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Interested committees:

Title: BS EN 1991-1-4 Eurocode 1 - Actions on structures

Part 1-4: General actions - Wind actions

Please notify the secretary if you are aware of any keywords that might assist in classifying or identifying the standard or if the content of this standard

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- ii) affects other national standard(s)
- iii) requires additional national guidance or information

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

For national standards, comments will be reviewed by the relevant UK national committee and the resulting standards published as a British Standard.

UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

- **Annotated drafts are not acceptable and will be rejected.**
- All comments should be submitted online at <https://standardsdevelopment.bsigroup.com/>. You will need to register in order to comment.

Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	

English Version

Eurocode 1 - Actions on structures - Part 1-4: Wind actions

Eurocode 1 - Actions sur les structures - Partie 1-4 :
Actions du vent

Eurocode 1 - Einwirkungen auf Tragwerke - Teil 1-4:
Windlasten

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/TC 250.

If this draft becomes a European Standard, CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

This draft European Standard was established by CEN 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 CEN-CENELEC Management Centre has the same status as the official versions.

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Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Warning : This document is not a European Standard. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a European Standard.



EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This document (prEN 1991-1-4:2024) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocode”, the secretariat of which is held by BSI. CEN/TC 250 is responsible for all Structural Eurocodes and has been assigned responsibility for structural and geotechnical design matters by CEN.

This document is currently submitted to the CEN Enquiry.

This document will supersede EN 1991-1-4:2005 and its amendments and corrigenda.

The first generation of EN Eurocodes was published between 2002 and 2007. This document forms part of the second generation of the Eurocodes, which have been prepared under Mandate M/515 issued to CEN by the European Commission and the European Free Trade Association.

The Eurocodes have been drafted to be used in conjunction with relevant execution, material, product and test standards, and to identify requirements for execution, materials, products and testing that are relied upon by the Eurocodes.

The Eurocodes recognize the responsibility of each Member State and have safeguarded their right to determine values related to regulatory safety matters at national level through the use of National Annexes.

0 Introduction

0.1 Introduction to the Eurocodes

The structural Eurocodes comprise the following standards generally consisting of a number of parts:

- EN 1990, Eurocode — Basis of structural and geotechnical design
- EN 1991, Eurocode 1 — Actions on structures
- EN 1992, Eurocode 2 — Design of concrete structures
- EN 1993, Eurocode 3 — Design of steel structures
- EN 1994, Eurocode 4 — Design of composite steel and concrete structure
- EN 1995, Eurocode 5 — Design of timber structures
- EN 1996, Eurocode 6 — Design of masonry structures
- EN 1997, Eurocode 7 — Geotechnical design
- EN 1998, Eurocode 8 — Design of structures for earthquake resistance
- EN 1999, Eurocode 9 — Design of aluminium structures
- New Eurocodes under development, e.g. Eurocode for design of structural glass

The Eurocodes are intended for use by designers, clients, manufacturers, constructors, relevant authorities (in exercising their duties in accordance with national or international regulations), educators, software developers, and committees drafting standards for related product, testing and execution standards.

NOTE Some aspects of design are most appropriately specified by relevant authorities or, where not specified, can be agreed on a project-specific basis between relevant parties such as designers and clients. The Eurocodes identify such aspects making explicit reference to relevant authorities and relevant parties.

0.2 Introduction to EN 1991 (all parts)

EN 1991 specifies actions for the structural design of buildings, bridges and other civil engineering works, or parts thereof, including temporary structures, in conjunction with EN 1990 and the other Eurocodes.

EN 1991 does not cover the specific requirements of actions for seismic design. Provisions related to such requirements are given in EN 1998 (all parts), which complement and are consistent with EN 1991.

EN 1991 is also applicable to existing structures for their:

- structural assessment,
- strengthening or repair,
- change of use.

NOTE In these cases, additional or amended provisions can be necessary.

EN 1991 is applicable for the design of structures where materials or actions outside the scope of the other Eurocodes are involved.

NOTE In this case, additional or amended provisions can be necessary.

EN 1991 is subdivided in various parts:

- EN 1991-1-1, *Eurocode 1 — Actions on structures — Part 1-1: Specific weight of materials, self-weight of construction works and imposed loads for buildings*
- EN 1991-1-2, *Eurocode 1 — Actions on structures — Part 1-2: Actions on structures exposed to fire*
- EN 1991-1-3, *Eurocode 1 — Actions on structures — Part 1-3: Snow Loads*
- EN 1991-1-4, *Eurocode 1 — Actions on structures — Part 1-4: Wind Actions*
- EN 1991-1-5, *Eurocode 1 — Actions on structures — Part 1-5: Thermal Actions*
- EN 1991-1-6, *Eurocode 1 — Actions on structures — Part 1-6: Actions during execution*
- EN 1991-1-7, *Eurocode 1 — Actions on structures — Part 1-7: Accidental actions*
- EN 1991-1-8, *Eurocode 1 — Actions on structures — Part 1-8: Actions from waves and currents on coastal structures*
- EN 1991-1-9, *Eurocode 1 — Actions on structures — Part 1-9: Atmospheric icing*
- EN 1991-2, *Eurocode 1 — Actions on structures — Part 2: Traffic loads on bridges and other civil engineering works*
- EN 1991-3, *Eurocode 1 — Actions on structures — Part 3: Actions induced by cranes and machines*
- EN 1991-4, *Eurocode 1 — Actions on structures — Part 4: Silos and tanks*

0.3 Introduction to prEN 1991-1-4

prEN 1991-1-4 gives design guidance and actions for the structural design of buildings and civil engineering works for wind.

prEN 1991-1-4 is intended to be used with EN 1990, the other Parts of EN 1991 and EN 1992 to EN 1999 for the design of structures.

0.4 Verbal forms used in the Eurocodes

The verb “shall” expresses a requirement strictly to be followed and from which no deviation is permitted in order to comply with the Eurocodes.

The verb “should” expresses a highly recommended choice or course of action. Subject to national regulation and/or any relevant contractual provisions, alternative approaches could be used/adopted where technically justified.

The verb “may” expresses a course of action permissible within the limits of the Eurocodes.

The verb “can” expresses possibility and capability; it is used for statements of fact and clarification of concepts.

0.5 National Annex for prEN 1991-1-4

National choice is allowed by this standard where explicitly stated within notes. National choice includes the selection of values for Nationally Determined Parameters (NDPs).

The national standard implementing prEN 1991-1-4 can have a National Annex containing all national choices to be used for the design of buildings and civil engineering works to be constructed in the relevant country.

When no national choice is given, the default choice given in this standard is to be used.

When no national choice is made and no default choice is given in this standard, the choice can be specified by the relevant authority or, where not specified, agreed for a specific project by the relevant parties.

National choice is allowed in prEN 1991-1-4 through notes to the following clauses:

5.4(8)	6.1(3)	6.2(1)	6.2(2)
6.2(4)	6.2(5)	6.3.1(1)	6.3.2(1)
6.3.2(3)	6.3.3(2)	6.4(2)	6.4(3)
6.4(4)	6.5(1)	7.1(2)	9(1)
B.1(1)	B.3(1)	B.4.1(2)	B.4.3(5)
B.5(5)	B.8.1(1)	B.8.2(1)	Table B.3 (NDP)
B.8.3(2)	C.3.1(1)	C.3.2(1)	C.4.1(4)
C.4.1(6)	C.4.2(6)	C.4.3(3)	Table C.3 (NDP)
C.4.4(3)	C.4.4(4)	C.4.5(3)	C.4.5(4)
C.4.6(3)	C.4.8(1)	C.4.9(2)	C.4.9(3)
C.5.1(2)	C.5.2(1)	C.5.3(1)	C.6.1.1(1)
C.6.1.1(4)	C.6.2(1)	C.6.3(1)	C.7(7)
D.3.2(1)	D.3.3(1)	D.3.6(1)	D.4.2(1)
D.4.3(1)	E.3.1(3)	E.3.3(1)	E.3.4(1)
E.3.5(1)	E.3.5(2)	E.3.5(7)	E.3.6(1)
E.3.7(1)	E.4(1)	E.5.1(1)	E.5.1(3)
E.5.6(1)	E.7.1(1)	E.8.1(1)	E.8.1(4)
E.8.1(5)	E.8.2(1)	E.8.2.2(4)	E.8.2.3(1)
E.8.2.4(3)	E.8.2.5(1)	F.1(1)	F.5.3(2)
F.9.2(1)	G.1(1)	G.3(2)	H.1(1)
H.3(4)	H.5.3.2(1)	H.5.3.4(1)	H.5.4(2)
H.5.5.1(1)	H.5.5.2(2)	H.5.5.2(3)	H.5.6.1(1)
H.5.6.2(1)	H.5.6.3(1)	H.6.4(2)	I.1(1)
J.1(1)	J.4.2.8(4)	J.4.3(1)	J.4.3(2)
J.5.3.2.2(2)	J.5.3.2.3(1)	J.5.3.2.8(4)	K.1(1)
L.1(1)	M.1(1)		

prEN 1991-1-4:2024 (E)

National choice is allowed in prEN 1991-1-4 on the application of the following informative annexes:

Annex B	Annex F	Annex G	Annex H
Annex I	Annex J	Annex K	Annex L
Annex M			

The National Annex can contain, directly or by reference, non-contradictory complementary information for ease of implementation, provided it does not alter any provisions of the Eurocodes.

1 Scope

1.1 Scope of prEN 1991-1-4

(1) This document gives principles and rules for the determination of natural wind actions for the structural design of building and civil engineering works for each of the loaded areas under consideration. This includes the whole structure or parts of the structure or elements attached to the structure, e.g. components, cladding units and their fixings, safety and noise barriers.

(2) This part is applicable to:

- buildings and civil engineering works with heights up to 300 m;
- bridges having no span greater than 200 m.

(3) This part is intended to predict characteristic wind actions on land-based structures, their components and appendages.

(4) This part is also applicable to structures less than 1 km offshore from the main coastline. For offshore structures more than 1 km from the main coastline, the terrain effects defined in this part do not apply.

(5) This part does not give guidance on non-synoptic winds (e.g. thunderstorms, downbursts, microbursts, tornadoes, etc.), mixed wind climates, nor does it give guidance on how to account for local effects (e.g. thermal effects, funnelling, strong arctic thermal surface inversion, etc.).

(6) This document addresses simplified procedures for dynamic effects, mostly based on the assumption of a dominant single-mode response. General criteria for performing a full dynamic analysis under aerodynamic excitation are not treated in this document.

(7) Wind pressure effects of passing vehicles are outside the scope of this document.

NOTE See EN 1991-2 for wind effects from passing trains.

1.2 Assumptions

(1) The assumptions given in EN 1990:2023, 1.2 apply.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE See the Bibliography for a list of other documents cited that are not normative references, including those referenced as recommendations (i.e. in 'should' clauses), permissions ('may' clauses), possibilities ('can' clauses), and in notes.

EN 1990, *Eurocode — Basis of structural and geotechnical design*

ISO 2394, *General principles on reliability for structures*

ISO 3898, *Bases for design of structures — Names and symbols of physical quantities and generic quantities*

ISO 8930, *General principles on reliability for structures — Vocabulary*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 1990, ISO 2394, ISO 3898 and ISO 8930 and the following apply.

3.1.1

fundamental basic wind velocity

characteristic 10-minute mean wind velocity with an annual probability of being exceeded of 0,02, irrespective of wind direction and time of year, at a height of 10 m above ground level in flat open country terrain with large windward fetch of low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights, and accounting for altitude effects (if required)

Note 1 to entry: This terrain corresponds to terrain category II in Table 6.1 and is illustrated in B.1.

3.1.2

basic wind velocity

fundamental basic wind velocity modified to account for the annual probability of exceedance, the direction of the wind, the season and the altitude (if required)

3.1.3

mean wind velocity

basic wind velocity modified to account for the effect of terrain roughness, orography and height above ground level

3.1.4

peak factor for turbulence

factor corresponding to a gust duration of approximately 3 seconds, which corresponds to standardized gust durations at meteorological stations

3.1.5

pressure coefficient

coefficient which gives the pressure on the surfaces of buildings or civil engineering works; external pressure coefficients apply to the external surfaces; internal ones to the internal surfaces

3.1.6

net pressure coefficient

coefficient that accounts for the resulting pressure difference across a skin

3.1.7

force coefficient

coefficient that accounts for the overall effect or the effect per unit length of the wind on a structure, structural element or component, including friction, if not specifically excluded

3.1.8

friction coefficient

coefficient that accounts for the effects of wind friction on the external surfaces of buildings and structures

3.1.9

background response factor

factor to allow for the lack of full correlation of the pressure on the structural surfaces

3.1.10

resonance response factor

factor to allow for the amplification of effects of wind turbulence at the natural frequency of the relevant vibration mode

3.2 Symbols

(1) For the purposes of this document, the following symbols apply.

NOTE The notation used is based on ISO 3898. In this part the symbol dot in Formulae indicates the multiplication sign. This notation has been employed to avoid confusion with functional Formulae.

(2) A basic list of notations is provided in EN 1990:2023, 1.6; the additional notations below are specific to prEN 1991-1-4.

3.2.1 Latin upper case letters

A	area
A_{fr}	area swept by the wind
A_{ref}	reference area
A_{shed}	base area
B^2	background response factor
C	wind load factor for bridges
E	Young's modulus
F_{fr}	resultant friction force
F_j	vortex exciting force at point j of the structure
F_w	resultant wind force
H	height of a topographic feature
I_u	turbulence intensity
K	mode shape factor; shape parameter; factor
K_a	aerodynamic damping parameter
K_{iv}	interference factor for vortex shedding
K_{rd}	reduction factor for parapets
$K_{R,L}$	load distribution factor
K_w	correlation length factor
K_x	non dimensional coefficient
L	length of the span of a bridge deck; turbulent length scale; projected length, chord length
L_d	actual length of a leeward slope
L_e	effective length of a windward slope
L_j	correlation length
L_u	actual length of a windward slope
N	number of cycles caused by vortex shedding; number

N_g	number of loads for gust response
P	member force
Q	parameter
R	wind resistance
R^2	resonant response factor
Re	Reynolds number
S	wind action; load effect
Sc	Scruton number
S_u	non-dimensional power spectral density function for along-wind turbulence
S_v	non-dimensional power spectral density function for lateral wind turbulence
S_w	non-dimensional power spectral density function for vertical wind turbulence
St	Strouhal number
T	return period
W_s	weight of the structural parts contributing to the stiffness of a chimney
W_t	total weight of a chimney

3.2.2 Latin lower case letters

a_G	factor of galloping instability
a_{IG}	combined stability parameter for interference galloping
$a_{p,x}$	along-wind peak acceleration
b	width of the structure (the length of the surface perpendicular to the wind direction if not otherwise specified)
c_{alt}	altitude factor
c_d	dynamic factor
c_{dir}	directional factor
c_e	exposure factor
c_f	force coefficient
$c_{f,o}$	force coefficient of structures or structural elements without free-end flow
$c_{f,l}$	lift force coefficient
$c_{f,cw}$	across-wind force coefficient
c_{fr}	friction coefficient
c_L	force coefficient in the across-wind plane
c_M	moment coefficient
c_p	pressure coefficient
c_{pe}	external pressure coefficient
$c_{pe,1}$	external local pressure coefficient

$c_{pe,10}$	external detailed pressure coefficient
$c_{pe,G}$	external global pressure coefficient
c_{pi}	internal pressure coefficient
$c_{p,net}$	net pressure coefficient
c_{prob}	probability factor
c_r	roughness factor
c_o	orography factor
c_s	size factor
c_{sd}	structural factor
c_{season}	seasonal factor
d	depth of the structure (the length of the surface parallel to the wind direction if not otherwise specified)
e	eccentricity of a force or edge distance
f_L	non dimensional frequency
h	height of the structure
h_{ave}	obstruction height
h_{dis}	displacement height
k	equivalent roughness
k_B	peak factor background turbulence
k_I	turbulence factor
k_R	peak factor resonance turbulence
k_r	terrain factor
k_u	peak factor for turbulent wind
k_θ	torsional stiffness
l	length of a horizontal structure
m	mass per unit length
m_1	equivalent mass per unit length
n_i	natural frequency of the structure of the mode i
$n_{1,x}$	fundamental frequency of along-wind vibration
$n_{1,y}$	fundamental frequency of across-wind vibration
$n_{1,z}$	fundamental frequency of vertical vibration
n_o	ovalling frequency
p	annual probability of exceedance
q_b	reference mean (basic) velocity pressure
q_m	mean velocity pressure

q_p	peak velocity pressure
r	radius
s	factor; coordinate
t	time
v_{CG}	onset wind velocity for galloping
v_{CIG}	critical wind velocity for interference galloping
v_{crit}	critical wind velocity of vortex shedding
v_{div}	divergence wind velocity
v_m	mean wind velocity
$v_{b,0}$	fundamental value of the basic wind velocity
v_b	basic wind velocity
w	wind pressure
x	horizontal distance in direction of the wind
x -direction	horizontal direction, perpendicular to the span
y -direction	horizontal direction along the span
y_{max}	maximum across-wind amplitude at critical wind speed
z	height above ground
z_{ave}	average height
z -direction	vertical direction
z_0	roughness length
z_e, z_i	reference height for external wind action, internal pressure
z_g	distance from the ground to the considered component
z_{max}	maximum height
z_{min}	minimum height
z_s	reference height for determining the structural factor

3.2.3 Greek upper case letters

Φ	windward slope
$\Phi_{1,x}$	fundamental along-wind modal shape
$\Phi_{i,x}$	fundamental along-wind modal shape of mode i

3.2.4 Greek lower case letters

α_G	galloping instability parameter
α_{IG}	combined stability parameter of interference galloping
β_k	critical wind direction
χ^2	one-dimensional admittance function

δ	logarithmic decrement of damping
δ_a	logarithmic decrement of aerodynamic damping
δ_d	logarithmic decrement of damping due to special devices
δ_s	logarithmic decrement of structural damping
ε	coefficient
ε_0	bandwidth factor
ε_1	frequency factor
η	variable
φ	solidity ratio, blockage of canopy
λ	slenderness ratio
μ	opening ratio, permeability of a skin
ν	up-crossing frequency; Poisson ratio; kinematic viscosity
θ	torsional angle; wind direction; angle of wind incidence to the normal in plane; slope
ρ	air density, which depends on the altitude, temperature and barometric pressure to be expected in the region during the relevant wind conditions
σ_u	standard deviation of the along-wind turbulence
σ_v	standard deviation of the lateral wind turbulence
σ_w	standard deviation of the vertical wind turbulence
ψ	angle of wind incidence to the longitudinal axis
ψ_{mc}	reduction factor for multibay canopies
ψ_r	reduction factor of force coefficient for square sections with rounded corners
ψ_λ	reduction factor of force coefficient for structural elements with end-effects
$\psi_{\lambda\alpha}$	end-effect factor for circular cylinders
ψ_s	shelter factor for walls and fences
ζ	exponent of mode shape

3.2.5 Indices

A	ancillary item
C	cable
c	circular-section members
crit	critical
e	external; exposure; effective
F	face
f	flat-sided members
fr	friction
G	guy
H	mast height

<i>i</i>	internal; mode number
<i>j</i>	current number of incremental area or point of a structure
<i>M</i>	bare mast or mast only
<i>m</i>	mean; mast
<i>n</i>	single frame
<i>p</i>	peak; parapet; combined effects of patch loads
<i>PL</i>	patch load
<i>ref</i>	reference
<i>S</i>	structure
<i>s</i>	structural scaling factor
<i>sup</i>	super-critical
<i>T</i>	bare tower or only tower
<i>t</i>	mean and gust wind
<i>u</i>	wind velocity in along-wind direction
<i>v</i>	wind velocity in lateral wind direction
<i>W</i>	in the direction of the wind
<i>w</i>	wind velocity in vertical direction; with wind
<i>i</i>	in the across-wind direction
<i>x</i>	along-wind direction; in the across-wind direction
<i>y</i>	lateral wind direction
<i>Z</i>	in the vertical direction
<i>z</i>	vertical direction; height above ground level
θ	angle of wind incidence

4 Design situations

(1) The relevant wind actions shall be determined for each design situation identified in accordance with EN 1990.

(2) In accordance with EN 1990, other actions (such as snow, traffic, ice or rain) which can modify the effects of wind actions should be taken into account.

NOTE See also EN 1991-1-3 for snow, prEN 1991-1-9 for atmospheric icing, and EN 1991-2 for traffic.

(3) The changes to the structure during construction stages (such as different stages of the form of the structure, dynamic characteristics, etc.), which can modify the effects of wind actions, should be taken into account.

NOTE See also EN 1991-1-6 for actions during execution.

(4) Fatigue due to the effects of wind actions should be considered where relevant, see EN 1990.

NOTE Stress ranges and number of load cycles can be obtained from Annex F, G and H.

(5) Structures should be designed to resist wind forces in all directions including torsion.

5 Modelling of wind actions

5.1 Representations of wind actions

(1) The wind action shall be represented by a simplified set of pressures or forces whose effects are equivalent to the extreme effects of the turbulent wind.

NOTE 1 Wind actions fluctuate with time and act directly as pressures on the external surfaces of enclosed structures and indirectly on the internal surfaces because of porosity of the external surface. They can also act directly on the internal surface of open structures.

NOTE 2 Pressures acting on a surface results in forces normal to the surface of the structure or of individual cladding components.

NOTE 3 When large areas of structures are swept by the wind, friction forces acting tangentially to the surface can be significant.

NOTE 4 The effect of the wind on the structure (i.e. the response of the structure), depends on the size, shape and dynamic properties of the structure. Wind actions in general include steady and fluctuating components which can be amplified at natural frequencies of the structure. Stiff structures with high natural frequencies respond in a quasi-static way to wind speed fluctuations. Structures with lower frequencies have increasingly important resonant responses, but up to a point they can still be treated as quasi-static.

5.2 Classification of wind actions

(1) Unless otherwise specified, wind actions should be classified as variable free actions.

NOTE See EN 1990 for the classification of actions.

5.3 Characteristic values

(1) The wind actions calculated using prEN 1991-1-4 are intended to be characteristic values corresponding to a 2 % probability of being exceeded per year as defined in EN 1990. This is equivalent to a return period of 50 years, see EN 1990.

NOTE 1 EN 1990 provides appropriate partial factors on wind load to reduce the probability of failures to acceptable levels.

NOTE 2 In the case of vortex shedding responses occurring at more frequent wind speeds, rules for calculation of the responses and additional fatigue are provided in Annex H.

NOTE 3 Factored wind speeds are used to ensure that excessive aeroelastic responses due to galloping or flutter will not occur with significant probability within the range of factored wind actions, see Annex H.

NOTE 4 Further guidance concerning the probabilistic description of wind actions is provided in Annex M.

5.4 Loading models

(1) The wind actions on structures should be calculated from:

- the peak velocity pressure q_p according to Clause 6, depending on the wind climate, the terrain roughness and orography, and the reference height,
- and the aerodynamic coefficients:
 - the external and internal pressure coefficients given in Annex C for buildings and other structures,
 - the net pressure coefficients given in Annex D for walls and roofs, or

— the force coefficients given in Annex E for structures and structural elements.

NOTE 1 Table 5.1 and Table 5.2 describe a design process to assist in the determination of wind velocities, velocity pressures and aerodynamic coefficients, and give reference to relevant clauses and annexes.

NOTE 2 This part covers use of equivalent quasi-static methods where $c_{sd} \leq 1,2$. See 8.2 for guidance on estimating c_{sd} . The clauses below refer to Annexes providing additional guidance for structures which can have significant resonant responses.

Table 5.1 — Guidance for determination of wind velocity and velocity pressure

Determine fundamental value of the basic wind velocity $v_{b,0}$ from wind map	6.2(1) NOTE 1
Determine: altitude factor c_{alt} directional factor c_{dir} seasonal factor c_{season} probability factor c_{prob}	6.2(2) NOTE 1 6.2(2) NOTE 2 6.2(2) NOTE 3 Formula (6.2)
Determine: basic wind velocity v_b reference height z_e terrain roughness category	Formula (6.1) Annex C, D or E 6.3.2
Determine whether orography is significant? If orography is significant, determine c_o (otherwise $c_o = 1$)	6.3.3 B.3
If the structure height is < 200 m	
Determine: basic velocity pressure q_b	Formula (6.3)
If orography is <u>not significant</u> exposure factor $c_e(z)$ peak velocity pressure $q_p(z)$	Figure 6.3 Formula (6.11) Formula (6.13) Figure 6.3
If orography is <u>significant</u>	
roughness factor $c_r(z)$ turbulence intensity $I_u(z)$ mean wind velocity $v_m(z)$ peak wind velocity $v_p(z)$ peak velocity pressure $q_p(z)$	Formula (6.6) Formula (6.10) Formula (6.4) Formula (6.12) Formula (6.11)
For slender structures up to 300 m height, $c_r(z)$ and $I_u(z)$ can be determined from B.6.	

Table 5.2 — Guidance for determination of wind load

Wind pressures and forces for buildings:	
Obtain: external pressure coefficient, c_{pe} internal pressure coefficient, c_{pi} friction coefficient, c_{fr}	Annex C Clause C.5 Clause E.7
Determine: Wind pressure acting on external surfaces, w_e Wind pressure acting on internal surfaces, w_i	Formula (7.2) Formula (7.3)
Determine: Forces from external wind pressure, $F_{w,p,e}$ Forces from internal wind pressure, $F_{w,p,i}$ Forces from friction, $F_{p,fr}$	Formula (7.6) Formula (7.7) Formula (7.8)
Determine wind force $F_{w,p}$ as vector sum of $F_{w,p,e}$, $F_{w,p,i}$ and $F_{p,fr}$	Subclause 7.5(4)
Net wind pressures and forces on canopy roofs, porches, balconies, free-standing walls, parapets, fences, and signboards:	
Obtain: net pressure coefficient, $c_{p,net}$	Annex D
Determine: net wind pressure net wind force	Subclause 7.3(3) Formula (7.5)
Wind forces on elongated structures and structural elements:	
Obtain: force coefficient, c_f	Annex E
Determine: wind force, $F_{w,p}$ lattice towers and guyed masts	Formula (7.4) or Formula (7.5) Annex J

- (3) The following effects of wind-induced vibrations should be estimated when relevant:
- along-wind resonant turbulence giving along-wind buffeting vibrations of flexible structures;
 - transverse resonant turbulence giving across-wind buffeting vibrations of flexible structures;
 - along-wind resonant turbulence and across-wind resonant turbulence giving torsional buffeting vibrations of flexible structures;
 - vortex shedding and other aeroelastic phenomena giving vibrations of flexible structures.

NOTE 1 Procedures for wind-induced vibrations cover structures where only one dominant mode is significant.

NOTE 2 The estimation of peak acceleration considering only the dominant mode is a simplified approach. Estimating local peak acceleration is much more complex.

(4) The along-wind response of flexible structures should be calculated using the structural factor c_{sd} , which is composed of the size factor c_s and the dynamic resonance factor c_d , both contributing to the equivalent static wind action.

NOTE 1 8.2 gives further guidance.

NOTE 2 Table 5.3 describes a design process to assist in the determination of the along-wind buffeting response and gives reference to relevant clauses and annexes.

Table 5.3 — Guidance for determination of structural factor, c_{sd}

Determine: whether $c_{sd} = 1$ may be used as an appropriate simplifying value	Subclause 8.2
Or: Evaluate c_{sd} by a more rigorous method	Annex F

(5) Across-wind response and torsional response should be considered for structures described in Clause 9 and 10.

NOTE Table 5.4 describes a design process to assist in the determination of the across-wind response and gives reference to relevant clauses and annexes.

Table 5.4 — Guidance for determination of across-wind dynamic response

For buildings where $h/\sqrt{b \cdot d} < 3$, calculation of across-wind dynamic response is not necessary.	–
For buildings where $3 \leq h/\sqrt{b \cdot d} \leq 6$, calculate across-wind response.	Clause 9 Annex G
For buildings where $6 < h/\sqrt{b \cdot d} \leq 8$, calculate across-wind response.	Clause 9 Annex G – Annex H
For buildings where $h/\sqrt{b \cdot d} > 8$, calculate across-wind response.	Clause 9 – Clause 10 Annex H
For other flexible, slender structures (e.g. chimneys, bridge decks, etc.), calculate across-wind response.	Clause 10 Annex H

(6) The aeroelastic response from vortex shedding and other aeroelastic phenomena should be considered for flexible structures and structural members, such as cables and other slender elements, masts, chimneys and bridges.

NOTE Simplified guidance on aeroelastic response is given in Clause 10 and Annex H.

(7) Where the design of the structure is critically dependent on the level of structural damping, for instance for serviceability limit states and across-wind vibrations, the sensitivity to variation in structural damping shall be investigated.

NOTE 1 Values of structural damping given in Annex I are approximate and cannot be lower bound. This can result in the inclusion supplementary damping devices or provision for their retrofit.

NOTE 2 Annexes F, G and H give guidance on the calculations of vibrations.

(8) It should be assessed whether a dynamic response procedure is needed for bridges. If a dynamic response procedure is not needed, c_{sd} may be taken equal to 1,0.

NOTE 1 For normal road and railway bridge decks of less than 40 m span a dynamic response procedure is generally not needed. For the purpose of this categorization, normal bridges are considered to include bridges constructed in steel, concrete, aluminium or timber, including composite construction, and whose shape of cross sections is generally covered by Figure E.1.6.

NOTE 2 The National Annex can give criteria to determine whether a dynamic response procedure is needed for bridges and related procedures.

5.5 Design assisted by testing and measurements

(1) In supplement to calculations, wind tunnel tests and proven and/or properly validated numerical methods may be used to obtain load and response information, using appropriate models of the structure and of the natural wind.

NOTE 1 See EN 1990:2023, 7.3(3) for achievement of the level of reliability required.

NOTE 2 Annex K gives further guidance on wind tunnel tests and numerical simulations.

(2) Load and response information and terrain parameters may be obtained from appropriate full scale data.

6 Wind velocity and velocity pressure

6.1 Basis for calculation

(1) The wind velocity and the velocity pressure should be considered to be composed of a mean and a fluctuating component.

(2) The mean wind velocity v_m should be determined from the basic wind velocity v_b which depends on the wind climate as described in 6.2, and on height above ground level, as described in 6.3.

NOTE 1 Procedures for terrain roughness are set out in 6.3.2 for structures not exceeding 200 m.

NOTE 2 Orography is explained in 6.3.3 and procedures calculating orography are set out in B.3.

NOTE 3 The peak velocity pressure is determined from 6.5.

(3) The fluctuating component of the wind should be represented by the turbulence intensity defined in 6.4.

NOTE 1 Annex B provides guidance for slender structures taller than 200 m and up to 300 m.

NOTE 2 The National Annex can give guidance on the application of Annex B for structures lower than 200 m.

NOTE 3 The National Annex can provide National climatic information from which the mean wind velocity v_m and the peak velocity pressure q_p can be directly obtained for the terrain categories considered.

NOTE 4 Table 5.1 contains a design process to assist in the determination of the peak velocity pressure.

NOTE 5 The basis for calculation covers structures less than 1 km offshore from the main coastline.

NOTE 6 The National Annex can provide additional guidance for structures with a distance from the main coastline exceeding 1 km, see 1.1(4).

6.2 Basic values

(1) The basic wind velocity should be calculated from the fundamental value of the basic wind velocity $v_{b,0}$, defined as the characteristic 10-minute mean wind velocity with an annual probability of being exceeded of 0,02, irrespective of wind direction and time of year, at a height of 10 m above ground level in flat open country terrain with large windward fetch of low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.

NOTE The fundamental value of the basic wind velocity can be set in the National Annex.

(2)P The basic wind velocity, v_b should be calculated from Formula (6.1).

$$v_b = c_{\text{prob}} \cdot c_{\text{dir}} \cdot c_{\text{season}} \cdot c_{\text{alt}} \cdot v_{b,0} \quad (6.1)$$

where

$v_{b,0}$ is the fundamental value of the basic wind velocity;

c_{alt} is the altitude factor;

c_{dir} is the directional factor;

c_{season} is the seasonal factor;

c_{prob} is the probability factor

NOTE 1 The value of c_{alt} is 1,0 unless the National Annex gives a different value.

NOTE 2 The value of the directional factor, c_{dir} , for various wind directions is 1,0 unless the National Annex gives a different value.

NOTE 3 The value of the seasonal factor, c_{season} , is 1,0 unless the National Annex gives a different value.

(3) For temporary structures and for all structures in the execution phase, the seasonal factor c_{season} may be used. For transportable structures, which can be used at any time in the year, c_{season} should be taken equal to 1,0.

NOTE See also EN 1991-1-6.

(4) The probability factor, c_{prob} should be calculated from Formula (6.2):

$$c_{\text{prob}} = \left(\frac{1 - K \cdot \ln(-\ln(1 - p))}{1 - K \cdot \ln(-\ln(0,98))} \right)^n = \left(\frac{1 + K \cdot \ln(T)}{1 + K \cdot \ln(50)} \right)^n \quad (6.2)$$

where

K is the shape parameter depending on the coefficient of variation of the extreme-value distribution;

n is the exponent;

p is the annual probability of exceedance;

T is the return period in years where $T \geq 1$.

NOTE 1 The probability factor, c_{prob} is multiplied with the basic wind velocity v_b to calculate the 10 minutes mean wind velocity having the probability p for an annual exceedance.

NOTE 2 The shape parameter K is equal to β/α defined in Annex M.

NOTE 3 The values for K and n are 0,2 and 0,5, respectively, unless the National Annex gives a different value. These values correspond to a coefficient of variation of 0,23 for the annual maximum velocity pressure.

NOTE 4 See also EN 1991-1-6 for actions during execution.

(5) The basic velocity pressure q_b shall be calculated from Formula (6.3):

$$q_b = \frac{1}{2} \cdot \rho \cdot v_b^2 \quad (6.3)$$

where

ρ is the air density.

NOTE The value for ρ is 1,25 kg/m³ unless the National Annex gives different values.

6.3 Mean wind velocity and pressure

6.3.1 Variation with height

(1) The mean wind velocity $v_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity, v_b , and should be determined using Formula (6.4):

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b \quad (6.4)$$

where

$c_r(z)$ is the roughness factor, given in 6.3.2;

$c_o(z)$ is the orography factor, taken as 1,0 unless otherwise specified in 6.3.3.

NOTE 1 If the orography is accounted for in the basic wind velocity, the value of c_o is 1,0, unless a different value is given in the National Annex.

NOTE 2 Design charts or tables for $v_m(z)$ can be given in the National Annex.

(2) The influence of neighbouring structures on the wind velocity should be considered (see 6.3.4).

(3) The mean velocity pressure $q_m(z)$ at height z , should be determined using Formula (6.5):

$$q_m(z) = \frac{1}{2} \cdot \rho \cdot v_m^2(z) = c_r^2(z) \cdot c_o^2(z) \cdot q_b \quad (6.5)$$

where

ρ is the air density.

NOTE The mean of the fluctuating component squared has been disregarded in the determination of the mean velocity pressure. See also F.5.3(1) Note 2.

6.3.2 Terrain roughness

(1) The roughness factor, $c_r(z)$, should account for the variability of the mean wind velocity at the site of the structure due to:

- the height above ground level
- the terrain roughness windward of the structure in the wind direction considered

NOTE Unless the National Annex gives a different procedure, the procedure for the determination of the roughness factor at height z , $c_r(z)$, is given in (2) when the windward distance with uniform terrain roughness is long enough to stabilise the profile sufficiently, see (3).

(2) The procedure for the determination of the roughness factor at height z , $c_r(z)$, should be taken as defined in Formula (6.6) and is based on a logarithmic velocity profile.

$$c_r(z) = k_r \cdot \ln\left(\frac{z}{z_0}\right) \quad \text{for} \quad z_{\min} \leq z \leq z_{\max} \quad (6.6)$$

$$c_r(z) = c_r(z_{\min}) \quad \text{for} \quad z \leq z_{\min}$$

where

z_0 is the roughness length;

k_r terrain factor depending on the roughness length z_0 calculated using Formula (6.7)

$$k_r = 0,19 \cdot \left(\frac{z_0}{z_{0,II}}\right)^{0,07} \quad (6.7)$$

where

$z_{0,II}$ = 0,05 m (terrain category II, Table 6.1);

$z_{\min}$ is the minimum height defined in Table 6.1;

$z_{\max}$ is to be taken as 200 m.

z_0 , $z_{\min}$ depend on the terrain category. Values are given in Table 6.1 depending on five representative terrain categories.

Table 6.1 — Terrain categories and terrain parameters

Terrain category		z_0 [m]	$z_{\min}$ [m]
0	Sea or coastal area exposed to the open sea	0,003	1
I	Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II	Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
III	Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)	0,3	5
IV	Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m	1,0	10
NOTE The terrain categories are illustrated in Figure B.1.			

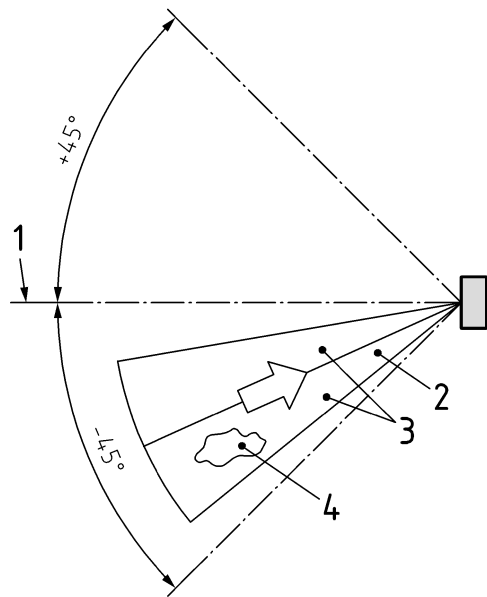
(3) The lowest terrain roughness category in an angular sector around the wind direction, as defined in Figure 6.1, should be used for a given wind direction. Small areas (less than 10 % of the area under consideration) with deviating roughness may be ignored, see Figure 6.1. The minimum windward distance that should be considered is shown in Figure 6.2, as a function of the height of the structure above terrain.

$$x = x_0 \cdot \left(\frac{h}{h_0} \right)^{1,2} \quad (6.8)$$

where

x_0 is the reference windward distance of 1 km;

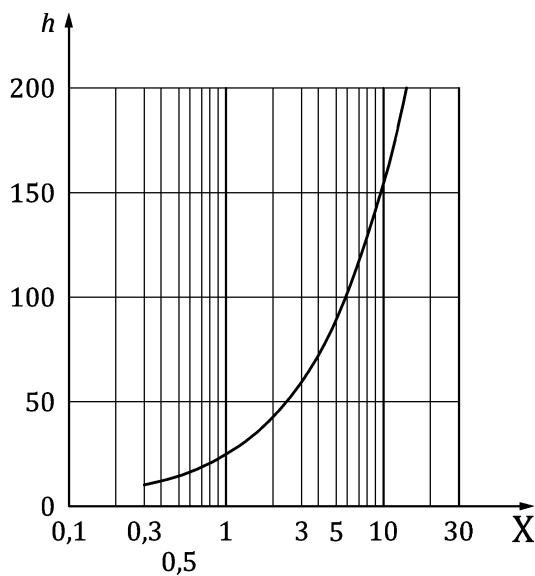
h_0 is the reference height of 23,2 m.



Key

- 1 nominal angular sector
- 2 windward distance is calculated using Formula (6.8)
- 3 consideration area
- 4 area with deviating roughness

Figure 6.1 — Assessment of terrain roughness



Key

- h building height, in metres
- X minimum windward distance, in kilometres

Figure 6.2 — Minimum windward distance X for obtaining uniform terrain roughness for a building height h

NOTE 1 The value of the angular sector can be taken as the 30° angular sector within $\pm 15^\circ$ from the wind direction unless the National Annex gives a different value.

NOTE 2 The value for the windward distance can be set in the National Annex.

(4) When a pressure or force coefficient is defined for a nominal angular sector, the lowest roughness length within any 30° angular wind sector should be used.

(5) When there is choice between two or more terrain categories in the definition of a given area, then the area with the lowest roughness length should be used.

(6) The windward distance x in Figure 6.2 is calculated using Formula (6.8).

6.3.3 Terrain orography

(1) Orography affects the wind flow and may increase the wind velocity. The effects of orography may be neglected when the average slope of the windward terrain is less than 5%. The windward terrain may be considered up to a distance of 10 times the height of the isolated orographic feature.

(2) Where orography (e.g. hills, cliffs etc.) has an average slope of more than 5 %, the effects should be taken into account using the orography factor c_o .

NOTE 1 B.3 gives guidance for determining c_o unless the National Annex gives a different procedure.

NOTE 2 The procedure given in B.3 applies to well defined hills and escarpments, surrounded by relatively flat terrain. In more complex terrain, or where the design is critically dependent on the assessment of orography, more detailed investigation is described in Annex K.

NOTE 3 In complex terrain, where the windward slope cannot be defined clearly, additional guidance can be given in the National Annex.

6.3.4 Large and considerably higher neighbouring structures

(1) If the structure is to be located close to another structure, which is at least twice as high as the height of the structure considered, then increased wind velocities for certain wind directions should be considered, depending on the properties of the higher structure

NOTE B.4 gives guidance on determining the influence of higher neighbouring structures.

6.3.5 Closely spaced buildings and obstacles

(1) The effect of closely spaced buildings and other obstacles may be taken into account.

NOTE In rough terrain, closely spaced buildings modify the mean wind flow near the ground, as if the ground level was raised to a height called the displacement height h_{dis} . B.5 gives guidance on effect of closely spaced buildings.

6.4 Wind turbulence

(1) The turbulence intensity $I_u(z)$ at height z should be taken equal to the standard deviation of the turbulence divided by the mean wind velocity.

(2) The turbulent component of wind velocity has a mean value of 0 and a standard deviation σ_u . The standard deviation of the turbulence σ_u may be determined using Formula (6.9).

$$\sigma_u = k_r \cdot v_b \cdot k_l \quad (6.9)$$

NOTE 1 For the terrain factor k_r see Formula (6.7), for the basic wind velocity v_b see Formula (6.1), k_l is the turbulence factor.

NOTE 2 The value for turbulence factor k_1 is 1.0 unless the National Annex gives a different value.

(3) $I_u(z)$ may be calculated from Formula (6.10).

$$I_u(z) = \frac{\sigma_u}{v_m(z)} = \frac{k_1}{c_o(z) \cdot \ln\left(\frac{z}{z_0}\right)} \quad \text{for } z_{\min} \leq z \leq z_{\max} \quad (6.10)$$

$$I_u(z) = I_u(z_{\min}) \quad \text{for } z < z_{\min}$$

where

k_1 is the turbulence factor.

NOTE The value of k_1 is 1.0 unless the National Annex gives a different value.

(4) For mean wind velocities lower than v_{limit} , stratified flow with zero turbulence should be considered for vortex-induced vibrations, see Annex H for further guidance.

NOTE Unless otherwise specified in the National Annex, v_{limit} is equal to 15 m/s.

6.5 Peak wind velocity and velocity pressure

(1) The peak velocity pressure $q_p(z)$ at height z , which includes mean and short-term velocity fluctuations, should be determined by using the Formula (6.11).

$$q_p(z) = \frac{1}{2} \cdot \rho \cdot v_p^2(z) \quad (6.11)$$

where

ρ is the air density;

$v_p(z)$ is the peak wind velocity given in Formula (6.12);

NOTE 1 A different rule can be given in the National Annex.

$$v_p(z) = v_m(z) \cdot (1 + k_u \cdot I_u(z)) \quad (6.12)$$

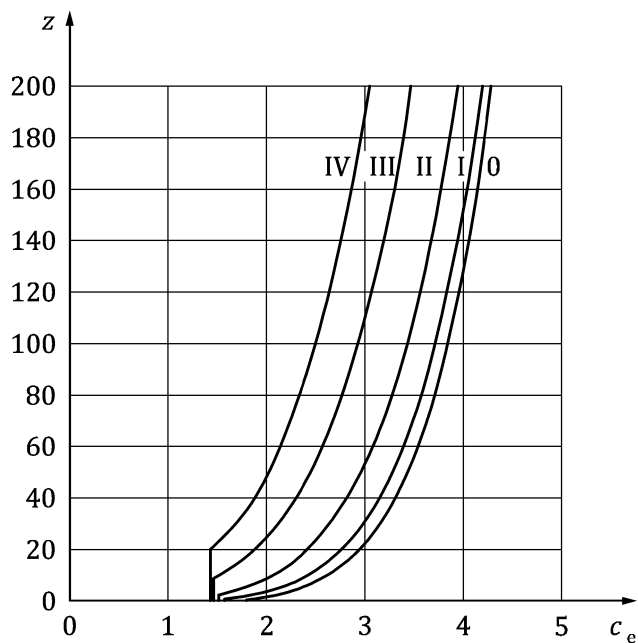
NOTE 2 The value of the peak factor for turbulence k_u is 2,8 unless the National Annex gives a different value. The peak factor for turbulence is consistent with the values of the aerodynamic coefficients specified in Annexes C to E.

(2) The exposure factor $c_e(z)$ at height z should be calculated from Formula (6.13).

$$c_e(z) = \frac{q_p(z)}{q_b} = c_r^2(z) \cdot c_o^2(z) \cdot [1 + k_u \cdot I_u(z)]^2 \quad (6.13)$$

where $q_p(z)$ is given in (1) and q_b is given in Formula (6.3).

(3) For flat terrain where $c_o(z) = 1,0$ (see 6.3.3), the exposure factor $c_e(z)$ is illustrated in Figure 6.3 as a function of height above terrain and a function of terrain category as defined in Table 6.1.



Key
 c_e exposure factor
 z height above ground, in metres

Figure 6.3 — Exposure factor $c_e(z)$ for $c_o = 1,0$, $k_1 = 1,0$

7 Wind actions

7.1 General

(1) Wind actions on structures and structural elements shall be determined taking account of both external and internal wind pressures.

NOTE A summary of calculation procedures with reference to relevant clauses and annexes is given:

- in Table 5.1 for the determination of wind velocity and velocity pressure;
- in Table 5.2 for the determination of wind load.

(2) For structures with a circular cross-section, the wind action depends on the Reynolds number, Re , defined by Formula (7.1):

$$Re(z) = \frac{v(z) \cdot d(z)}{\nu} \tag{7.1}$$

where

- v is the wind velocity, see Formula (6.12);
- d is the diameter;
- ν is the kinematic viscosity of the air

NOTE 1 The value of ν is $15 \cdot 10^{-6} \text{ m}^2/\text{s}$ unless the National Annex gives a different value.

NOTE 2 The flow around circular cross-sections and thereby the wind action depends on the particular Reynolds number regime being either sub-, super- or transcritical.

(3) The wind velocity used to calculate the Reynolds number may be the mean wind velocity or the peak wind velocity,

NOTE See Annexes C and E for further clarification for a particular structure.

7.2 Choice of aerodynamic coefficient

(1) Pressure coefficients defined in 7.3 should be determined for buildings using:

- C.2, C.3 and C.4 for external pressures,
- C.5 for internal pressures.

(2) Net pressure coefficients defined in 7.4 should be determined for:

- canopy roofs, porches and balconies using D.1,
- free-standing walls, parapets, fences and signboards using D.2.

(3) Force coefficients defined in 7.5 should be determined for:

- elongated structures and structural elements, using E.1,
- spheres, using E.2,
- lattice structures, using E.3,
- flags, using E.4,
- bridges, using E.6.

(4) Friction coefficients defined in 7.5 should be determined for walls and surfaces as specified in E.6.

(5) A reduction factor depending on the effective slenderness of the structure may be applied, using E.1.7.

NOTE Force coefficients give the overall effect or effect per unit length of the wind on a structure, structural element or component, including friction, if not specifically excluded.

7.3 Wind pressure on surfaces

(1) The wind pressure acting on the external surfaces, w_e , should be obtained from Formula (7.2).

$$w_e = q_p(z_e) \cdot c_{pe} \quad (7.2)$$

where

$q_p(z_e)$ is the peak velocity pressure defined in 6.5;

z_e is the reference height for the external pressure given in Annex C;

c_{pe} is the pressure coefficient for the external pressure, given in Annex C.

(2) The wind pressure acting on the internal surfaces of a structure, w_i , should be obtained from Formula (7.3)

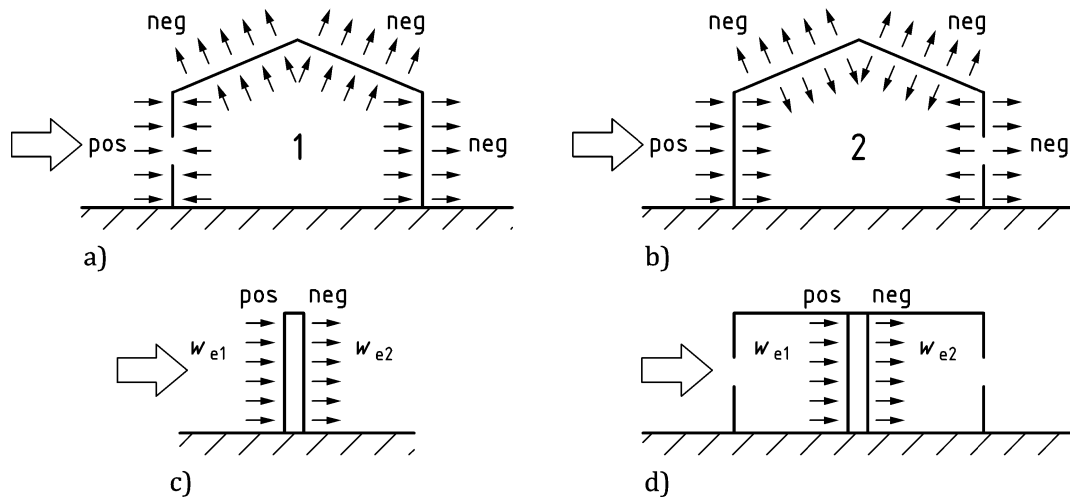
$$w_i = q_p(z_i) \cdot c_{pi} \quad (7.3)$$

where

$q_p(z_i)$ is the peak velocity pressure defined in 6.5;

- z_i is the reference height for the internal pressure given in Annex C;
 c_{pi} is the pressure coefficient for the internal pressure given in Annex C.

(3) Pressure, directed towards the surface should be taken as positive, and suction, directed away from the surface as negative (Figure 7.1).



Key

- 1 positive internal pressure
 2 negative internal pressure

Figure 7.1 — Pressure on surfaces

7.4 Net pressure on surfaces

- (1) The net pressure, w_{net} , is the difference between the pressures on opposite surfaces of an object taking due account of their signs.
 (2) Net pressure coefficients should be taken from Annex D.

7.5 Wind forces

- (1) The wind forces for the whole structure or a structural member should be determined:
 — by calculating forces using force coefficients, see (2) or
 — by calculating forces from surface pressures, see (3)
 (2) The wind force $F_{w,p}$ acting on a structure or a structural member as a whole or per unit length may be determined directly by using Formula (7.4)

$$F_{w,p} = c_{sd} \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \quad (7.4)$$

or by vector summation over the individual structural member by using Formula (7.5)

$$F_{w,p} = c_{sd} \cdot \sum_{\text{elements}} c_f \cdot q_p(z_e) \cdot A_{ref} \quad (7.5)$$

where

- c_{sd} is the structural factor as defined in Clause 8;
- c_f is the force coefficient for the structure or structural member, given in Annex E;
- $q_p(z_e)$ is the peak velocity pressure defined in 6.5 at reference height z_e of the structure or the member defined in Annex E;
- A_{ref} is the reference area of the structure or structural member as a whole or per unit length, given in Annex E.

NOTE Annex E gives c_f values for structures or structural members such as prisms, cylinders, roofs, signboards, plates and lattice structures etc.

(3) The wind force, $F_{w,p}$ acting on a structure or a structural member may be determined by vector summation of the forces $F_{w,p,e}$, $F_{w,p,i}$ and $F_{p,fr}$ calculated from the external and internal pressures using Formulae (7.6) and (7.7) and the frictional forces resulting from the friction of the wind parallel to the external surfaces, calculated using Formula (7.8).

external forces:

$$F_{w,p,e} = c_{sd} \cdot \sum_{\text{surfaces}} w_e \cdot A_{ref} \quad (7.6)$$

internal forces:

$$F_{w,p,i} = \sum_{\text{surfaces}} w_i \cdot A_{ref} \quad (7.7)$$

friction forces:

$$F_{p,fr} = c_{fr} \cdot q_p(z_e) \cdot A_{fr} \quad (7.8)$$

where

- c_{sd} is the structural factor as defined in Clause 8;
- w_e is the external pressure on the individual surface at height z_e , given in Formula (7.2);
- w_i is the internal pressure on the individual surface at height z_i , given in Formula (7.3);
- A_{ref} is the reference area of the individual surface;
- c_{fr} is the friction coefficient derived from Annex E;
- A_{fr} is the area of external surface parallel to the wind, given in Annex E.

NOTE 1 For elements (e.g. walls, roofs), the wind force becomes equal to the difference between the external and internal resulting forces.

NOTE 2 Friction forces F_{fr} act in the direction of the wind components parallel to external surfaces.

NOTE 3 The resulting force from this summation is not necessarily in the direction of the wind, especially if the structure is not symmetrical.

NOTE 4 This summation can be ignored for calculation of overall building forces unless the ground is sloping, or the calculation refers to part of a building.

(4) The effects of wind friction on the surface may be disregarded when the total area of all surfaces parallel with (or at a small angle to) the wind is equal to or less than 4 times the total area of all external surfaces perpendicular to the wind (windward and leeward).

(5) The mean wind force $F_{w,m}$ acting on a structure may be determined directly by using Formula (7.9)

$$F_{w,m} = c_f \cdot q_m(z_e) \cdot A_{ref} \quad (7.9)$$

or by vector summation over the individual structural members by using Formula (7.10)

$$F_{w,m} = \sum_{\text{elements}} c_f \cdot q_m(z_e) \cdot A_{ref} \quad (7.10)$$

where

c_f is the force coefficient for the structure or structural member, given in Annex E;

$q_m(z_e)$ is the mean velocity pressure defined in 6.3 at reference height z_e of the structure or the member defined in Annex E;

A_{ref} is the reference area of the structure or structural member as a whole or per unit length, given in Annex E.

NOTE Mean wind forces are applied in Annex E, F and J.

(6) The mean wind force, $F_{w,m}$ acting on a structure or a structural member may be determined by vector summation of the forces $F_{w,m,e}$ and $F_{w,m,i}$ calculated from the external and internal pressures using Formulae (7.11) and (7.12).

external forces:

$$F_{w,m,e} = \sum_{\text{surfaces}} c_{pe} \cdot q_m(z_e) \cdot A_{ref} \quad (7.11)$$

internal forces:

$$F_{w,m,i} = \sum_{\text{surfaces}} c_{pi} \cdot q_m(z_e) \cdot A_{ref} \quad (7.12)$$

(7) In the summation of the wind forces acting on building structures, the lack of correlation of wind pressures between the windward and leeward sides may be taken into account.

8 Structural factor c_{sd}

8.1 General

(1) The structural factor c_{sd} takes into account the effect on wind actions from the non-simultaneous occurrence of peak wind pressures on the surface together with the effect of the along-wind vibrations of the structure due to along-wind turbulence.

NOTE 1 Table 5.3 gives guidance for the determination of structural factor c_{sd} .

NOTE 2 c_{sd} can be derived using the detailed procedures in Annex F.

8.2 Approximate determination of c_{sd}

(1) c_{sd} may be taken as unity if any of the following criteria are satisfied:

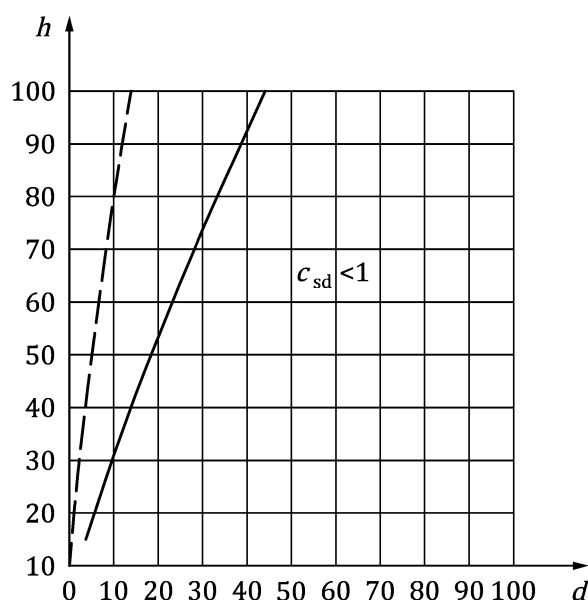
a) For buildings with a height less than 15 m.

- b) For structures having a first natural frequency greater than 5 Hz.
- c) For buildings up to 100 m high with a height less than 4 times the in-wind depth, and that have full height regular shear or cross-braced walls.
- d) Bridge decks within the scope of E.6.1 and where a dynamic response procedure is not necessary, see 5.5 (8).

NOTE 1 Figure 8.1 for multi-storey buildings and Figure 8.2 for chimneys show geometrical conditions for conservative structural factors c_{sd} being less than or equal to 1, when the basic wind velocity is less than 28 m/s.

NOTE 2 The dynamic response of flexible façade and roof elements is covered by CEN/TS 19100-2.

NOTE 3 The procedure for calculating c_{sd} covers flexible façade and roof elements with a natural frequency in the range of 3 Hz to 5 Hz. For natural frequencies above 5 Hz no dynamic effects are expected to occur and c_{sd} can be taken as 1,0.



Key

- multi-storey steel buildings
- - - multi-storey concrete buildings
- dimensions of h and d are given in m

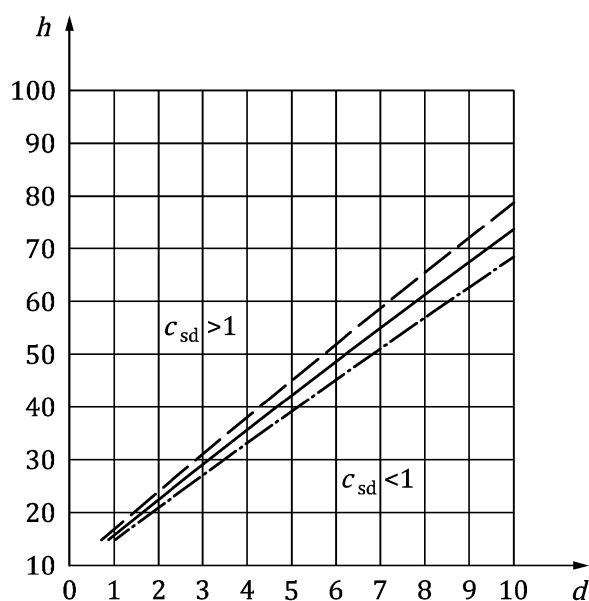
NOTE 4 Figure 8.1 based on:

Building with rectangular ground plan and vertical external walls, with regular, distribution of stiffness and mass

Roughness length	$z_0 = 0,05 \text{ m}$
Basic wind velocity	$v_b = 28 \text{ m/s}$
Logarithmic decrement of aerodynamic damping	$\delta_a = 0$
Logarithmic decrement of structural damping for steel	$\delta_s = 0,05$
Logarithmic decrement of structural damping for concrete	$\delta_s = 0,10$

The natural frequencies are estimated using the Formulae given in Annex I.

Figure 8.1 — $c_{sd} = 1,0$ for multi-storey steel and concrete buildings as function of across-wind width

**Key**

- steel chimneys without liners
 - concrete chimneys without liners
 - .-.-.- steel chimneys with liners
- dimensions of h and d are given in m

NOTE 5 Figure 8.2 based on:

Roughness length

$$z_0 = 0,05 \text{ m}$$

Basic wind velocity

$$v_b = 28 \text{ m/s}$$

Logarithmic decrement of aerodynamic damping

$$\delta_a = 0$$

NOTE 6 Specific based on Annex I:

Concrete chimneys without liners:

$$\varepsilon_1 = 700, W_s/W_t = 1,0 \text{ and } \delta_s = 0,03$$

Steel chimneys without liners:

$$\varepsilon_1 = 1\,000, W_s/W_t = 1,0 \text{ and } \delta_s = 0,012$$

Steel chimneys with liners:

$$\varepsilon_1 = 1\,000 \text{ and } W_s/W_t = 0,5$$

$$h/b < 18 \quad \delta_s = 0,02$$

$$20 \leq h/b \leq 24 \quad \delta_s = 0,04$$

$$h/b > 26 \quad \delta_s = 0,025$$

The natural frequencies are estimated using the Formulae given in Annex I.

Figure 8.2 — $c_{sd} = 1,0$ for chimneys

8.3 Serviceability assessments

(1) For serviceability assessments, displacements and accelerations of the structure at height z should be used.

(2) For the along-wind displacement, the equivalent static wind force defined in 7.5 should be used.

NOTE Methods for determining displacements and accelerations are given in Annexes F, G and H.

9 Across-wind and torsional actions on buildings

(1) The effects of across-wind and torsional-wind actions should be assessed for buildings.

NOTE 1 For $h/\sqrt{b \cdot d} < 3$ these effects are taken into account by the loading models in 5.4 see also 7.5(3).

NOTE 2 Annex G contains procedures applicable to rectangular plan buildings when $3 \leq h/\sqrt{b \cdot d} < 6$ where b , d and h are the width, depth and height of the building.

NOTE 3 For buildings with $h/\sqrt{b \cdot d}$ in the range of 6 to 8, Annex G can still be used, but the results it provides are not necessarily conservative. For buildings with $h/\sqrt{b \cdot d}$ in this range, the approach presented in H.4 and H.5 for slender structures can also be used, provided the building has a low value of the generalized Scruton Number.

NOTE 4 An approach for buildings with $h/\sqrt{b \cdot d}$ greater than 8 is given in H.4 and H.5.

NOTE 5 Limiting values of the generalized Scruton Number for the use of H.4 and H.5 can be provided by the National Annexes.

10 Aeroelastic phenomena

10.1 General

(1) The effects of aeroelastic phenomena should be assessed.

NOTE Annex H contains guidance for flexible, slender structures (e.g. chimneys, bridge decks, etc.). Annex H contains procedures applicable also to buildings when $h/\sqrt{b \cdot d} \geq 6$, see 9.

10.2 Basis for calculation

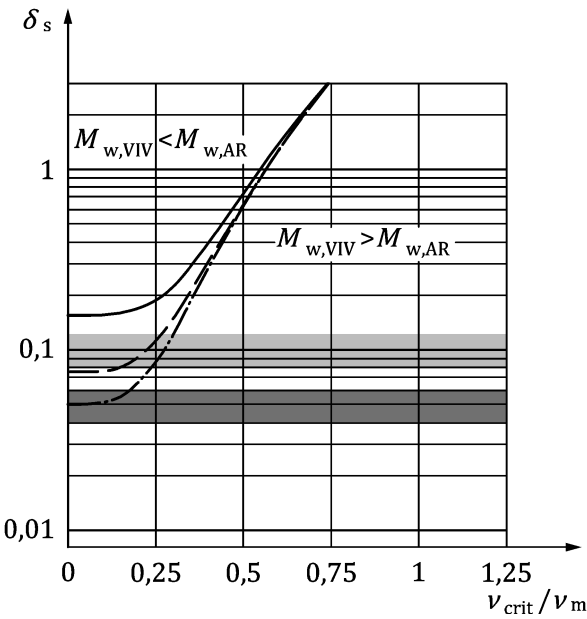
(1) The procedures given in this Clause should be used for single, slender structures with uniform sharp edged or circular cross-sections and an approximately uniform distribution of mass along their length.

NOTE Annex H provides guidance for calculation methods applicable to other types of structures.

(2) The dynamic properties of the structure, including natural frequencies and equivalent mass per unit length, should be determined.

NOTE 1 Annex I provides guidance for determination of dynamic properties of the structure.

NOTE 2 Figure 10.1 and 10.2 illustrate when the vortex-induced wind action are based on H.3, i.e. when the peak base moment from vortex-induced vibrations $M_{w,VIV}$ is larger than the peak base moment from along-wind dynamic response $M_{w,AR}$. The figures cover square buildings and chimneys. For selected ratios of the equivalent mass m_e defined in Annex I and the air mass $\rho \cdot b \cdot d$ the limit is shown as a function of the ratio between the critical wind velocity for vortex-induced vibrations and the mean wind velocity, v_{crit}/v_m , and the logarithmic decrement of structural damping, δ_s .



Key

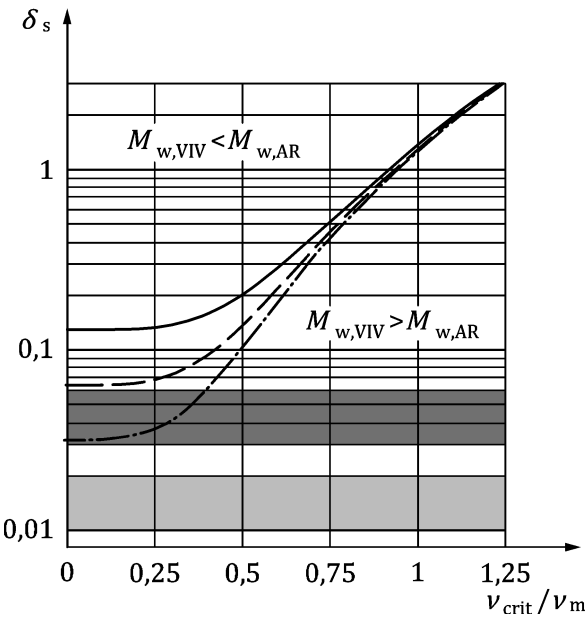
————	$m_e/(\rho \cdot b \cdot d) = 250$
- - - -	$m_e/(\rho \cdot b \cdot d) = 500$
- · - · -	$m_e/(\rho \cdot b \cdot d) = 750$
■	steel
■	reinforced concrete

NOTE 1 Figure 10.1 is based on:

Geometry and mode shape:	
Height	$h > 50 \text{ m}$
Height-to-width ratio	$h/b = 10$
Width-to-depth ratio	$d/b = 1$
Mode shape	Linear
Along wind response:	
Roughness length	$z_0 = 0,05 \text{ m}$
Force coefficient	$c_f = 1,54$
Structural factor	$c_{sd} = 1,0$
Vortex induced vibrations:	
Peak factor	$k_R = 4,0$
Aerodynamic constant	$C_c = 0,03$
Aerodynamic damping parameter	$K_a = 6,0$
Aerodynamic damping deflection term	$\frac{\sigma_y}{b \cdot a_L} = 0$

The range of typical damping values for steel and reinforced concrete buildings are shown shaded grey.

Figure 10.1 — Base moment for square buildings — No vortex-induced vibrations when $v_{crit}/v_m > 1,25$



Key

- $m_e/(\rho \cdot b \cdot d) = 50$
- - $m_e/(\rho \cdot b \cdot d) = 100$
- . - $m_e/(\rho \cdot b \cdot d) = 200$
- Steel
- Reinforced concrete

NOTE 2 Figure 10.2 is based on:

<u>Geometry and mode shape:</u>	
Height	$h > 50 \text{ m}$
Height-to-width ratio	$h/b = 10$
Width-to-depth ratio	$d/b = 1$
Mode shape	Parabolic
<u>Along wind response:</u>	
Roughness length	$z_0 = 0,05 \text{ m}$
Force coefficient	$c_f = 0,48$
Structural factor	$c_{sd} = 1,1$
<u>Vortex induced vibrations:</u>	
Peak factor	$k_R = 4,0$
Aerodynamic constant	$C_c = 0,005$
Aerodynamic damping parameter	$K_a = 1,0$
Aerodynamic damping deflection term	$\frac{\sigma_y}{b \cdot a_L} = 0$

The range of typical damping values for steel and reinforced concrete chimneys are shown shaded grey.

Figure 10.2 — Base moment for chimneys — No vortex-induced vibrations when $\nu_{crit}/\nu_m > 1,25$

10.3 Galloping

(1) Galloping may be neglected in single, free-standing circular cylinders with constant cross-section, unless subject to accretion of asymmetric ice or at critical Reynolds numbers where flow transitions from sub- to super-critical regime can lead to the so-called dry galloping.

NOTE 1 Galloping is a self-induced vibration of a flexible structure in across-wind bending mode. Non-circular cross-sections including L-, I-, U- and T-sections are prone to galloping.

NOTE 2 Ice can cause a stable cross-section to become unstable.

NOTE 3 For circular structures with variable surface roughness and asymmetry, inclined flow, and presence of water rivulets or other features can promote the risk of galloping, especially in the range of the critical Reynolds number transition, noting that this varies with surface roughness and other factors including incident small-scale turbulence.

NOTE 4 Galloping oscillation starts at a special onset wind velocity v_{CG} and normally the amplitudes increase rapidly with increasing wind velocity.

NOTE 5 Annex H provides criteria and procedures to estimate the critical divergence velocity, and methods pertaining to galloping of coupled cylinders and interference galloping.

10.4 Divergence and flutter

(1) Divergence and flutter shall be avoided, as they are likely to lead to structural collapse.

NOTE 1 Static torsional divergence and flutter vibrations are instabilities that occur for flexible plate-like structures, such as signboards, cantilever roofs or suspension-bridge decks, above a certain threshold or critical wind velocity. The instability is caused by the deflection of the structure modifying the aerodynamics to alter the loading.

NOTE 2 Annex H provides criteria and procedures to estimate the critical divergence velocity.

10.5 Wake buffeting

(1) For slender buildings ($h/\min(b, d) > 4$), chimneys ($h/\min(b, d) > 6,5$) and cooling towers in tandem or grouped arrangement, the effect of increased turbulence in the wake of nearby structures (wake buffeting) should be taken into account.

(2) Wake buffeting effects may be neglected if at least one of the following conditions applies:

- The distance between two structures referred in (1) is larger than 25 times the across-wind dimension of the upstream building or chimney.
- The natural frequency of the downstream building or chimney is higher than 1 Hz.

(3) If none of the conditions in (1) or (2) are fulfilled, wind tunnel tests should be performed, or specialist advice should be sought.

Annex A (informative)

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A.1 Editorial Note

Annex A has been removed. Due to the time constraints, the size of the document and the numerous elements (formulae, figures, tables, cross references) in the annexes that will require manual renumbering, the relevant editing will take place as appropriate after CEN Enquiry.

Annex B (informative)

Terrain effects

B.1 Use of this annex

(1) This Informative Annex provides complementary/supplementary guidance to 6 for the treatment of terrain effects.

NOTE National choice on the application of this Informative Annex is given in the National Annex. If the National Annex contains no information on the application of this Informative Annex, it can be used.

B.2 Scope and field of application

(1) This Informative Annex gives illustrations of the terrain categories.

(2) It gives an alternative equilibrium wind model applicable for slender structures with heights up to 300 m above terrain.

(3) It provides rules to calculate the effects of orography and roughness changes, and the influence of neighbouring structures.

(4) It provides a method for calculation of the displacement height, h_{dis} .

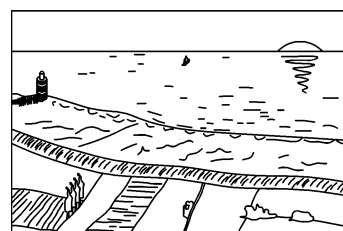
B.3 Illustrations of the upper roughness of each terrain category

(1) Terrain should be categorised to derive wind actions on a structure.

NOTE Terrain categories are illustrated in Figure B.1, to complement the descriptions given in Table 6.1. The National Annex can provide alternative images or sketches to illustrate regional differences.

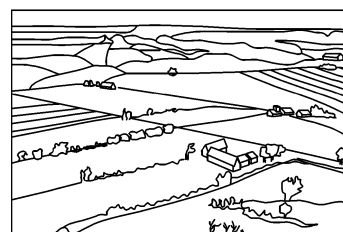
Terrain category 0

Sea, coastal area exposed to the open sea



Terrain category I

Lakes or area with negligible vegetation and without obstacles



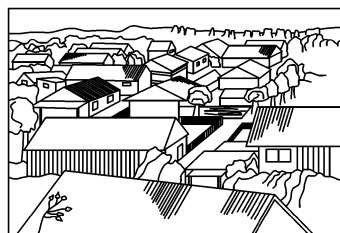
Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights



Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest)



Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m



Figure B.1 — Terrain categories

B.4 Transition between terrain categories 0, I, II, III and IV

B.4.1 General

(1) The transition between terrain categories of different roughness lengths shall be considered when calculating the peak velocity pressure, q_p and the structural factor, c_{sd} .

(2) The procedure to account for the transition between terrain categories of increasing roughness length in the wind direction shall be either Procedure 1 or Procedure 2.

NOTE The choice between Procedure 1 and Procedure 2 can be given in the National Annex.

B.4.2 Procedure 1

(1) When using Procedure 1, the terrain category with the lower roughness length in the windward direction should be used, provided that the structure is situated near a change of terrain category at a distance:

- less than 2 km from the smoother terrain category 0;
- less than 1 km from the smoother terrain categories I to III.

(2) Small areas (less than 10 % of the area under consideration) with deviating roughness may be ignored.

B.4.3 Procedure 2

(1) When using Procedure 2, the following steps should be followed:

- a) Determine the terrain categories for the upstream terrain in the angular sectors to be considered.
- b) For every angular sector, determine the distance x from the building to the upstream boundary between terrain categories.
- c) If the distance x from the building to a boundary with a terrain category with lower roughness length is smaller than the values given in Table B.1, then the smoother terrain category is used for the angular sector considered. If this distance x is larger than the value in Table B.1, the rougher terrain category is used.

(2) Small areas (less than 10 % of the area under consideration) with deviating roughness length may be ignored.

(3) Where no distance x is given in Table B.1 or for heights exceeding 50 m, the smoother terrain category should be used.

(4) For intermediate values of height z , linear interpolation may be used.

(5) A building in a certain terrain category may be calculated in a smoother terrain category if it is situated within the distance limits defined in Table B.1.

NOTE 1 Procedures 1 and 2 only deal with transitions between terrain categories of increasing roughness length in the wind direction and they result in the selection of conservative equilibrium wind and turbulence profiles. The National Annex can give alternative procedures to address other sequences of transition in terrain category and give non-equilibrium profiles.

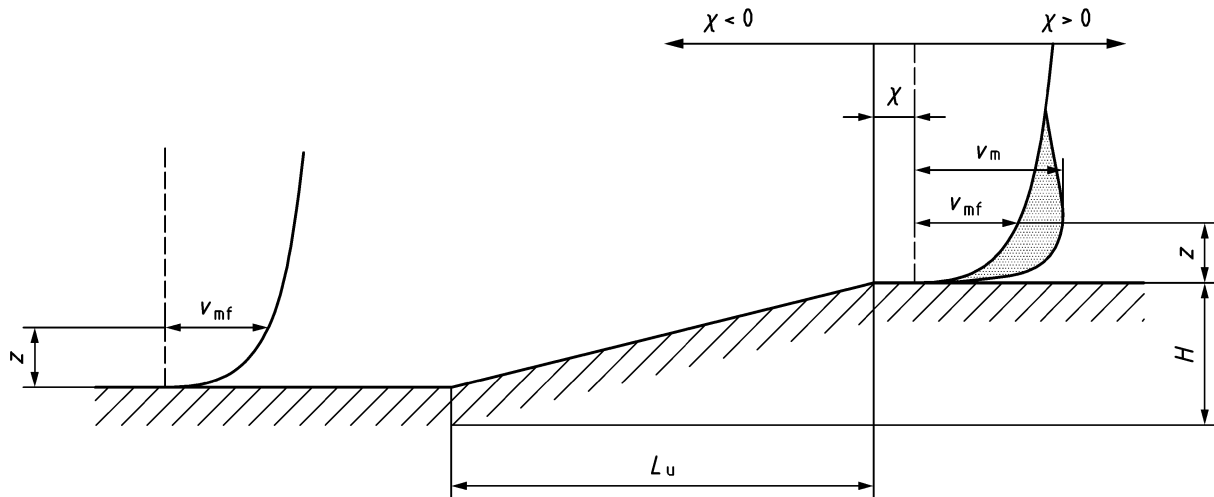
NOTE 2 The method given in the ESDU Wind Engineering Data Item 84011 is general and can be used to account for any sequence of change in upstream roughness length and give the corresponding non-equilibrium wind and turbulence profiles.

Table B.1 — Distance x

Height above ground, z	I to II	I to III
5 m	0,50 km	5,00 km
7 m	1,00 km	10,00 km
10 m	2,00 km	20,00 km
15 m	5,00 km	
20 m	12,00 km	
30 m	20,00 km	
50 m	50,00 km	
Height above ground, z	II to III	II to IV
5 m	0,30 km	2,00 km
7 m	0,50 km	3,50 km
10 m	1,00 km	7,00 km
15 m	3,00 km	20,00 km
20 m	7,00 km	
30 m	10,00 km	
50 m	30,00 km	
Height above ground, z	III to IV	
5 m	0,20 km	
7 m	0,35 km	
10 m	0,70 km	
15 m	2,00 km	
20 m	4,50 km	
30 m	7,00 km	
50 m	20,00 km	

B.5 Orography coefficients

(1) In the vicinity of isolated hills and ridges or cliffs and escarpments, mean wind velocities will increase, dependent on the upstream slope $\Phi = H/L_u$ in the wind direction, where the height H and the length L_u should be taken as defined in Figure B.2.



Key

v_m mean wind velocity at height z above terrain

v_{mf} mean wind velocity above flat terrain

$C_o = v_m/v_{mf}$

Figure B.2 — Illustration of increase of wind velocities over orography

(2) The effect of orography on the standard deviation of the turbulence (should be taken as defined in 6.4(1)) may be neglected, it only affects the mean wind velocity, $v_m(z)$.

NOTE 1 The turbulence intensity will decrease with increasing mean wind velocity and unchanged standard deviation of turbulence.

NOTE 2 The largest increase of wind velocities occurs near the crest of the topographic feature (i.e. $x \approx 0$).

(3) The effects of orography should be taken into account in the following situations:

For sites on windward slopes of hills and ridges:

- where $0,05 < \Phi \leq 0,3$ and $|x| \leq L_u/2$

a) For sites on leeward slopes of hills and ridges:

- where $\Phi < 0,3$ and $x < L_d/2$
- where $\Phi \geq 0,3$ and $x < 1,6H$

b) For sites on windward slopes of cliffs and escarpments:

- where $0,05 < \Phi \leq 0,3$ and $|x| \leq L_u/2$

c) For sites on leeward slopes of cliffs and escarpments:

- where $\Phi < 0,3$ and $x < 1,5L_e$

— where $\Phi \geq 0,3$ and $x < 5H$

(4) The orography factor, $c_o(z) = v_m/v_{mf}$ and should be defined by:

$$c_o = 1 \quad \text{for} \quad \Phi \leq 0,05 \quad (\text{B.1})$$

$$c_o = 1 + 2 \cdot s \cdot \Phi \quad \text{for} \quad 0,05 < \Phi \leq 0,3 \quad (\text{B.2})$$

$$c_o = 1 + 0,6 \cdot s \quad \text{for} \quad \Phi > 0,3 \quad (\text{B.3})$$

where

- s is the orographic location factor, to be obtained from Figure B.3 or Figure B.4 scaled to the length of the effective windward slope length, L_e ;
- Φ is the windward slope H/L_u in the wind direction (see Figure B.4);
- L_e is the effective length of the windward slope, should be taken as defined in Table B.2;
- L_u is the actual length of the windward slope in the wind direction;
- L_d is the actual length of the leeward slope in the wind direction;
- H is the effective height of the feature;
- x is the horizontal distance of the site from the top of the crest (positive leeward);
- z is the vertical distance from the ground level of the site.

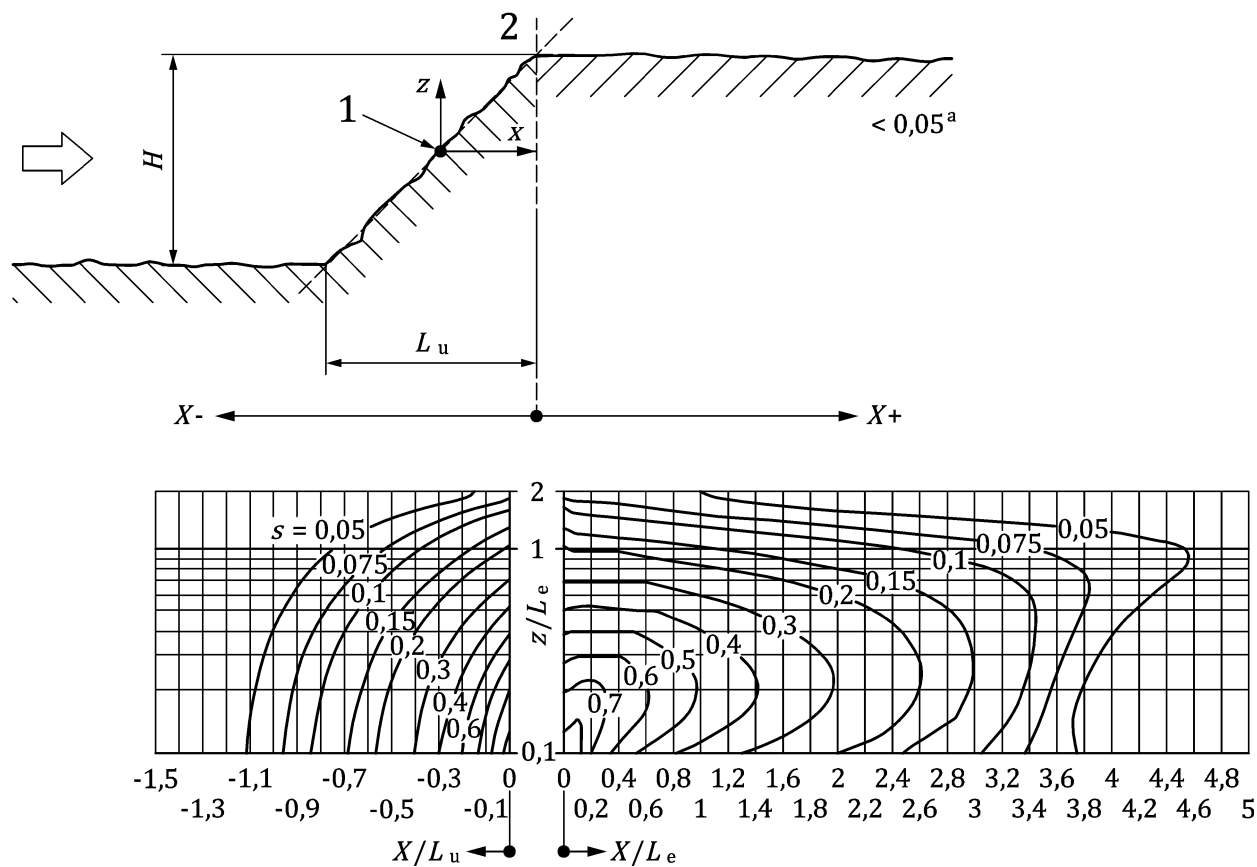
NOTE The orography factor, $c_o(z) = v_m/v_{mf}$ accounts for the increase of mean wind speed over isolated hills, ridges, cliffs and escarpments (not undulating and mountainous regions). It is related to the wind velocity at the base of the hill, ridge, cliff or escarpment.

Table B.2 — Values of the effective length L_e

Type of slope ($\Phi = H/L_u$)	
Shallow ($0,05 < \Phi \leq 0,3$)	Steep ($\Phi > 0,3$)
$L_e = L_u$	$L_e = H/0,3$

(5) In valleys, $c_o(z)$ may be set to 1,0 if no speed up due to funnelling effects is to be expected. For structures situated within, or for bridges spanning steep-sided valleys, care should be taken to account for any increase of wind speed caused by funnelling.

NOTE The National Annex can provide additional guidance to determine whether orography is significant.



Key

- 2 site
- 3 crest
- a downwind slope

Figure B.3 — Factor s for cliffs and escarpments