# INTERNATIONAL STANDARD

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Second edition
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# Atmospheric icing of structures

*Charges sur les structures dues à la glace*



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# Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www. iso. org/directives).

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The committee responsible for this document is ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.



This second edition cancels and replaces the first edition (ISO 12494:2001), of which it constitutes a minor revision. The changes made are the following:

— 8.1, line 2, replaced "ISO 4355" by "ISO 4354";

— 8.3, Figure 7, revised the right figure;

— 9.1, line 2 ,9.2, line 2 to 4, replaced "exceedence" by "exceedance";

— 9.2, line 11, replaced "to day's" by "today's";

— Clause 10, line 15, replaced "5.3" by "5.4";

— A.2, Table 3, line 1, replaced "the glaze mass" by "the mass of the ice, glaze or rime";

— A.2, Table 3, line 2, replaced "the glaze thickness" by "the thickness of the ice, glaze or rime";

— A.2, Table 3, line 4, replaced "the glaze density" by "the density of the ice, glaze or rime";

— A.2, Table 3, line 4, replaced "$r$" by "$\gamma$";

— A.2, Table 3, line 1 to 4, moved before Table 3,

— B.3.2, c), replaced "see Table 2 and 2.3" by "see Table 1 in 6.2.1";

— B.3.3, line 5, replaced "definitions 3.1 and 3.2" by "definitions B.3.1 and B.3.2";

— B.3.3, line 6, replaced "Table 4 or 5" by "Table 3 or 4";

— C.3, paragraph 6, line 4, replaced "0,7 $cm^{-3}$" by "0,7 g $cm^{-3}$";

— E.4, b), line1, replaced "ICG*x*" by "ICR*x*".

Annexes A to E of this document are for information only.

# Introduction

This document describes ice actions and can be used in the design of certain types of structures.

It should be used in conjunction with ISO 2394 and also in conjunction with relevant CEN standards.

This document differs in some aspects from other International Standards, because the topic is poorly known and available information is inadequate. Therefore, it contains more explanations than usual, as well as supplementary descriptions and recommendations in the annexes.

Designers might find that they have better information on some specific topics than those available from this document. This may be true, especially in the future. They should, however, be very careful not to use only parts of this document partly, but only as a whole.

The main purpose of this document is to encourage designers to think about the possibility of ice accretions on a structure and to act thereafter.

As more information about the nature of atmospheric icing becomes available during the coming years, the need for updating this document is expected to be more urgent than usual.

Guidance is given as a NOTE, after the text for which it is a supplement. It is distinguished from the text by being in smaller typeface. This guidance includes some information and values which might be useful during practical design work, and which represents results that are not certain enough for this document, but may be useful in many cases until better information becomes available in the future.

Designers are therefore welcome to use information from the guidance notes, but they should be aware of the intention of the use and also forthcoming results of new investigations and/or measurements.



 

# Atmospheric icing of structures

## 1 Scope

This document describes the general principles of determining ice load on structures of the types listed in this clause.

In cases where a certain structure is not directly covered by this or another standard or recommendation, designers can use the intentions of this document. However, it is the user's responsibility to carefully consider the applicability of this document to the structure in question.

The practical use of all data in this document is based upon certain knowledge of the site of the structure. Information about the degree of "normal" icing amounts (= ice classes) for the site in question is used. For many areas, however, no information is available.

Even in such cases, this document can be useful because local meteorologists or other experienced persons should be able to, on the safe side, estimate a proper ice class. Using such an estimate in the structural design will result in a much safer structure than designing without any considerations for problems due to ice.

**CAUTION — It is extremely important to design for some ice instead of no ice, and then the question of whether the amount of ice was correct is of less importance. In particular, the action of wind can be increased considerably due to both increased exposed area and increased drag coefficient.**



This document is intended for use in determining ice mass and wind load on the iced structure for the following types of structure:



— 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 transmission lines, wind turbines, etc.

Atmospheric icing on electrical overhead lines is covered by IEC (International Electrotechnical Commission) standards.

This document is intended to be used in conjunction with ISO 2394.

NOTE Some typical types of structure are mentioned, but other types can also be considered by designers by thinking in terms of which type of structure is sensitive to unforeseen ice, and act thereafter.

Also, in many cases, only parts of structures are to be designed for ice loads because they are more vulnerable to unforeseen ice than is the whole structure.

Even if electrical overhead lines are covered by IEC standards, designers can use this document for the mast structures to overhead lines (which are not covered by IEC standards) if they so wish.

 

## 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.

ISO 2394:2015, *General principles on reliability for structures*

## 3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

**3.1**
**accretion**
process of building up ice on the surface of an object, resulting in the different types of icing on structures

**3.2**
**drag coefficient**
shape factor for an object to be used for the calculation of wind forces in the along-wind direction



**3.3**
**glaze**
clear, high-density ice



**3.4**
**ice action**
effect of accreted ice on a structure, both as gravity load (= self-weight of ice) and as wind action on the iced structure

**3.5**
**ice class**
**IC**
classification of the characteristic ice load that is expected to occur within a mean return period of 50 years on a reference ice collector situated in a particular location

**3.6**
**in-cloud icing**
icing due to super-cooled water droplets in a cloud or fog

**3.7**
**precipitation icing**
icing due to either

a) freezing rain or drizzle, or

b) accumulation of wet snow

**3.8**
**return period**
average number of years in which a stated action statistically is exceeded once

Note 1 to entry: A long return period means low transgression intensity (occurring rarely) and a short return period means high transgression intensity (occurring often).

 

**3.9**
**rime**
white ice with in-trapped air

## 4 Symbols

| | | |
|---|---|---|
| $C_i$ | drag coefficient of an iced object | 1 |
| $C_{0,3}$ | drag coefficient for large objects (width >0,3 m) | 1 |
| $C_0$ | drag coefficient of an object without ice | 1 |
| $D$ | diameter of accreted ice or total width of object including ice | mm |
| $F_w$ | wind force | N/m |
| $H$ | height above terrain | m |
| $k$ | factor for velocity pressure from wind action | 1 |
| $K_h$ | height factor | 1 |
| $L$ | length of ice vane measured in windward direction | mm |
| $m$ | mass of accreted ice per meter unit length | kg/m |
| $m_W$ | ice mass for ice on large objects | kg |
| $T$ | return period | year |
| $t$ | ice thickness | mm |
| $t_a$ | air temperature | °C |
| $W$ | width of object (excluding ice) perpendicular to wind direction | mm |
| $\alpha$ | angle of incidence between wind direction and the objects longitudinal axis | ° |
| $\gamma$ | density of ice | $kg/m^3$ |
| $\theta$ | angle of wind incidence in a vertical plane | ° |
| $\tau$ | solidity ratio: $\frac{\text{exposed panel area}}{\text{total panel area within outside boundaries}}$ | 1 |
| $\tau'$ | increased value of $\tau$ caused by icing to be used in calculations | 1 |
| $\phi$ | factor of combination | 1 |



 

# 5 Effects of icing

## 5.1 General

The general effects of icing are 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.

NOTE Clause 5 describes the way the ice loads act on a structure, and this can enable designers to understand the background and to use this document, even in cases which are not mentioned here.

## 5.2 Static ice loads

Different types of structure are more or less sensitive to varying aspects concerning ice action, and some examples on this are as follows.

a) Tensioned steel ropes, cables and guys, etc., are generally very sensitive to ice action, consequently tension forces in such elements can increase considerably in an iced condition.

b) Slender lattice structures, especially guyed masts, are sensitive to the increased axial compression forces from accreted ice on the structure.

c) Antennas and antenna structures can easily be overloaded by accreted ice, if this has not been foreseen. In particular, small fastening details are weak when increased load is added on top of other actions, because the ice may easily double the normal load.



d) "Sagging of ice" on non-structural elements can be harmful. Non-structural elements such as antennas and cables, may be exposed to unexpected ice load because the ice sags downwards and covers or presses on the elements. The ice action on these elements can then be substantially greater than the ice load normally accreted on them.



e) The load of accreted ice can easily deform or damage envelope elements (claddings, etc.), and damage also might occur if the ice has not fallen off before forces have grown too great.

## 5.3 Wind action on iced structures

Structures such as masts and towers, together with tensioned steel ropes, cables, mast guys, etc., are sensitive to increased wind drag caused by icing.

Wind action on iced structures may be calculated based on the same principles as the action on the ice-free structure. However, both the dimensions of the structural members and their drag coefficients are subject to changes. Therefore, the main purpose of this document is to specify proper values for

— dimensions and weight of accreted ice,

— shapes of accreted ice, and

— drag coefficients of accreted ice.

## 5.4 Dynamic effects

A significant factor influencing the dynamic behaviour of a structure is its natural frequencies.

Normally, the natural frequencies of a structure are decreased considerably if the structure is heavily iced. This is important in connection with dynamic investigations because the lower frequencies normally are the critical ones.

In addition, the change in cross-sectional shape due to the accreted ice may require dynamic investigations to be made. For example, the eccentric cross-sectional shape of ice on a cable or guy can cause aerodynamic instability resulting in heavy oscillations (e.g. galloping). Also, fully iced mast or tower sections can introduce vortex shedding, resulting in cross wind vibrations.

Shedding of ice from a structure can cause severe dynamic effects and stresses in the structure, depending on the type of structure and the amount and properties of the ice. Such dynamic effects should be investigated if the structure in question is sensitive to those actions. For a guyed mast, the shedding of ice from heavily iced guys may introduce severe dynamic vibrations and should be considered (see Clause 10).

NOTE This phenomenon has caused total collapses of very tall, guyed masts.

### 5.5 Damage caused by falling ice

When a structure is iced, this ice will sooner or later fall from the structure. The shedding of ice can be total or (most often) partial.

Experience shows that ice shedding typically occurs during increasing temperatures. Normally, accreted ice does not melt from the structure, but breaks because of small deflections, vibrations, etc. and falls off in fragments.

It is extremely difficult to avoid such falling ice, so this should be considered during design and when choosing the site for the structure.

Damage can occur to structural or non-structural elements (antennas, etc.) when ice from higher parts fall and hit lower elements in the structure. The height of falling ice is an important factor when evaluating risks of damage, because a greater height means greater dynamic forces from the ice. A method of avoiding or reducing damage from falling ice is the use of shielding structures.



NOTE See also 5.2 d) about "sagging of ice" and Clause 10 about unbalanced ice on guys, and Clause 11 on considerations on ice falling from a structure.



## 6 Fundamentals of atmospheric icing

### 6.1 General

The expression "atmospheric icing" comprises all processes where drifting or falling water droplets, rain, drizzle or wet snow in the atmosphere freeze or stick to any object exposed to the weather.

The accretion processes and resulting types of ice are described in this clause. The more theoretical explanation of the processes is given in Annexes C and D.

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

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

Therefore, local (national) work has to be done, and such work should be based upon this document (see Annex B). It is urgent to be able to undertake comparisons between collected data and to exchange experiences, because this will be a way to improve knowledge and data necessary for a future comprehensive International Standard for atmospheric icing.

Detailed information about icing frequency, intensity, etc. should be collected.

The following methods may do this.

— A: collecting existing experiences.

— B: icing modelling based on known meteorological data.

— C: direct measurements of ice for many years.

 

Method A is a good starting one, because it makes it possible to obtain quickly information of considerable value. However, it will be necessary to have different types of structures established on proper areas, to be able to collect sufficiently broad information on ice frequencies and intensities. Therefore, experienced people in those fields should be consulted, e.g. telecommunication and power transmission companies, meteorological services and the like with in-service experience. The method can be recommended as the first thing to do, while awaiting results from Method C.

Method B usually demands some additional information or assumptions about the parameters.

The principles of icing modelling are presented in Annexes C and D.

For Method C, standardized measuring devices shall be operating in the areas representative of the planned site or at the actual construction site.

It is important that measurements follow standardized procedure, and such a procedure is described in Annex B.

Measurements should be taken for a sufficient long period to form a reliable basis for extreme value analysis. The length of the period could be from a few years to several decades, depending on the conditions.

However, shorter series can be of valuable help and can also be connected to longer records of meteorological data, either statistically or (better) physically, in combination with theoretical models.

## 6.2 Icing types



### 6.2.1 General

Atmospheric icing is traditionally classified according to two different formation processes:



a) precipitation icing;

b) in-cloud icing.

However, a classification may be based on other parameters, see Tables 1 and 2.

The physical properties and the appearance of the accreted ice will vary widely according to the variation in meteorological conditions during the ice growth.

Besides the properties mentioned in Table 1, other parameters, such as compressive strength (yield and crushing), shear strength, etc., may be used to describe the nature of accreted ice.

The maximum amount of accreted ice will depend on several factors, the most important being humidity, temperature and the duration of the ice accretion.

A main preconditions for significant ice accretion are the dimensions of the object exposed and its orientation to the direction of the icing wind. This is explained in more detail in Clause 7.

**Table 1 — Typical properties of accreted atmospheric ice**

| Type of ice | Density<br>kg/m$^3$ | Adhesion and cohesion | General appearance | |
|---|---|---|---|---|
| | | | Colour | Shape |
| Glaze | 900 | strong | transparent | evenly distributed/icicles |
| Wet snow | 300 to 600 | weak (forming)<br>strong (frozen) | white | evenly distributed/eccentric |
| Hard rime | 600 to 900 | strong | opaque | eccentric, pointing windward |
| Soft rime | 200 to 600 | low to medium | white | eccentric, pointing windward |

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

A cloud or fog consists of small water droplets or ice crystals. Even if the temperature is below the freezing point of water, the water droplets may remain in the water state. Such super-cooled droplets freeze immediately on impact with objects in the airflow.

**Table 2 — Meteorological parameters controlling atmospheric ice accretion**

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



NOTE 2 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.

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.

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

Figure 1 gives an indication of the parameters controlling the major types of ice formation.

The density of accreted ice varies widely from low (soft rime) over medium (hard rime) to high (glaze).

 