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Eurocode 1 - Actions on structures - Part 1-9: General actions - Atmospheric icing

Eurocode 1 - Actions sur les structures - Partie 1-9 : Givrage atmosphérique

Eurocode 1 - Einwirkungen auf Tragwerke - Teil 1-9: Allgemeine Einwirkungen - Atmosphärische Eisbildung

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

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Contents

European foreword

This document (prEN 1991-1-9:2023) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, 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 is a new part of EN 1991-1.

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.

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 parts >

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

(1) EN 1991 provides the actions to be considered 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.

(2) The actions on structures, including in some cases geotechnical structures in conjunction with EN 1997 as appropriate, provided in EN 1991 are intended to be applied in conjunction with the other Eurocodes for the verification of safety, serviceability and durability, as well as robustness of structures, including the execution phase.

(3) The application of this document for the verifications mentioned in (2) follows the limit state principle and is based on the partial factor method, unless explicitly prescribed differently.

(4) EN 1991 does not cover actions for structures in seismic regions, unless explicitly prescribed by EN 1998. Provisions related to such requirements are given in EN 1998, which complements and is consistent with EN 1991.

(5) EN 1991 is also applicable in the case of existing structures for their:

- structural assessment,
- design of repairs, improvements and alterations,
- assessment for changes of use.

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

(6) EN 1991 is also applicable to 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.

0.3 Introduction to EN 1991-1-9

EN 1991-1-9 gives design guidance for actions due to atmospheric icing on structures and civil engineering works.

EN 1991-1-9 is intended to be used with EN 1990, the other Parts of EN 1991 and EN 1992 to1999 for the design of structures.

Atmospheric icing on electrical overhead lines is covered by the CENELEC (European Committee for Electrotechnical Standardization) standard EN 50341-1.

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 EN 1991-1-9

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

The national standard implementing EN 1991-1-9 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 is given in this standard, the choice can be specified by a relevant authority or, where not specified, agreed for a specific project by appropriate parties.

National choice is allowed in EN 1991-1-9 through notes to the following clauses:

6.1 (2) NOTE

6.1 (3) NOTE 1

6.1 (4) NOTE

6.1 (5) NOTE 1

6.1 (5) NOTE 2

6.1 (5) NOTE 3

6.1 (5) NOTE 4

6.4.1 (3) NOTE

6.4.2.1 (1) NOTE 1

6.5 (5) NOTE 2

7.2 (1) NOTE

National choice is allowed in EN 1991-1-9 on the application of the following informative annexes:

- Annex A Falling ice considerations (A.1 (1));
- Annex B Information on how ice loads act on structures (B.1 (1));
- Annex C Types of icing and data collection (C.1 (1));

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 EN 1991-1-9

(1) EN 1991-1-9 gives principles and rules to determine the values of loads due to atmospheric icing to be used for following types of structures:

- masts,
- towers,
- antennas and antenna structures,
- cables, stays, guy ropes, etc.,
- rope ways (cable railways),
- structures for ski-lifts,
- buildings or parts of them exposed to potential icing,
- towers for special types of construction such as for example transmission lines and wind turbines.

NOTE Atmospheric icing on electrical overhead lines is covered by EN 50341-1.

(2) EN 1991-1-9 specifies values for:

- dimensions and weight of accreted ice,
- shapes of accreted ice.

(3) EN 1991-1-9 cover types of icing, ice loads acting on structures, and falling ice considerations.

NOTE Wind actions on iced structures are covered by EN 1991-1-4.

1.2 Assumptions

The assumptions given in FprEN 1990:2022, 1.2 apply to EN 1991-1-9.

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.

FprEN 1990:2022, *Eurocode — Basis of structural and geotechnical design*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in FprEN 1990:2022 and the following apply.

3.1.1
in-cloud icing
icing due to super cooled water droplets in a cloud or fog

3.1.2
precipitation icing
icing due to either

a) freezing rain or drizzle, or

b) accumulation of wet snow

3.1.3
accretion
process of building up ice on the surface of an object, resulting in different types of icing on structures

3.1.4
fundamental basic ice load
theoretical maximum characteristic value of rime ice mass or characteristic value of glaze ice thickness obtained on a reference collector, irrespective of wind direction, orientation of the object of icing and of the time of year, at 10 m above the ground level in open country, with an annual probability of exceedance of 0,02

3.1.5
glaze
clear, high-density ice

3.1.6
rime
white ice that forms when water droplets freeze to the outer surface of an object, trapping air

3.1.7
reference collector
30 mm diameter cylinder not less than 0,5 m in length, which slowly rotates around its own axis

3.1.8
ice class
IC
classification of the characteristic values of ice load that is expected to occur with an annual probability of exceedance of 0,02 on a reference ice collector situated in this particular location at 10 m height above the ground

3.1.9
characteristic rime ice mass
rime ice mass on the reference collector with an annual probability of exceedance of 0,02

3.1.10

characteristic glaze ice thickness

glaze ice thickness on the reference collector with an annual probability of exceedance of 0,02

3.1.11

basic ice load

fundamental basic ice load modified to account for the direction of icing wind, the characteristics of the object of icing (e.g. fixed or rotating object, surface property, colour), the orientation of the iced object (e.g. vertical or horizontal), the season and the variation with height above the ground

3.1.12

directional factor

factor taking into account the reduction of the basic ice load in cases where the icing is not uniform with respect to wind direction

3.1.13

object factor

factor taking into account the reduction of the basic ice load due to ice shedding from non-rotating objects triggered by e.g. solar radiation, temperature variations, turbulent wind or other local meteorological conditions

3.1.14

orientation factor

factor taking into account the reduction of the basic ice load in cases where the ice load depends on the object orientation, e.g. a reduction for glaze ice on vertical elements in areas where icing occur under low wind speed condition

3.1.15

seasonal factor

factor taking into account the reduction of the basic ice load in cases of temporary structures (in order of seasons length) and for structures in the execution phase

3.1.16

ice action

accreted ice on a structure, both as gravity load due to the self-weight of the ice and additional wind action on the iced structure

3.2 Symbols and abbreviations

For the purpose of this European standard, the symbols given in FprEN 1990:2022, 3.2 apply together with the following additional notations which are specific to this Part.

NOTE The notation used is based on ISO 3898:2013.

3.2.1 Latin upper case letters

D	Diameter of accreted ice or total width of object including ice
H	Height above the ground
L	Length of ice vane measured in windward direction
T	Air temperature
W_c	Width of object (excluding ice) perpendicular to wind direction
W_{dir}	Wind direction

3.2.2 Latin lower case letters

c_{dir}	Direction factor
c_{h}	Height factor
$c_{\mathrm{h}}^{\mathrm{R}}$	Height factor for rime
$c_{\mathrm{h}}^{\mathrm{G}}$	Height factor for glaze
c_{object}	Object factor
c_{orient}	Orientation factor
c_{season}	Seasonal factor
d	Diameter of object (excluding ice)
k	Factor for reduction of velocity pressure for determination of wind action
m	Mass of accreted ice per unit length
i_{b}	Basic ice load
$i_{\mathrm{b,0}}$	Fundamental basic ice load
m_{w}	Ice mass for ice on big objects
t	Ice thickness

3.2.3 Greek lower-case letters

ρ	Density of ice

4 Design situations

(1) The relevant ice loads shall be determined for each design situation identified, in accordance with FprEN 1990:2022.

(2) The combination of wind actions with icing in the persistent/transient design situations which include icing should be taken into account.

NOTE This leads to the increased vertical loads on the iced structure and increased wind drag caused by the increased wind-exposed area. The latter can lead to more severe wind loads than without icing.

(3) The impact of falling ice should be considered as accidental design situation.

NOTE Guidance for considering ice falling off the structure can be found in Annex A.

5 Classification of actions

(1) Ice loads shall be classified as variable, fixed actions unless otherwise specified in this standard.

NOTE See FprEN 1990:2022, 6.1.1 for classification of actions.

(2) For the particular case of falling ice, ice load should be considered as an accidental action.

(3) Ice loads covered in this standard should be classified as static actions.

NOTE See FprEN 1990:2022, 7.1.2 for modelling of static actions.

(4) Ice loads should be classified to “glaze”, (G), and “rime”, (R), due to the different characteristics of the icing types, see Clause 6.

6 Ice load on structures

6.1 Basic values

(1) The basic ice load i_b is the basis for specification of the ice load on a structure and shall be determined from the fundamental basic ice load (defining the icing climate).

(2) The fundamental values of the basic ice loads $i_{b,0}$ should be defined.

NOTE The fundamental values of the basic ice loads $i_{b,0}$ to be used in a country can be found in the National Annex.

(3) The fundamental values of the basic ice loads $i_{b,0}$ should be specified as a glaze (G) thickness or as a rime (R) mass.

NOTE 1 The choice between glaze thickness and rime mass is given in the National Annex.

NOTE 2 The typical properties of the different icing types are indicated in Table C.1.

(4) The fundamental values of the basic ice loads ib,0 should be provided either as characteristic values (i.e. characteristic glaze ice thickness or characteristic values of rime ice mass) directly or classified using the definition of icing classes.

NOTE The choice of providing the fundamental basic ice loads either as characteristic values or as icing classes is given in the National Annex.

(5) The basic ice load i_b shall be calculated from Formula (6.1).

$$i_b = c_{dir} \cdot c_{object} \cdot c_{orient} \cdot c_{\mathrm{season}} \cdot c_h \cdot i_{b,0} \tag{6.1}$$

where

c_{dir} is the directional factor, see NOTE 1;

c_{object} is the object factor (e.g. fixed or rotating objects), see NOTE 2;

c_{orient} is the orientation factor (e.g. vertical or horizontal), see NOTE 3;

c_{season} is the seasonal factor, see NOTE 4;

c_h is the height factor ($c_h = c_h^R$ for rime mass and $c_h = c_h^G$ for glaze thickness), see 6.5;

$i_{b,0}$ is the fundamental value of the basic ice load, see 6.1 to 6.4.

NOTE 1 Value of the directional factor is 1,0 unless the National Annex gives a different value for use in the country.

NOTE 2 Value of the object factor is 1,0 unless the National Annex gives a different value for use in the country.

NOTE 3 Value of the orientation factor is 1,0 unless the National Annex gives a different value for use in the country.

NOTE 4 Value of the seasonal factor is 1,0 unless the National Annex gives a different value for use in the country

(6) In case of tall structures, the basic ice loads should be calculated at multiple representative heights (see 6.5).

NOTE The flow chart shown in Annex D can be used as guidance for the calculation procedure.

6.2 Ice classes and characteristic values of glaze and rime

(1) If classes (ICs) are to represent the fundamental basic ice load (see 6.1 (3)), they should be determined for both glaze (ICG) and rime (ICR), because the characteristics for these differ. ICG should be determined for glaze deposits and ICR for rime deposits.

NOTE Guidance to estimate the characteristic values for rime ice mass or characteristic glaze ice thickness is given in Annex C.

6.3 Glaze

(1) If ice accretion is glaze, ice action shall be based on the Ice class for Glaze (ICG's) at 10 m above the ground given in Table 6.1, or the characteristic glaze ice thickness at 10 m above the ground at the site.

Table 6.1 — Ice thicknesses for ICGs

Ice classes ICG	G1	G2	G3	G4	G5	G6
Characteristic ice thickness *t* (mm)	10	20	30	40	50	*
*To be used for extreme ice accretions NOTE The numbers represent the upper bound for the corresponding ICGs.						

(2) The glaze ice thickness should be used for determination of the ice load on a structure according to the icing model for glaze illustrated in Figure 6.1.

(3) The ice mass on a cylinder for a given ice thickness should be calculated from

$$m = \pi \cdot \rho \cdot t\left(d + t\right) \tag{6.2}$$

where

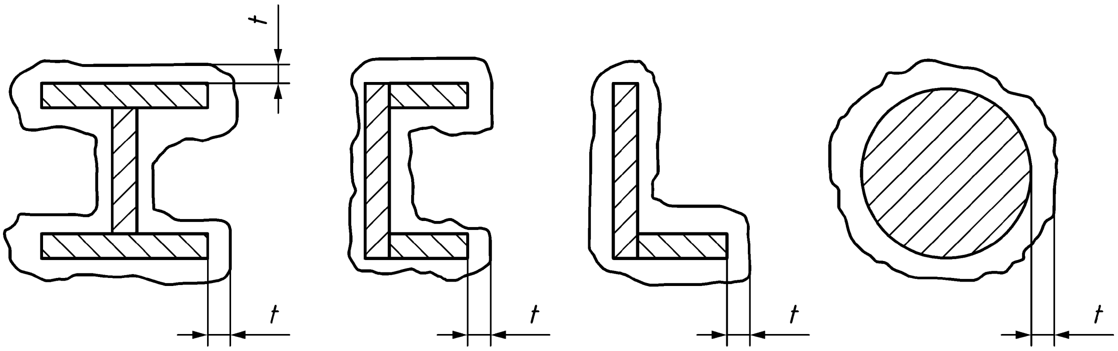
m is the glaze mass;

t is the glaze thickness;

d is the cylinder diameter;

ρ is the glaze density; ρ = 900 kg/m^3.

(4) The ice mass on other section types should be calculated by adding a constant ice thickness t to the original cross section.



Key

t thickness of ice on different profiles

Figure 6.1 — Ice accretion model for glaze

6.4 Rime

6.4.1 General

(1) If ice accretion is rime, ice action shall be based on the Ice Class for Rime (ICRs) at 10 m above the ground given in Table 6.2, or the characteristic rime ice mass at 10 m above the ground at the site.

Table 6.2 — Ice masses for ICRs

Ice classes for rime	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Characteristic Ice mass m (kg/m)	0,5	0,9	1,6	2,8	5,0	8,9	16,0	28,0	50,0	*
*To be used for extreme ice accretions NOTE The numbers represent the upper bound for the corresponding ICRs.										

(2) Unless otherwise specified, all rime ice should be considered vane-shaped (see Figure 6.2) on profiles up to a width of 0,3 m.

NOTE 1 The point of reference for the rime ice vane accretion is defined as the most windward point of the object, as seen from the icing wind direction.

NOTE 2 For asymmetric objects, the apparent cross-sectional area perpendicular to the icing wind direction defines the object width.

NOTE 3 Guidance for calculation of icing on inclined members is given in Annex B.

(3) A rime ice density should be specified for all calculations of ice thickness and vane dimensions.

NOTE The rime ice density is 500 kg/m^3 unless the National Annex gives a different value.

6.4.2 Rime on single members

6.4.2.1 Slender structural members with width (W) ≤ 0,3 m

(1) For single members with profile of width $W \leq 0{,}3$ m, the length L and the thickness t of rime should be calculated from Formulae (6.3), (6.4) and (6.5), see Figure 6.2.

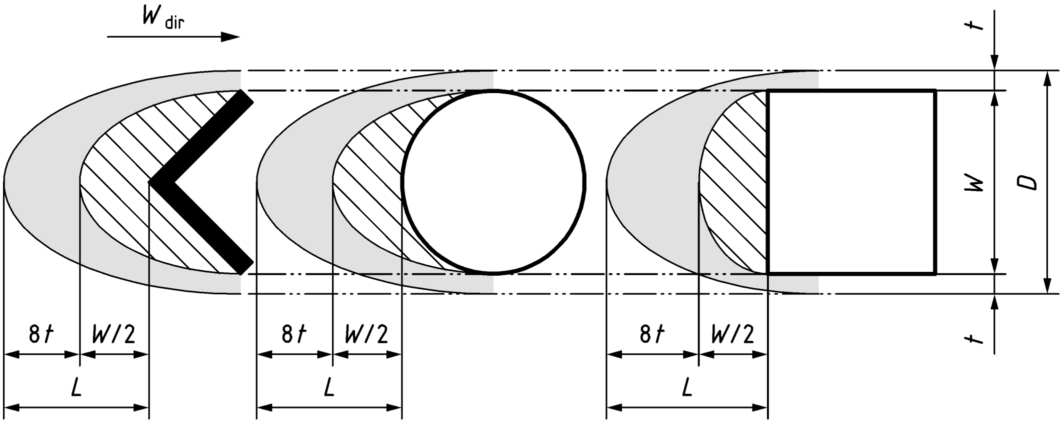
NOTE 1 Tables with the length L and the thickness t can be given for relevant ICRs in the National Annex for use in a country.

$$L = \frac{4 \cdot m}{\pi \cdot \rho \cdot W} \text{ when } W \geq \sqrt{\frac{8 \cdot m}{\pi \cdot \rho}} \tag{6.3}$$

$$L = \frac{W}{2} + 8 \cdot t \text{ when } W < \sqrt{\frac{8 \cdot m}{\pi \cdot \rho}} \tag{6.4}$$

$$t = \frac{1}{32}\left(\sqrt{68 \cdot W^2 + \frac{m}{\rho} \cdot 81{,}49} - 10 \cdot W\right) \tag{6.5}$$

NOTE 2 Formula (6.3) applies when $t = 0$.



NOTE 3 The dimensions L and t are the increase due to ice of the exposed length and width of the original profiles.

NOTE 4 The shaded area indicated with a length of $W/2$ from the point of reference shows the first stage of rime ice accretion without any increase of object width. The dimension $8t$ indicates the way in which further ice accretion occurs, where t is the increase in width measured perpendicular to the icing wind direction.

NOTE 5 The model for rime is based on the precondition that the iced member is non-rotatable and oriented in a plane perpendicular to the icing wind direction.

Figure 6.2 — Ice accretion model for Rime for members up to 0,3 m maximum dimension (for a constant wind direction the ice is formed into a "vane")

(2) Cylindrical accreted ice is only valid for slender elements of low torsional stiffness and sloping not more than about 45° to a horizontal plane (e.g. cables and steel ropes). In such cases, ice dimensions may be calculated from ice masses, defined in 6.4.1 and Formula (6.6) may be used to calculate the rime diameter D on a rotating cylinder, for an ice mass per unit length m and ice density ρ.

$$D = \sqrt{\frac{4 \cdot m}{\pi \cdot \rho} + d^2} \qquad (6.6)$$

(3) Better information may be used if this is available from e.g. measurements.

6.4.2.2 Single members with width (*W*) > 0,3 m

(1) For single members with profile of width $W > 0{,}3$ m (up to 5 m), the accretion model for rime on members should be calculated from Formula (6.7), see

(2) Figure 6.3.

NOTE 1 Ice mass on a wide object increases with width, in contrast to a small object where it is independent of width.

$$m_W = m + \left(W - W_0\right) \cdot L \cdot \rho \qquad (6.7)$$

where

L is the ice vane length for member with width $W = 0{,}3$ m (see Formulae (6.3) and (6.4));

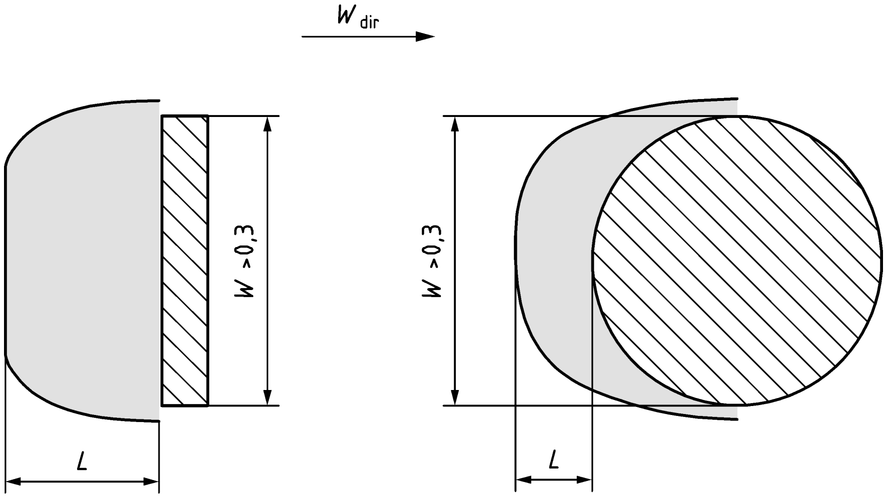
W_0 = 0,3 m

m is the ice mass per unit length for ICRs or alternatively the characteristic ice mass;

m_w is the ice mass for $W > 0{,}3$ m.

NOTE 2 *L* can be found from Formulae (6.3) and (6.4) and used together with the value of relevant ice density *ρ*.

NOTE 3 Within each ICR the length (L) of the ice vane for W = 0,3 m (in accordance with Figure 6.2 and 6.3) is kept constant for all member widths, W > 0,3 m. The ice mass is gradually increased with increasing member width.



Key

L	ice vane length
W_{dir}	wind direction

Figure 6.3 — Schematic illustration of ice aggregation for rime — large members

(3) Profiles with $W > 0{,}3$ m and non-lattice structures, such as concrete towers, claddings or other structures with solidity ratio near to or equal to 1,0, should be handled in accordance with 6.4.2.2 (1), and there is no upper limit for *W*.

(4) Better information may be used if this is available from e.g. measurements.

6.4.3 Direction of ice vanes on the structure

(1) The prevailing icing wind direction should be estimated for determination of ice load, regardless of the wind directions considered for design of the structure without icing.

NOTE The ice vanes accrete in the prevailing icing wind direction.

(2) When the prevailing icing wind direction is not known, the wind forces should be determined under the most unfavourable assumption. The ice vanes should be placed on the structures as if the icing wind direction is perpendicular to the direction of the wind used for the design of the structure without icing. For structures designed for several wind directions, this procedure should be carried out for each wind direction.

(3) Because structural cross sections have different dimensions (e.g. profile width) when seen from different directions in the horizontal plane, and the ice vanes' dimensions will be different as well, new calculations of the ice vanes' dimensions should be carried out for each wind direction.

(4) The following simpler (conservative) calculation may be used: Find the icing wind direction which produces the greatest wind action on the whole structure in question. Use this wind action and ice load for all wind directions to be investigated.

6.4.4 Rime on lattice structures

(1) For structures built of interconnected, slender elements (such as lattice masts) it should be taken into account that the ice vanes can grow together and result in much larger ice formations than possible for the equivalent solid, unperforated profile.

(2) The ice load on single members of the structure should be specified. The mass of ice should be based on ICR, or alternatively the characteristic ice mass for the site location, and all ice dimensions on any profile dimension should be determined using the Formulae in 6.4.2.

(3) The total ice mass (self-weight of ice) should be found from the sum of ice masses per unit length, where the specific mass per unit length is taken from the Formulae in 6.4.2.

(4) Reduction of ice mass due to icing overlaps may be done if sufficient data are available.

NOTE For high ICRs, icing dimensions can lead to considerable icing overlaps at intersections of structural members, because of the ice thickness. Consequently, the total ice mass can be on the conservative side.

6.5 Variation with height above the ground

(1) A height factor c_h should be used to take into account the variation of ice mass on a structure with height above the ground.

(2) The height factor should be determined based on site specific data on cloud base level/cloud profile, temperature, wind speed and precipitation.

(3) Approximate height factors $c_\mathrm{h}{}^\mathrm{G}$ and $c_\mathrm{h}{}^\mathrm{R}$ should be used for glaze and rime loads at higher levels above the ground (not above sea level).

(4) The height factor for glaze may be determined by Formula (6.8):

$$c_\mathrm{h}{}^\mathrm{G} = \left(\frac{H}{H_0}\right)^{0,13} \quad \text{for H} \geq 10 \text{ m} \tag{6.8}$$

where

H_0 = 10 m;

H is the height above the ground in meters;

The value of the height factor $c_h{}^G$ is 1 for $H < 10$ m.

(5) The height factor for rime may be determined by Formula (6.9):

$$c_\mathrm{h}{}^R = e^{\alpha \cdot (H - H_0)} \quad \text{for H} \geq 10 \text{ m} \tag{6.9}$$

where

H_0 = 10 m;

α = 0,01 m^{-1}

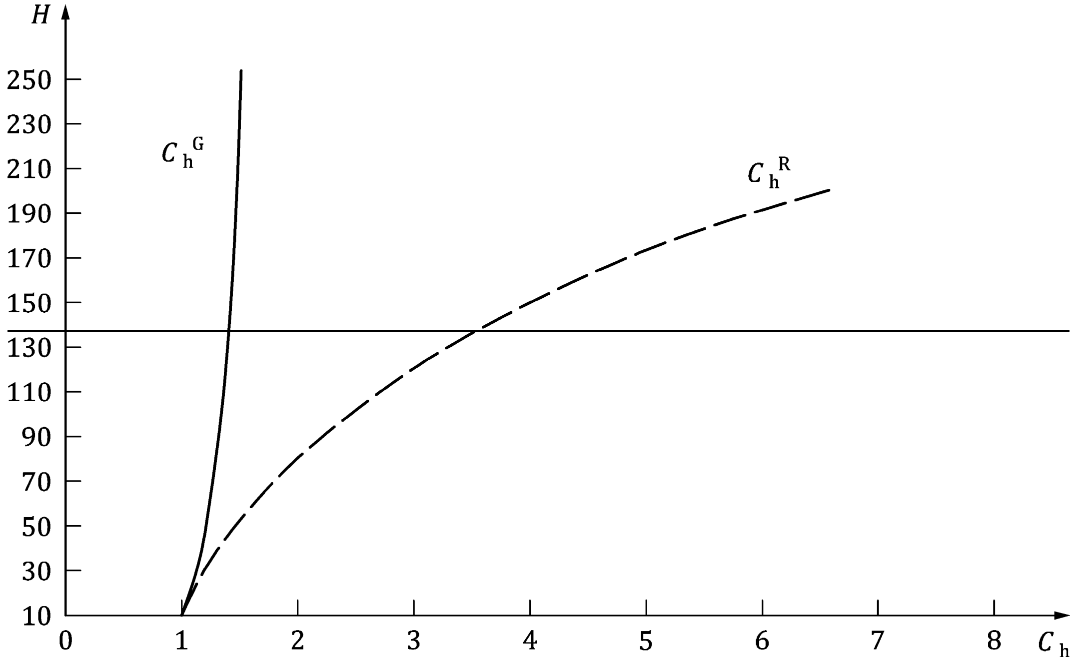
H is the height above the ground in meters. $H \geq 10$ m

The value of height factor $c_h{}^R$ is 1 for $H < 10$ m.

NOTE 1 The height factors for glaze and rime ice are shown in Figure 6.4.

NOTE 2 Height factors can be given in the National Annex.

(6) In case of a tall structure in a cold and moist climate, attention should be paid to the dependence of the rime ice load on the height, even when no icing has been observed at ground level. In such a case, the dependence on height (c_h^R) should be evaluated by assuming ice Class R1 at 10 m height.



Key

C_h^G	height factor glaze
C_h^R	height factor rime
C_h	height factor
H	height of the structure in metres [m]

Figure 6.4 — Height factors for rime and glaze

7 Combination of ice loads with other actions

7.1 General

(1) The combination of ice loads with other actions shall be based on FprEN 1990:2022, in conjunction with the supplementary provisions given in this standard.

(2) The ice accretion on structures shall be taken into account for determination of wind actions on iced structures, see FprEN 1990:2022.

NOTE The values of force coefficients for iced structural members and for lattice structures are given in Annex E of prEN 1991-1-4.

(3) Individual member's dimensions should be used as input parameters in the model used to calculate wind actions on a structure and should be adjusted for ice accretion.

(4) For rime ice, the simple approach may be used to calculate wind actions on a structure assuming that all ice vanes are perpendicular to the wind direction.

NOTE This model can give conservative results particularly if icing direction is known.

(5) If icing direction is known, ice vane direction may be fixed independent of wind direction.

(6) If the ice vane direction is kept fixed, the wind direction perpendicular to ice vane direction should be investigated carefully.

7.2 Supplementary provisions for combination of ice and wind actions

(1) The reduction factor *k* should be used to decrease wind pressure because the low probability that the wind action of 50-years return period will occur simultaneously with heavy icing condition.

NOTE The value of *k* is given in Table 7.1 (NDP) unless the National Annex gives different values.

Table 7.1 — (NDP) Factor *k* for reduction of wind pressure

ICG	k	ICR	k
G 1	0,40	R 1	0,40
G 2	0,45	R 2	0,45
G 3	0,50	R 3	0,50
G 4	0,55	R 4	0,55
G 5	0,60	R 5	0,60
		R 6	0,70
		R 7	0,80
		R 8	0,90
		R 9	1,00
		R 10	1,00

Annex A
(informative)

Falling ice considerations

A.1 Use of this Informative Annex

(1) This Informative Annex provides supplementary guidance to 4 (3) for falling ice.

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.

A.2 Scope and field of application

(1) This Informative Annex covers falling ice considerations.

A.3 Impact of falling ice

(1) When placing a structure, from which falling icing is expected, near to passing traffic or buildings, the danger of damage from the impact of falling ice should be taken into account.

(2) If a structure is guyed and the IC is R4, G2 or higher, public access to the areas located directly under the guy, such as roads and footways, should be prevented.

NOTE Falling ice can cause personal injury and excessive damage to objects below. This includes not only the lower parts of the tall structure itself but also other facilities nearby.

(3) For structures less than 30 m tall in R1 to R3 and G1, falling rime or glaze may be considered as minor hazard.

NOTE On large, close to horizontal surfaces, such as roofs, accumulated snow can melt and re-freeze at the edges, forming icicles. Thus, ice falling from roofs requires attention in all snowy areas.

(4) In the absence of expert advice or lack of data, Table A.1 may be used to determine the minimum safety distance for falling ice.

NOTE 1 There is little information about the area of a site which can be hit by shedding ice. It depends strongly on the structure of the ice in question and the actual wind speed occurring during ice shedding events. The wind direction will determine the direction of the falling ice.

NOTE 2 When a piece of ice is released from a structure, gravity and wind pressure determine its trajectory. Exact trajectories are difficult to predict because ice pieces are of different sizes, densities and shapes. Generally, the higher the wind speed and the smaller the ice dimensions, the longer is the distance between the structure and the impact location on the ground.

Table A.1 — Minimum safety distance for falling ice

IC		**Distance for falling ice**
R1-R3	G1	1/2 of structure height
R4-R6	G2-G3	2/3 of structure height
R7-R8	G4-G5	Equal to structure height
R9-R10	G6	1½ times structure height

Annex B
(informative)

Information on how ice loads acts on structures

B.1 Use of this Informative Annex

(1) This Informative Annex provides supplementary guidance to Clause 6 on how ice loads act on structures.

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 covers how ice loads act on structures.

B.3 General considerations

(1) The following should be taken into account for determination of load effects due to icing on a structure:

- Under the same meteorological conditions, the ice accretion rate will vary with the dimensions, shape and orientation of the exposed object to the wind.
- The most severe ice accretion will occur on an object which is placed in a plane, perpendicular to the wind direction, and with small cross-sectional dimensions.
- Specific objects with small cross-sectional dimensions, such as cables, mast guys, antenna elements, lattice structures, and the like, can be exposed to much higher ice accretion rates than objects of greater diameter, and a solid structural type.
- On larger objects, the accreted ice will normally be concentrated on rims and sharp edges.
- If the icing duration is long enough, the accreted rime ice layer of different cross-sectional dimensions will be almost similar.
- The rime ice mass will be significantly reduced on a “one-dimensional” object, (e.g. a wire) orientated parallel to the wind direction.

B.4 Glaze on lattice structures

(1) The masses and dimensions from 6.3 may be used directly. Adjustments because of icing overlaps at member intersections may be omitted.

(2) Based on knowledge and experience, allowance for severe formation of icicles should be made for ICG3 and greater, possibly resulting in greater ice actions than determined from 6.3 (3) and 6.3 (4).

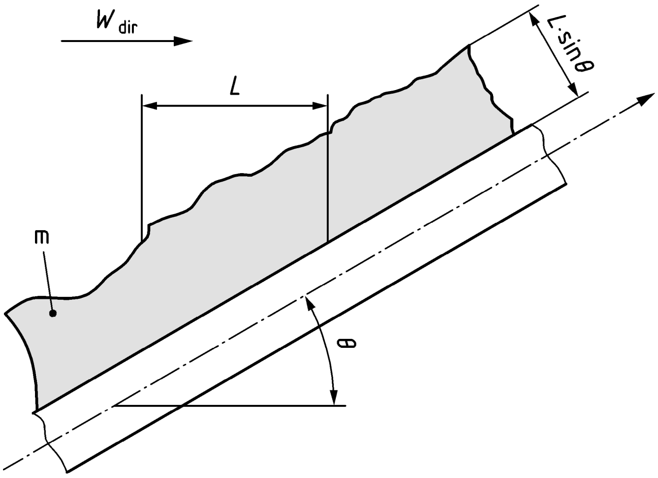
(3) The specified ice thickness should be applied to sloping members; it should be considered perpendicular to the longitudinal axis of the member and assumed to be the same in all directions around the member.

(4) No reduction of the glaze ice load should be made for members inclined to the wind direction.

B.5 Rime icing on members inclined to the wind direction

(1) The longitudinal axis of rime ice vanes should be considered horizontal, and all dimensions of ice measured in the horizontal plane.

(2) The inclination to the wind should be measured from the horizontal plane (see Figure B.1) and the resulting ice thickness along the axis of a member taken as $L \sin \theta$, and the ice mass as $m \sin \theta$ as well, where m is the ice mass for ICRs or alternatively the characteristic ice mass.



Key

L	length of ice vane measured in windward direction [m]
m	ice mass [kg/m]
W_{dir}	wind direction

Figure B.1 — Calculations for inclined members

(1) For ice formation to occur on horizontal members with longitudinal axis in the wind direction, the angle θ should be considered not smaller than 15° corresponding to a change of wind direction (in all planes) ±15° during ice accretion.

NOTE This means that a bar which is theoretically situated parallel to the icing wind direction, will at least accrete ice corresponding to an angle of incidence of 15°, resulting in an ice mass of at least $m \sin (15°)$, where m is the ice mass for ICRs or alternatively the characteristic ice mass.

B.6 Wet snow

(1) Wet snow is able to adhere to the surface of an object and should be treated as rime, i.e. ICRs or the characteristic wet snow mass at the site should be used for determination of the length L of wet snow vanes or of diameter D of wet snow accretion on a rotating cylinder (see 6.4.2).

NOTE 1 Wet snow sticks to objects because of the occurrence of free water in the partly melted snow crystals. The density and adhesive strength can vary widely with, among other things, the fraction of melted water and the wind speed (see Tables C.1 and C.2).

NOTE 2 Wet snow is a type of precipitation icing (see Table C.2). Nevertheless, wet snow is treated as rime, because both form vanes and the densities of the resulting deposits are similar.

(2) The variation of wet snow mass with height above the ground should be considered by using the approximate height factor c_h^G for glaze.

NOTE The use of height factor c_h^G for glaze results from the fact that wet snow is a type of precipitation icing.

B.7 Unbalanced ice load

(1) Asymmetric or unbalanced ice load due to ice accretion on the leeward side of a structure being smaller than on the windward side should be taken into account.

(2) Guyed masts should be considered as subjected to unbalanced ice loads where some of the guy ropes can be heavily iced, while the other guys have little or no ice due to the differences in the accretion of ice or due to shedding of ice on one side.

Annex C
(informative)

Types of icing and data collection

C.1 Use of this Informative Annex

(1) This Informative Annex provides supplementary guidance to Clause 6 for assessing the fundamental basic ice loads on a national level.

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.

C.2 Scope and field of application

(1) This Informative Annex is intended:

- to help National Authorities to assess and provide fundamental basic ice loads;
- to establish harmonized procedures to assess the fundamental basic ice loads.

C.3 Icing types

(1) Atmospheric icing should classified according to two different formation processes:

a) precipitation icing;

b) in-cloud icing.

(2) A classification may also be based on other parameters, as set out in Tables C.1 and C.2.

NOTE 1 A main precondition for significant ice accretion is the dimension of the object exposed and its orientation to the direction of the icing wind. This is explained more in detail in Clause 7.

Table C.1 — Typical properties of accreted atmospheric ice

Type of ice	Density [kg/m^3]	Adhesion and Cohesion	Formation process	General Appearance	
				Colour	Shape
glaze	900	strong	precipitation icing or in-cloud icing	transparent	evenly distributed/ icicles
wet snow	300–700	weak (forming) strong (frozen)	precipitation icing	white	eccentric, pointing windward
hard rime	600–900	strong	In-cloud icing	opaque	eccentric, pointing windward
soft rime	200–600	weak to medium	In-cloud icing	white	eccentric pointing windward

NOTE 2 In practice, accretions formed of layers of different types of ice (as mentioned in the Table C.1) can also occur, but from an engineering point of view, the types of ice do not need to be described in detail. Table C.2 gives a schematic outline of the main meteorological parameters controlling ice accretion.

Table C.2 — Meteorological parameters, controlling atmospheric ice accretion

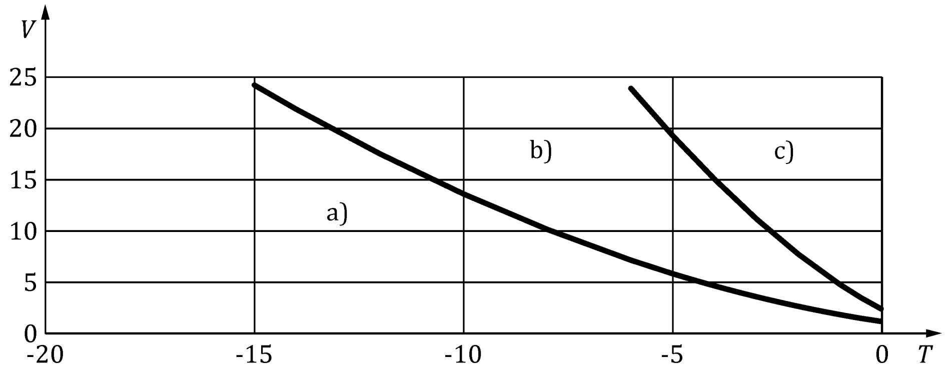
Type of ice	**Air temperature** T [°C]	**Wind speed** [m/s]	**Droplet size**	**Water content in air**	**Typical storm duration**
Precipitation icing					
Glaze (freezing rain or drizzle)	$-10 < T < 0$	any	large	medium	hours
Wet snow	$0 < T < +3$	any	flakes	very high	hours
In-cloud icing					
Glaze	see Figure C.1	see Figure C.1	medium	high	hours
Hard rime	see Figure C.1	see Figure C.1	medium	medium	days
Soft rime	see Figure C.1	see Figure C.1	small	low	days

NOTE 3 When the flux of water droplets towards the object is less than the freezing rate, each droplet freezes before the next droplet impinges on the same spot, and the ice growth is said to be dry.

NOTE 4 When the water flux increases, the ice growth will tend to be wet, because the droplets do not have the necessary time to freeze, before the next one impinges.

NOTE 5 In general, dry icing results in different types of rime (containing air bubbles), while wet icing always forms glaze (solid and clear).

(1) Figure C.1 may be used to select the parameters controlling the main types of ice formation. The density of accreted ice varies widely from low (soft rime), medium (hard rime), to high (glaze).



Key

T	temperature [°C]
V	wind speed [m/s]
a)	soft rime
b)	hard rime
c)	glaze

NOTE The curves in Figure C.1 shift to the left with increasing liquid water content and with decreasing object size.

Figure C.1 — Type of accreted ice as a function of wind speed (10 min. mean) and air temperature

C.4 Data Collection

NOTE 1 Unlike other meteorological parameters such as temperature, precipitation, wind and snow depths for example, there is generally very limited data available about ice accretions.

NOTE 2 The wide variety of local topography, climate and icing conditions make it difficult to standardize actions from ice accretion.

(1) Detailed information should be collected about icing, including frequency and intensity. The following methods may be used for specification of icing classes or characteristic values of icing:

A: existing practice and experience,

B: icing modelling based on meteorological data,

C: direct measurements of ice over many years.

(A) Method A should include collection of broad information on icing frequencies and intensities for different types of structures located within representative areas and may be used as a starting point. Persons with experience of icing in appropriate conditions and circumstances should be consulted.

(B) Method B should include collecting some additional information or assumptions about the icing parameters (i.e. mass concentration and size distribution of supercooled liquid water droplets) which often are difficult to measure directly. Alternatively, these parameters may be extracted from a numerical weather prediction (NWP) model at a horizontal resolution required to resolve the local terrain effects and employing an advanced cloud microphysics scheme which respect to the representation of the cloud and precipitation processes in the atmospheric boundary layer.

(C) In Method C, systematic measurements by an ice collecting object are required over many years, preferably decades. If this object is not the Reference collector, then the data should be transformed to the characteristic value of ice mass / glaze ice thickness as appropriate.

(2) Combination of the methods A, B and C may be used.

(3) Measurements should follow standardized procedure, consistent with the principle of the reference object.

(4) Measurements should be carried out for a sufficiently long period to form a reliable basis for extreme value analysis. The common length of the period should be at least 2 decades, depending on the conditions.

NOTE A shorter measurement period can be valuable where a link can be made to longer records of meteorological data, either physically or statistically, in combination with theoretical models. For example, a NWP model hindcast of the required quality covering several decades can be combined with a short measurement period (e.g. 2 - 5 years) in order to estimate the long term statistical distribution of ice loads.

(5) Such long-term correction of ice loads should be carried out in collaboration with specialized meteorologists.

Annex D
(informative)

Guidance how to use EN 1991-1-9

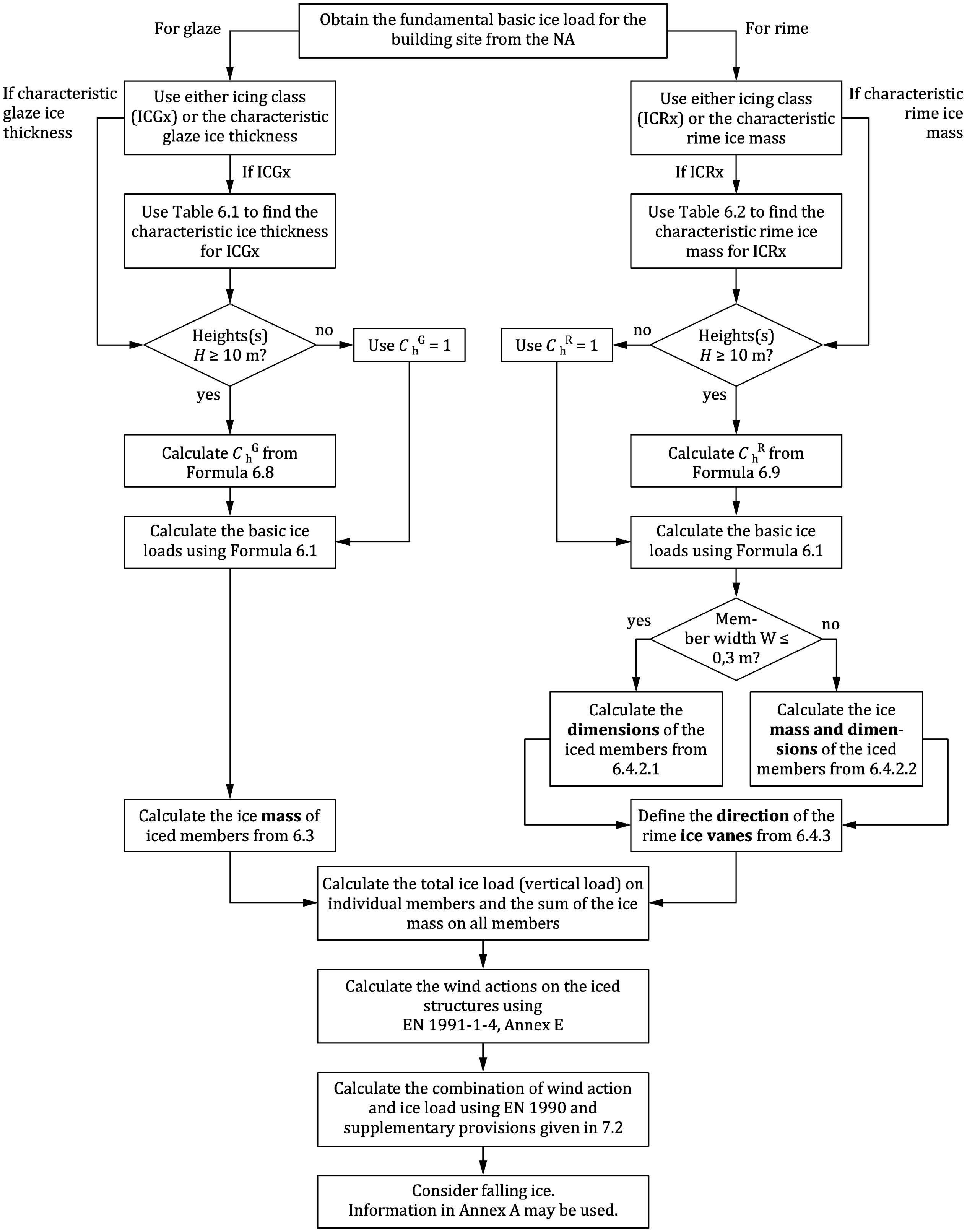


Figure D.1 — Guidance on how to use EN 1991-1-9

Bibliography

References contained in recommendations (i.e. "should" clauses)

The following documents are referred to in the text in such a way that some or all of their content constitutes highly recommended choices or course of action of this document. Subject to national regulation and/or any relevant contractual provisions, alternative documents could be used/adopted where technically justified. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

None.

References contained in permissions (i.e. "may" clauses)

The following documents are referred to in the text in such a way that some or all of their content expresses a course of action permissible within the limits of the Eurocodes. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

None.

References contained in permissions (i.e. "can" clauses) and notes

The following documents are cited informatively in the document, for example in "can" clauses and in notes.

[1] EN 50341-1, *Overhead electrical lines exceeding AC 1 kV — Part 1: General requirements — Common specifications*

[2] prEN 1991-1-4,[1] *Eurocode 1 — Actions on structures — Part 1-4: General actions — Wind actions*

[3] ISO 3898:2013, *Bases for design of structures — Names and symbols of physical quantities and generic quantities*

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[1] Under preparation.