5: Structural analysis

Section 6: Ultimate limit states

Section 7: Serviceability limit states

Section 8: Design assisted by testing

Section 9: Fatigue

1.2 Normative references

(1) The following normative documents contain provisions which, through references in this text, constitute provisions of this European standard. For dated references, subsequent amendments to or revisions of any of these publications do not apply. However, parties to agreements based on this European standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references the latest edition of the normative document referred to applies.

EN 1090	*Execution of steel structures and aluminium structures*
EN 10025	*Hot rolled products of non-alloy structural steels. Technical delivery conditions*
EN 10088	*Stainless steels*
EN 13084-1	*Free standing industrial chimneys – Part 1 : General Requirements*
EN ISO 5817	*Welding - Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded) - Quality levels for imperfections*

1.3 Assumptions

(1) See 1.3 of EN 1993-1-1.

1.4 Distinction between principles and application rules

(1) See 1.4 of EN 1993-1-1.

1.5 Terms and definitions

(1) The terms and definitions that are defined in EN 1990 for common use in the Structural Eurocodes apply to this Part 3.2 of EN 1993.

(2) Supplementary to Part 1 of EN 1993, for the purposes of this Part 3.2, the following definitions apply. Definitions used for chimney structures are shown in Figure 1.1.

1.5.1
chimney
Vertical construction works or building components that conduct waste gases, or other flue gases, supply or exhaust air to the atmosphere.

1.5.2
self-supported chimney
A chimney whose supporting shaft is not connected with any other construction above the base level.

1.5.3
guyed chimney
A chimney whose supporting shaft is held in place by guys at one or more height levels.

1.5.4
single-wall chimney
A chimney whose structural shell also conducts the flue gases. It may be fitted by thermal insulation and/or internal lining.

1.5.5
double-wall chimney
A chimney consisting of an outer steel structural shell and one inner liner which carries the flue gases.

1.5.6
multi-flue chimney
A group of two or more chimneys structurally interconnected or a group of two or more liners within a structural shell.

1.5.7
liner
The structural element (membrane) of the lining system, contained within the structural shell.

1.5.8
lining system
Total system, if any, which separates the flue gases from the structural shell. This comprises a liner and its supports, the space between the liner and structural shell and insulation, where existing.

1.5.9
structural shell
The main load-bearing steel structure of the chimney, excluding any flanges.

1.5.10
aerodynamic device
A device fitted to the chimney to reduce vortex excitation without increasing the structural damping.

1.5.11
damping device
A device fitted to the chimney to reduce vortex excited oscillations by increasing the structural damping.

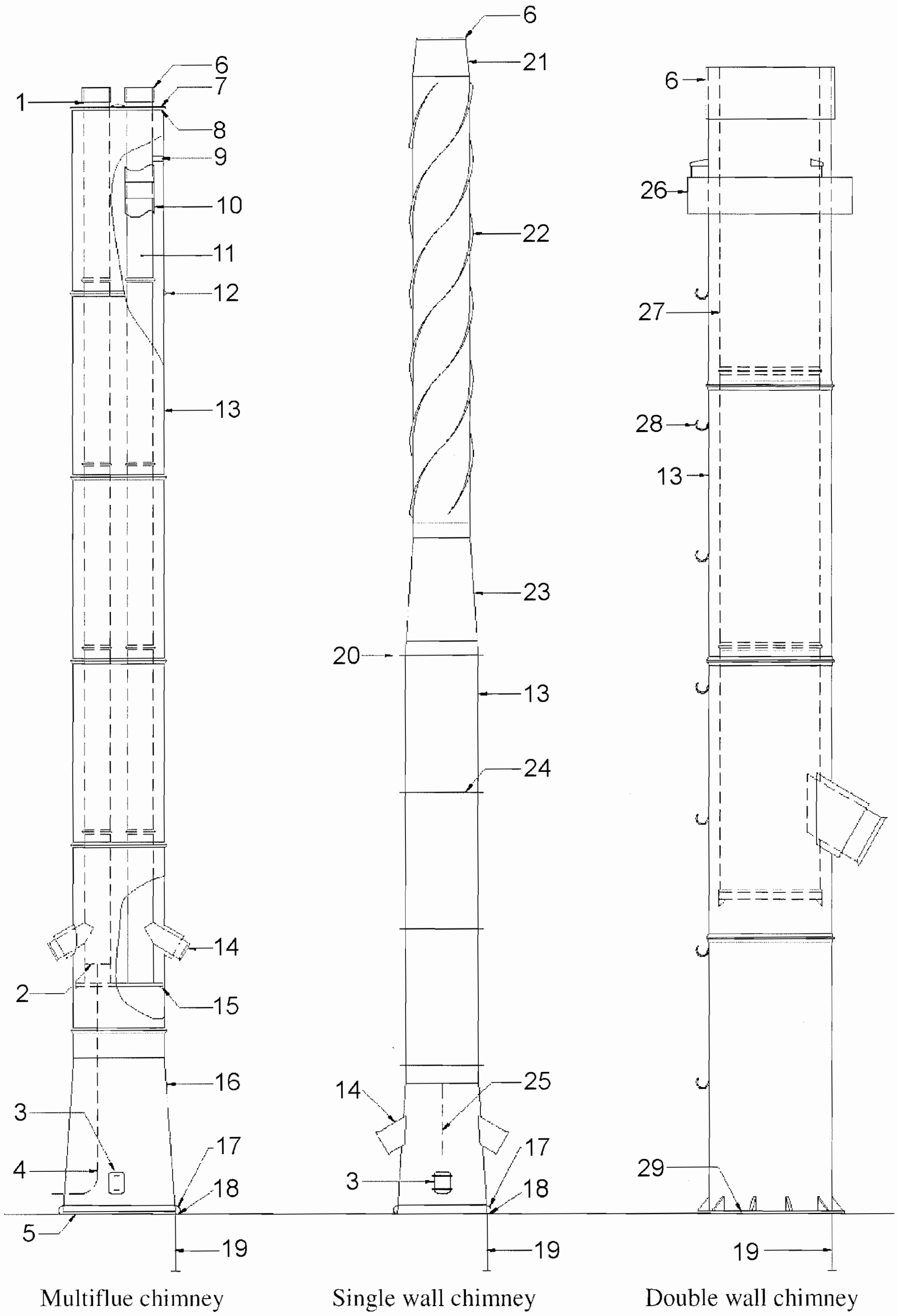
1.5.12
spoiler
A device attached to the surface of a chimney with the objective of reducing cross wind response.

1.5.13
helical strakes, shrouds or slats
Devices fitted to the outer surface of the chimney to reduce cross wind response.

1.5.14
base plate
A horizontal plate fixed to the base of a chimney.

1.5.15
anchor bolt
A bolt for the connection of the chimney to the foundation.

1.5.16
stiffening rings
Horizontal members to prevent ovalling and to hold the chimney shell round during fabrication and transport. Horizontal members to provide stiffeners at cut outs and openings or possibly at changes in slope of the structural shell.



1 Cravat
2 Tundish
3 Access door
4 Drain pipe
5 Base or bearing plate
6 Cope hood
7 Cap plate
8 Cope angle
9 Lateral supports
10 Mineral wool insulation
11 Liners
12 Jointing flange
13 Structural shell
14 Inlet
15 Liner base
16 Base cone
17 Compression ring
18 Base stool
19 Anchor bolts
20 Possible stiffening ring
21 Top cone
22 Helical aerodynamic stabilizers
23 Intermediate cone
24 Jointing flange
25 Splitter plate
26 Damping device
27 Liner
28 Access hooks
29 Base plate

Figure 1.1 Definitions used for Chimneys

1.6 Symbols used in Part 3.2 of Eurocode 3

(1) In addition to those given in EN 1993-1-1 the following main symbols are used.

c corrosion allowance
N number of cycles
b diameter
d bolt diameter

h height
m slope
t time
w wind pressure

ref reference
crit critical value
ext external
F load
f fatigue
int internal
lat lateral (cross wind)
top top
R rupture
Temp temperature

λ equivalence factor
η factor to account for second order effects

(2) Further symbols are defined where they first occur.

2 Basis of design

2.1 Requirements

2.1.1 Basic Requirements

(1) See EN 1993-1-1.

(2)P A chimney shall be designed so that provided it is properly constructed and maintained it is capable of satisfying the fundamental requirements specified in EN 1990 and in EN 13084-1.

(3) The structural design of guyed chimneys should be in accordance with the relevant clauses of EN 1993-3-1 as well as this Part.

2.1.2 Reliability management

(1) Different levels of reliability may be adopted for the ultimate limit states verifications for chimneys, depending on the possible economic and social consequences of their collapse.

NOTE: For the definition of different levels of reliability see Annex A.

2.2 Principles of limit state design

(1) See 2.2 of EN 1993-1-1.

2.3 Actions and environmental influences

2.3.1 General

(1)P The general requirements of section 4 of EN 1990 shall be satisfied.

(2) The strength and stability of chimneys should be verified for the actions described in 2.3.2 and 2.3.3.

2.3.2 Permanent actions

(1) In calculating self-weight, the full thickness of steelwork should be considered, with no loss due to corrosion.

(2) The permanent actions should include the estimated weight of all permanent structures and other elements, including fittings, insulation, dust loads, clinging ash, coatings and other loads. The weight of the chimney and its lining should be determined according to EN 1991-1-1 taking account of long-term effects of fluids or moisture on the density of linings if relevant.

2.3.3 Variable actions

2.3.3.1 Imposed loads

(1) Imposed loads should be applied on platforms and railings.

NOTE 1: The National Annex may give information on imposed loads on platforms and railings. The following characteristic values of imposed loads are recommended:

- Imposed loads on platforms: **2,0 kN/m²** (see also EN 13084-1) ... (2.1a)
- Horizontal loads on railings: **0,5 kN/m** ... (2.1b)

NOTE 2: These loads may be assumed to act in the absence of other climatic loads.

2.3.3.2 Wind actions

(1) Wind action should be taken from EN 1991-1-4.

(2) Wind loads should be applied on the external surfaces of a chimney as a whole and on accessory components, for example a ladder. Besides the drag forces due to the gusty wind acting in general in the wind direction, forces due to vortex shedding that cause cross wind vibrations of a chimney should be considered.

NOTE: For guyed chimneys see also Annex B to EN 1993-3-1.

(3) Other wind actions, for instance due to uneven wind pressure distribution (ovalling) or interference effects, should be taken into account if the relevant criteria are exceeded, see 5.2.1.

(4) Actions caused by interference galloping or classical galloping should be assessed according to EN 1991-1-4.

(5) If chimneys are predicted to be subject to excessive wind vibrations, measures may be taken to reduce these in the design, or by installation of damping devices, see Annex B.

2.3.3.3 Internal pressures

(1) If events are possible that may lead to abnormal under-pressure or to over-pressure, these cases should be treated as accidental loads.

NOTE: The under-pressure may be determined, for example, from the gas flow velocity, the gas density, the total resistance to flow and the ambient conditions, see EN 13084-1, Annex A.

2.3.3.4 Thermal actions

(1) The thermal action may be composed of a temperature uniformly distributed over the structure and differential temperature action caused by meteorological and operational effects including those arising from an imperfect gas flow.

(2) For meteorological thermal actions see EN 1991-1-5.

(3) Temperatures from operational effects and due to imperfect gas flow, should also be taken into account, see EN 13084-1 and EN 13084-6.

2.3.3.5 Ice loads

(1) For chimneys that are likely to be subject to ice loading, the appropriate ice thicknesses, densities and distributions should be determined.

NOTE 1: The National Annex may give further information on ice loading.

NOTE 2: See also 2.3.2 of EN 1993-3-1.

2.3.3.6 Seismic actions

(1) Seismic actions should be determined from EN 1998-6. See also EN 13084-1.

2.3.3.7 Fire

(1) The risk of a fire inside a chimney should be considered.

NOTE: Chimney fires may be caused by ignition of:

- unburned fuel carried over the associated boiler or furnace;
- unburned hydrocarbon carryover following a furnace tube rupture;
- soot and sulphur deposits; and
- any deposits, for example from textile industry, grease or condensates.

(2) The load bearing structure should not fail due to fire action, and any other parts near the chimney should not be heated to their ignition temperature. If there is a risk of fire, appropriate fire proofing should be provided. See EN 13084-6 and EN 13084-7.

2.3.3.8 Chemical actions

(1) For chemical actions see EN 13084-1.

2.4 Ultimate limit state verifications

(1) For design values of actions and combination of actions see EN 1990.

(2) In addition to ultimate limit state and to fatigue assessment limiting amplitudes in the serviceability limit state (see Section 7) may be relevant for design.

NOTE: For partial factors for ultimate limit states see Annex A.

2.5 Geometrical data

(1) The stiffnesses and strengths of the structural parts should be determined with nominal geometrical data taking account of both corrosion allowances or temperature effects if relevant, see sections 3 and 5.

2.6 Durability

(1) Durability should be satisfied by complying with the fatigue assessment (see section 9) and appropriate choice of the calculated shell thickness (see 4) and/or by appropriate corrosion protection. See also section 4 of EN 1993-1-1.

NOTE: The National Annex may give information on the design service life of the structure. A service life of 30 years is recommended.

3 Materials

3.1 General

(1) See EN 1993-1-1, EN 1993-1-3 and EN 1993-1-4.

3.2 Structural steels

3.2.1 Material properties

(1) Due account should be taken of the variation of mechanical properties of the steels due to ambient and operational temperatures, see 3.2.2(1).

(2) For temperatures exceeding 400°C the effects of temperature creep should be considered to avoid creep rupture.

(3) For toughness requirements of structural steels see EN 1993-1-10.

3.2.2 Mechanical properties for structural carbon steels

(1) For the mechanical properties of structural carbon steels S 235, S 275, S 355, S 420, S 460 and for weathering steel S 235, S 275, S 355 see EN 1993-1-1. For properties at higher temperatures see EN 13084-7.

3.2.3 Mechanical properties of stainless steels

(1) For the mechanical properties related to stainless steels see EN 1993-1-4 valid for temperature up to 400°C. For properties at higher temperatures see EN 10088 and EN 13084-7.

3.3 Connections

(1) For connection material, welding consumables, etc., see EN 1993-1-8.

4 Durability

4.1 Allowance for corrosion

(1) When allowance for corrosion is made for exposed surfaces, the calculations for the resistance and fatigue should be based on the corroded thickness of the steel, unless the uncorroded thickness produces more unfavourable stress conditions.

(2) Allowance for corrosion should be the sum of external (c_{ext}) and internal allowances (c_{int}) as given below. Where relevant these allowances should be applied in all or part of each 10 year period.

(3) This total allowance should be added to the thickness needed to satisfy the requirements for strength and stability of the members.

4.2 External corrosion allowance

(1) External corrosion allowance should be appropriate to the environmental conditions.

NOTE: The National Annex may give values for the external allowance c_{ext}. For normal environment the values in Table 4.1 are recommended.

Table 4.1 External corrosion allowance (c_{ext})

Protection system	Exposure time	
	First 10 years	Each additional 10 years period
painted carbon steel (with no planned programme for repainting)	0	1 mm
painted carbon steel (with a planned programme for repainting)	0	0 mm
painted carbon steel protected by insulation and waterproof cladding	0	1 mm
unprotected carbon steel	1,5 mm	1 mm
unprotected weathering steel (see (3))	0,5 mm	0,3 mm
unprotected stainless steel	0	0
unprotected inner surface of the structural shell and unprotected outer surface of the liner in a double skin or multi-flue chimney (for carbon or weathering steel)	0,2mm	0,1mm

(2) The external corrosion allowances only apply to the top 5*b* of the chimney, where *b* is the external diameter of the chimney. When a chimney is sited in an aggressive environment, caused by industrial pollution, nearby chimneys or close proximity to the sea, consideration should be given to increasing the allowances or taking protective measures.

(3) The following measures should be taken:

a) all connections should be designed to eliminate or minimise moisture retention. For example orientation of members, edge and pitch distance, etc., should be taken into consideration, or detailed protection of these connections should be provided;

b) vegetation at the ground line should be maintained clear of the structure; and

c) direct embedment or foundation attachments should be coated to minimize the potential for corrosion due to contact with soil and exposure to constant moisture.

(4) If weathering steel is used the measures set out in (3) should be adopted.

4.3 Internal corrosion allowance

(1) Values of internal corrosion allowance (c_{int}) for steel are given in EN 13084-7.

5 Structural analysis

5.1 Modelling of the chimney for determining action effects

(1) Generally for ultimate limit state verifications of the chimney, possible composite action between the structural shell and the liner should be disregarded. Restraints of the liner that may adversely affect the safety of the shell should however be taken into account.

NOTE: Damping effects from interaction of the structural shell and the liner may be taken into account. The National Annex may give further information.

(2) The strength and stability of the liner should then be assessed with due regard to the deformations imposed from the structural shell.

(3) Due regard should be given to the temperature effects on the stiffness and strength of the steels used in the chimney structure.

(4) In calculating the stiffness of the chimney the corroded thickness of the shell should be adopted unless the uncorroded thickness produces more onerous stress conditions. Due account of both the external and internal corrosion should be considered in accordance with 4.2 and 4.3.

5.2 Calculation of internal stress resultants and stresses

5.2.1 Analysis of the structural shell

(1) For the calculation of stress resultants and stresses in the structural shell see EN 1993-1-6.

(2) In general, linear shell analysis (LA), either by analytical tools or by finite elements, may be used.

NOTE: Rules and formulae for LA analysis of cylindrical and conical shells are given in EN 1993-1-6.

(3) For unstiffened vertical circular cylindrical shells the membrane stresses from external actions may be determined from membrane theory, treating the cylinder as a global beam, where shell bending effects can be neglected, apart from the circumferential bending moments due to non-uniform wind pressure distribution around circumference:

NOTE: The criteria for neglecting shell effects may be given in the National Annex. The recommended criteria are as follows:

$$\ell / r_m \geq 0{,}14 r_m / t + 10 \qquad \text{... (5.1)}$$

where ℓ is the total height

r_m is the medium radius of the shell (i.e. in the middle of the plate)

t is the corroded plate thickness

The circumferential bending moments per unit length may be approximately determined from:

$$m_y = 0{,}5 r_m^2 w_e \qquad \text{... (5.2)}$$

where w_e is the wind pressure, acting on the external surface of a structure, determined from 5.1 of EN 1991-1-4 taking z as the height of the chimney.

Circumferential bending moments due to wind pressure (for basic wind velocities up to 25m/sec (see EN 1991-1-4) may be neglected in unstiffened cylindrical shells where:

$$r_m / t \leq 160 \qquad \text{... (5.3)}$$

For ring-stiffened cylindrical shells and for assemblies of ring-stiffened cylindrical and conical shells the membrane stresses may, independent of the ℓ / r_m - and r_m/t-ratios, be determined from membrane theory treating the structure as a global beam. Shell bending effects may be neglected, provided that the following conditions are fulfilled:

- ring stiffeners provided to carry wind pressure should be designed for the circumferential bending moments
- ring stiffeners provided at the intersections between cylinders and cones should be designed for the equilibrium forces resulting from deviating the meridional membrane forces.

The stress resultants and stresses resulting from the above calculations should be used for both the strength verification, see 6.2.1, and the shell buckling verification, see 6.2.2.

5.2.2 Imperfections

(1) Horizontal imperfections of self-supporting cantilevered chimneys should be allowed for by assuming a lateral deviation, Δ in [m], from the vertical at the top of:

$$\Delta = \frac{h}{500}\sqrt{1+\frac{50}{h}} \qquad \text{... (5.4)}$$

where h is the total height of the chimney in [m].

(2) Local imperfections of the structural shell are included in the strength formulae for the buckling resistance given in EN 1993-1-6 and need not be allowed for in the global analysis.

NOTE: See also relevant geometrical tolerances in Annex E.

(3) Member imperfections of other members of the chimney for members with axial compression should be considered in accordance with 5.3 of EN 1993-1-1.

5.2.3 Global analysis

(1) When the structural shell is calculated as a beam, see 5.2.1, it may be calculated using global first order beam theory, when:

$$\frac{N_b}{N_{crit}} \leq 0{,}10 \qquad \text{... (5.5)}$$

where N_b is the design value of the total vertical load, at the foot of the shell

N_{crit} is the elastic critical value for failure, at the foot of the shell (see EN 1993-1-6)

(2) When the structural shell is calculated as beam, see 5.2.1, and global second order theory has to be applied, the second order bending moments, M_b' for the beam may be approximately determined from the first order moment, M_b, from:

$$M_b' = M_b\left(1+\frac{\eta^2}{8}\right) \qquad \text{... (5.6)}$$

with $$\eta = h\sqrt{\left(\frac{N_b}{EI}\right)} \qquad \text{... (5.7)}$$

where h is the total height of the shell

EI is the bending stiffness at the foot of the shell

(3) This simplified method may only be applied when:

$$\eta \leq 0{,}8; \text{ and} \quad \dots (5.8a)$$

$$\frac{N_{top}}{N_b} \leq 0{,}10 \quad \dots (5.8b)$$

where $N_{\rm top}$ is the design value of the total vertical load at the top of the shell.

6 Ultimate limit states

6.1 General

(1)P The partial factor γ_M shall be taken as follows:

- resistance of structural elements or members related to the yield strength f_y, when no global or local buckling occurs — γ_{M0}
- resistance of structural elements or members related to the yield strength f_y, where global or local buckling is considered — γ_{M1}
- resistance of structural elements or members related to the ultimate tensile strength f_u — γ_{M2}
- resistance of connections and joints — see EN 1993-1-8

NOTE: Partial factors for chimneys may be defined in the National Annex. The following numerical values are recommended:

$\gamma_{M0} = 1{,}00$

$\gamma_{M1} = 1{,}10$

$\gamma_{M2} = 1{,}25$

(2)P Chimneys shall be checked for the following ultimate limit states:

- static equilibrium;
- strength of its structural elements;
- overall stability;
- local buckling of its structural elements;
- fatigue (including low cycle fatigue if relevant) of its structural elements; and
- failure of connections.

6.2 Structural shells

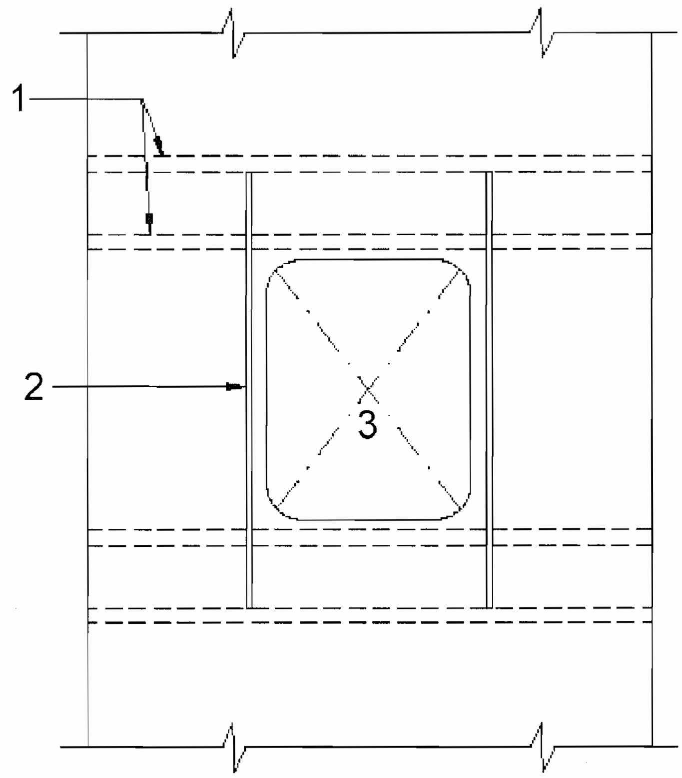
6.2.1 Strength verification

(1) The strength of the structural shell and liner should be verified by checking it for the ultimate limit state of plastic collapse or tensile rupture.

(2) When the structural shell or liner is designed for external actions as a global beam, see 5.2.1, it should be verified according to EN 1993-1-1 or EN 1993-1-3, taking due account of the class of section.

(3) In all other cases the structural shell or liner should be verified according to the methods given in EN 1993-1-6.

(4) Weakening of cross-section components by cut-outs and openings (e.g. manholes, flue openings, etc.) should be compensated for by adequately sized reinforcement, taking into account local shell stability and fatigue effects, as a result of which stiffeners may be required around the edges (see Figure 6.1).



1 Possible stiffening rings
2 Longitudinal stiffener
3 Cut out

Figure 6.1 Stiffening round cut-outs and openings

(5) When longitudinal stiffeners are used, care should be taken to ensure that any circumferential bending stresses of the shell walls, occurring in the vicinity above and below the respective openings are included if load distribution of the meridional (longitudinal) stresses is considered.

(6) The longitudinal stiffeners should be chosen long enough so as to be capable of distributing stresses into the main area of the shell.

> **NOTE:** The National Annex may define limits for the opening. The following limits are recommended:
> Local stress distribution may generally be deemed to be satisfied if the stiffeners project above and below the opening at least 0,8 times the spacing of the stiffeners or 0,8 times the height of the opening, whichever is the greatest and the maximum angle of the opening should be 120°.

(7) Additional ring stiffeners attached at the hole's edge, and at the end of the longitudinal stiffeners,

may be used for the absorption of the circumferential bending stresses.

(8) Ring stiffeners should be checked according to annex C of EN 1993-1-6.

6.2.2 Stability verification

(1) The stability of the structural shell should be verified by checking it for the ultimate limit state of local shell buckling, using the methods given in section 8 of EN 1993-1-6.

(2) When the structural shell is calculated for external actions as a global beam, see 5.2.1, the stress design concept in EN 1993-1-6 should be applied.

(3) When global second order beam theory needs to be applied, see 5.2.3, the shell buckling check should be carried out with meridional compressive membrane stresses which include second order effects.

6.3 Safety assessment of other structural elements of the chimney

(1) The strength and stability of bar type elements of the chimney should be verified as part of the structural shell, see 6.2.

(2) The strength and stability of liners of double-skin chimneys or multi-flue chimneys should be verified analogously to the structural shell, see 6.2.

(3) If relevant, the shell buckling check of a liner may be handled as a serviceability check, see section 7.

(4) If the load bearing system of the chimney is connected to other structural elements, the strength and stability of such elements and their connections should be verified in accordance with 6.2 and 6.4.

6.4 Joints and connections

6.4.1 General

(1) For joints and connections see EN 1993-1-8.

NOTE: The partial factors for joints and connections in chimneys may be given in the National Annex. The numerical values given in Table 2.1 of EN 1993-1-8 are recommended.

6.4.2 Flange bolted connections

(1) The stress in the bolts and in the flange should be calculated taking consideration of the eccentricity of the loading transmitted by the shell.

NOTE: The National Annex may give further information on the design of flange bolted connections.

(2) Flanges should be continuously welded to the structural shell. Intermittent welding should not be used.

(3) Preloaded high strength bolts should be used.

(4) The maximum distance between centres of the bolts should be $10d$. When considering leakage effects, reference should be made to EN 13084 : Part 6 as the spacing may need to be reduced further (possibly to $5d$) where d is the diameter of the bolt.

(5) The minimum bolt diameter should be d = 12 mm.

(6) If the bolts are not inspectable during the whole lifetime of the chimney, internal flanges should normally be avoided.

(7) The flanges should be formed into a ring to accurately fit the structural shell. Any gap between the flange and the structural shell should be such as to allow the welding specification to be met.

(8) The possibility of stress concentrations in the shell near the bolts, the bending of the flange and of the shell and additional stresses due to possible deformations should be considered.

(9) Due consideration should be given to temperature and variation of temperature of the flange joint in the joint design.

6.4.3 Connection of chimney to the foundation or supporting structure

(1) The connection of the steel shell to the concrete foundation or to the supporting structure should resist the overturning moment, normal force and shear force developed at the shell base and transmitted to the foundation.

(2) When the connection is made using a base plate and anchor bolts, the load in the bolts should be calculated taking into consideration the eccentricity of the loading transmitted by the shell.

NOTE 1: The National Annex may give further information on the design of the connections to foundations.

NOTE 2: For fatigue verification see section 9.

NOTE 3: It may be possible, for example, that non-preloaded bolts meet the fatigue requirements if oscillations are significantly reduced by using aerodynamic or damping devices.

(3) If other methods of connecting the steel shell to the foundations are used, for instance by extending and embedding the shell directly into the concrete foundation, it should be shown that the design model is structurally reliable, and the particular constructional details associated with the adopted method, should be taken into account.

6.5 Welded connections

(1) For connections in steel chimneys made by welding see EN 1993-1-8, EN 1993-1-9 and EN 13084-1.

7 Serviceability limit states

7.1 Basis

(1) The following serviceability limit states should be considered for steel chimneys:

- deformations or deflections in the along wind direction and/or in the cross-wind direction which adversely affect the appearance or effective use of the structure;
- vibrations, oscillations or sway which may cause alarm among bystanders;
- deformations, deflections, vibrations, oscillations or sway which cause damage to non-structural elements.

(2) Where simplified compliance rules are given in the relevant clauses dealing with serviceability limit states, detailed calculations using combinations of actions need not be undertaken.

NOTE: Partial factors are normally taken as 1,00 for all serviceability limit states.

7.2 Deflections

(1) The maximum value of deflection (δ_{max}) as determined from EN 1991-1-4 in the along-wind direction at the top of a self-supporting chimney due to the characteristic value of along-wind loading should

be limited.

NOTE: The National Annex may give the limiting value. The following value is recommended:

$$\delta_{max} = h/50 \qquad \text{... (7.1)}$$

where h is the overall height of the chimney.

(2) The maximum values for the vibration amplitudes at the top of a self-supporting chimney due to vortex shedding should be limited.

NOTE 1: For determining the maximum values see Annex E of EN 1991-1-4.

NOTE 2: The National Annex may give limiting values for vibration amplitudes. Where the reliability classes according to Annex A of this Part are used the limiting values according to Table 7.1 are recommended.

Table 7.1 Recommendations for maximum amplitudes of cross-wind vibration

Reliability class	Limits to cross-wind vibration amplitude	
3	0,05	times the outer diameter
2	0,10	times the outer diameter
1	0,15	times the outer diameter

8 Design assisted by testing

(1) The provisions for design assisted by testing given in EN 1990 should be followed.

(2) Values of logarithmic decrement different from EN 1991-1-4 should be proved by test. For guidance see annex D.

9 Fatigue

9.1 General

(1) Consideration should be given to possible fatigue effects that arise from stress ranges induced by in-line forces and by cross wind forces.

NOTE: As fatigue from cross wind vortex vibrations normally governs design, the fatigue verification related to inline forces need normally not be undertaken.

(2) For fatigue verification see EN 1993-1-9.

(3) Where the geometrical stress method is used, such as at openings or by a particular shape of connection, stress concentration factors may be used according to EN 1993-1-6.

NOTE: The National Annex may give further information on the modelling for stress analysis.

(4) For chimneys made of heat resistant alloy steels which are used for temperatures > 400°C the addition of the temperature induced damage with the fatigue damage should be duly accounted for.

NOTE: The National Annex may give further information.

(5) This Part does not cover corrosion fatigue.

9.2 Fatigue loading

9.2.1 Along-wind vibrations

(1) In assessing fatigue loading due to along-wind vibrations, gust effects need to be taken into account.

NOTE: For assessing fatigue loading from along-wind vibrations see 9.2.1 of EN 1993-3-1.

9.2.2 Cross-wind vibrations

(1) The fatigue loading for cross-wind vibrations may be determined from the maximum stress ranges.

NOTE: For determining the stress ranges and the number of cycles see 2.4 and 1.5.2.6 of annex E of EN 1991-1-4.

(2) No fatigue verification need be undertaken for chimneys which are lower than 3m in height.

(3) If the critical wind speed of the chimney for vortex excitation is greater than 20 m/sec the correlation length(s) below 16m above ground need not be taken into account, see EN 1991-1-4.

(4) Higher modes should be considered where the critical wind speed for those modes is below the limiting value (see EN 1991-1-4).

9.3 High cycle fatigue resistances

(1) For tables of fatigue resistances for constructional details of welded shell structures of chimneys, see EN 1993-1-9.

NOTE: Guidance on the use of EN 1993-1-9 and enhancement of fatigue resistances according to the quality of welds see Annex C.

(2) If there is a corrosion allowance for the plate thickness instead of a corrosion protection system, the details should be classified one detail category lower than that value given in the tables of the detail categories. (See Figure 7.1 of EN 1993-1-9.)

9.4 Safety assessment

(1) The safety assessment for fatigue should be performed according to 8(2) EN 1993-1-9, using:

$$\Delta\sigma_{E,2} = \lambda \Delta\sigma_{E} \qquad \text{... (9.1)}$$

where λ is the equivalence factor to transfer $\Delta\sigma_E$ to $N_c = 2 \times 10^6$ cycles

$\Delta\sigma_E$ is the stress range associated with N cycles (see 9.2) allowing for stress concentration factors where appropriate

(2) The equivalence factor λ may be determined from:

$$\lambda = \left(\frac{N}{2x10^6} \right)^{\frac{1}{m}} \qquad \text{... (9.2)}$$

where m is the slope of the S-N curve

9.5 Partial factors for fatigue

(1) The partial factors for fatigue should be taken as specified in 3(6) and (7) and 6.2(1) of EN 1993-1-9.

NOTE: The National Annex may give the numerical values for γ_{Ff} and γ_{Mf}. For γ_{Ff} the value $\gamma_{Ff} = 1,00$ is recommended. For γ_{Mf} see Table 3.1 in EN 1993-1-9.

Annex A [normative] – Reliability differentiation and partial factors for actions

A.1 Reliability differentiation for steel chimneys

(1) Reliability differentiation may be applied to steel chimneys by the application of reliability classes.

NOTE: The National Annex may give relevant reliability classes related to the consequences of structural failure. The classes in Table A.1 are recommended.

Table A.1 Reliability differentiation for chimneys

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.

A.2 Partial factors for actions

(1) Partial factors for actions may be dependant on the reliability class of the chimney.

NOTE 1: In the choice of partial factors for permanent actions γ_G and for variable actions γ_Q the dominance of wind actions for the design may be taken into account.

NOTE 2: The National Annex may give numerical values of γ_G and γ_Q. Where the reliability classes recommended in A.1 are used the numerical values in Table A.2 for γ_G and γ_Q are recommended.

Table A.2 Partial factors for permanent and variable actions

Type of Effect	Reliability Class, see NOTE to 2.1.2	Permanent Actions	Variable Actions
unfavourable	3	1,2	1,6
	2	1,1	1,4
	1	1,0	1,2
favourable	All Classes	1,0	0,0
Accidental situations		1,0	1,0

NOTE 3: The National Annex may also give information on the use of dynamic response analysis for wind action, see also Annex B of EN 1993-3-1.

Annex B [informative] – Aerodynamic and damping measures

B.1 General

(1) Where justified by standard aerodynamic and vibration-engineering methods, vibrations may be effectively reduced by application of single or combined auxiliary measures such as by:

- aerodynamic devices, such as helical strakes, spoilers or shrouds;
- vibration absorbers;
- cables with damping devices; and
- direct damping (at a fixed point).

B.2 Aerodynamic measures

(1) Aerodynamic measures, such as strakes, shrouds, or slats, which disturb the regular vortex shedding may be used to reduce the exciting force. Steel chimneys with helical strakes may be designed using the following criteria provided the Scruton number is larger than 8 (see Annex E to EN 1991-1-4). For other aerodynamic measures, independent proof as to the effectiveness of such measures should be provided, such as results from wind tunnel tests.

(2) If helical strakes are arranged at the top of the chimney, the basic value of the lift coefficient, c_{lat}, over the total chimney height may be multiplied by a factor α obtained from:

$$\alpha = \left(1 - \frac{\ell_s}{h}\right)^3 \qquad \text{... (B.1)}$$

where ℓ_s is the length of the shell fitted with strakes

h is the total height of the chimney

(3) Equation (B.1) should only be used provided the geometry of such helical strakes is as follows:

- three start strakes;
- pitch of the strakes $h_s = 4{,}5\ b$ to $5{,}0\ b$; ... (B.2a)
- depth of the strakes $t = 0{,}10\ b$ to $0{,}12\ b$; and ... (B.2b)
- strakes extend over a length ℓ_s of at least 0,3 h, and normally between 0,3 h and 0,5 h. However, a top portion not exceeding 1,0 b with no strakes is permitted and may be included in the length ℓ_s in equation (B.1).

where b is the diameter of the chimney

NOTE: In the above it is assumed that approach 1 of Annex E to EN 1991-1-4 is used. In the calculation of cross-wind amplitudes a correlation length factor K_w of 1,0 is assumed (see E.1.5.2.1 of EN 1991-1-4).

(4) For two or more similar chimneys located close to each other, the strakes may prove less effective than indicated in equation (B.1). If the centre distance between chimneys is less than 5d, either a special investigation of the effects of strakes with respect to vortex shedding should be made, or else the strakes should be assumed to be ineffective.

(5) The provision of strakes or shrouds will increase the drag factor of the chimney section on which they are mounted. For strakes whose height is up to 0,2 times the chimney diameter, the drag factor should be taken as 1,2 on the overall diameter (i.e. including the height of the strakes).

B.3 Dynamic vibration absorber

(1) A dynamic vibration absorber may be used to reduce vibrations, for example a resiliently supported vibratory auxiliary mass. The damper should be designed taking into account the mass, natural frequency, damping and other relevant parameters, in order to enhance the damping of the structure.

(2) The required magnitude of the effective damping should be determined from the analysis of the cross wind vibration, including fatigue effects.

(3) Tests to verify the capability of function, frequency adaption and damping of the system should be undertaken. A certificate should be prepared, which, in the light of the tests, verifies that the achieved damping is in agreement with the furnished analysis.

(4) If dampers are to be installed it should be stated by the manufacturers at what intervals an inspection and/or maintenance service of the damper should be undertaken.

B.4 Cables with damping devices

(1) Cables with a damping device may be used to provide additional damping.

(2) The efficiency of such dissipation measures should be proven by appropriate tests conducted on the completed chimney.

(3) If cable ends have been firmly fixed, a structural design assessment should also be furnished for the maximum wind load being encountered, incorporating the cables.

B.5 Direct damping

(1) If a fixed point near the stack at a sufficient height is available, direct damping may be provided by mounting a damping element between the stack and the fixed point, for the particular mode under consideration.

NOTE: For coupled identical stacks with the same natural frequency no increase of structural damping because of the coupling may be allowed.

Annex C [informative] – Fatigue resistances and quality requirements

C.1 General

(1) In selecting the relevant detail category from table 8.1 to 8.5 of EN 1993-1-9 shell details may be treated as flats as indicated in Table C.1.

(2) The minimum quality level for the welds of shells subjected to fatigue is quality level C according to EN ISO 5817.

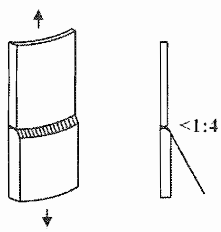
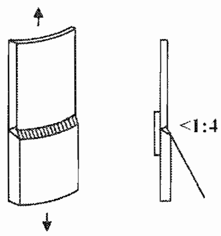
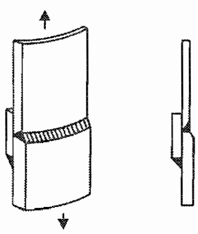
C.2 Enhancement of fatigue strength for special quality requirements

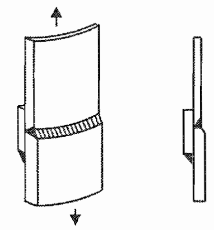
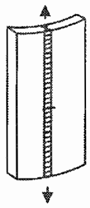
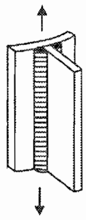
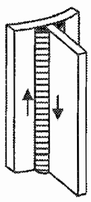
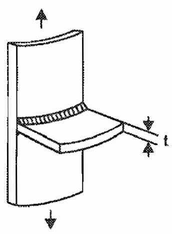
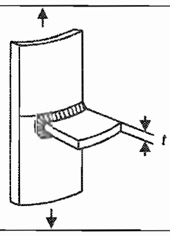
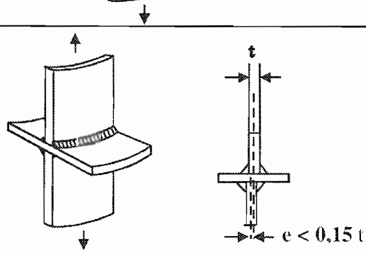
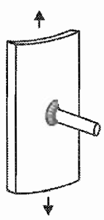
(1) Where enhanced quality requirements are applied and these quality requirements may result in an increase of fatigue strength, a detail category higher than that specified in EN 1993-1-9 may be used if this is verified by appropriate tests.

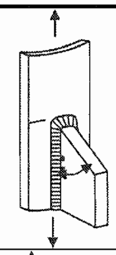
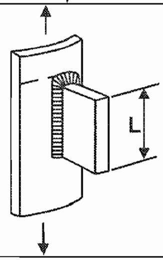
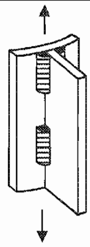
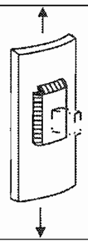
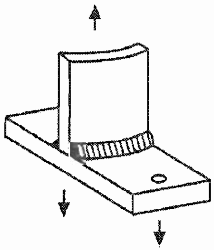
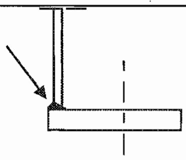
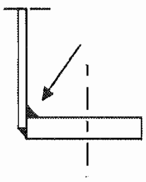
NOTE: The National Annex may give information on detail classes concerned and the associated enhanced quality requirements. Enhancement of fatigue strength can be considered for the following details, if quality level B is applied:

- transverse splices in shell with butt welds carried out from both sides
- longitudinal splices in shell with continuous seam weld
- continuous longitudinal attachment with or without shear flow
- cruciform joints with partial penetration welds

Table C.1 Allocation of details to detail categories

Reference	Sketch of the detail	Description
EN 1993-1-9 Table 8.3 Detail 4 and 7		Transverse splices in shell. Butt weld carried out from both sides.
EN 1993-1-9 Table 8.3 Detail 14		Transverse splices in shell. Butt weld made from one side only.
EN 1993-1-9 Table 8.3 Detail 16 (<1:4)		Transverse splices in shell. Butt weld made on a permanent backing strip.

Reference	Sketch of the detail	Description
Detail category 50		Transverse splices in shell. Butt weld made from one side only.
EN 1993-1-9 Table 8.2 Detail 10		Longitudinal splice in shell. Continuous seam weld.
EN 1993-1-9 Table 8.2 Detail 1, 2, 3,5 and 7		Continuous longitudinal attachment.
EN 1993-1-9 Table 8.5 Detail 8		Continuous longitudinal attachment with shear flow. (Transverse continuous attachments see also in this case)
EN 1993-1-9 Table 8.4 Detail 6 and 7		Continuous transverse attachment.
EN 1993-1-9 Table 8.4 Detail 6 and 7		Short transverse attachment. (Also for continuous transverse attachments with intermittent welds.)
EN 1993-1-9 Table 8.5 Detail 1, 2 and 3		Cruciform joints with partial penetration welds.
EN 1993-1-9 Table 8.4 Detail 9		Effect of welded connection on base material.

Reference	Sketch of the detail	Description
EN 1993-1-9 Table 8.4 Detail 2		Longitudinal attachments.
EN 1993-1-9 Table 8.4 Detail 1		Short longitudinal attachments.
EN 1993-1-9 Table 8.2 Detail 8		Continuous longitudinal attachments with intermittent welds.
EN 1993-1-9 Table 8.5 Detail 6 and 7		Reinforcing plate (with or without other attachments).
EN 1993-1-9 Table 8.5 Detail 1, 2 and 3		Footing with fillet/butt weld.
EN 1993-1-9 Table 8.5 Detail 11		Flange connection with butt weld. For the structural detailing of the bolts see EN 1993-1-8.
EN 1993-1-9 Table 8.5 Detail 12		Flange connection with fillet weld. For the structural detailing of the bolts see EN 1993-1-8.

Annex D [informative] – Design assisted by testing

D.1 General

(1) When the values for the logarithmic decrement of damping given in EN 1991-1-4 are considered inappropriate or when after the installation of damping measures the effects of these dampers need to be verified, the following guidance should be used to determine the logarithmic damping decrement for chimneys from test.

D.2 Definition of the logarithmic damping decrement

(1) For the definition of the logarithmic damping decrement see Annex D of EN 1991-1-4.

D.3 Procedure for measuring the logarithmic damping decrement

(1) The signal of the measurement may be obtained from acceleration, deflection, forces or strain of the chimney.

(2) Different measurement methods may be used, such as decay curve method, auto-correlation method or half-band-width method.

(3) It should be ensured that the measurement includes the total vibration energy, thus the measurement should be undertaken in two orthogonal directions simultaneously.

(4) The dependency of vibration amplitudes should be taken into account in the analysis of the measured data.

(5) The amplitude in the test should be in the range of the estimated amplitude of the chimney design due to vortex shedding or it should be ensured that the damping of this estimated amplitude is on the safe side.

(6) The influence of the aerodynamic damping should be subtracted from the measured value if there is wind blowing during the test. For the definition of aerodynamic damping see Annex D of EN 1991-1-4.

Annex E [informative] – Execution

E.1 General

(1) Chimneys should be fabricated and erected according to the execution standard EN 1090, Part 2. Specific requirements for chimneys provided in EN 13084-7 should be applied.

(2) The execution tolerances given in E.2 should be assumed in design.

NOTE: The strength and stability rules in EN 1993-3-2 are based on the assumption that the particular execution tolerances given in E.2 are achieved.

(3) When fitted together before bolting, any gap between the flanges should not exceed 1,5 mm.

(4) Flanges should be flat to a tolerance of 0,5 mm per 100 mm width and the total tolerance across the circumference should not exceed 1,0 mm.

(5) For chimneys fabricated with a base plate and anchor bolts, non-shrinking grout should be used between the plate and the foundation.

E.2 Execution tolerances

(1) The permitted horizontal deviation Δ from the vertical of the steel shell at any level h (in m) above the base of a self-supporting chimney should be:

$$\Delta = \frac{h}{1000}\sqrt{1+\frac{50}{h}} \quad \text{... (E.1)}$$

(2) This tolerance should also apply to the centreline of the liner.

E.3 Quality of welds and fatigue

(1) The quality of welds that has been chosen in selecting the appropriate fatigue class of a structural detail, see 9.3, should be specified on the drawings for the execution of the chimney.