INTERNATIONAL STANDARD

ISO 12494

First edition
2001-08-15

Atmospheric icing of structures

Charges sur les structures dues à la glace

Reference number
ISO 12494:2001(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

Printed in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 3.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 12494 was prepared by Technical Committee ISO/TC 98, *Bases for design of structures*, Subcommittee SC 3, *Loads, forces and other actions*.

Annexes A to E of this International Standard are for information only.

Introduction

This International Standard 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 International Standard 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 International Standard. This may be true, especially in the future. They should, however, be very careful not to use only parts of this International Standard partly, but only as a whole.

The main purpose of this International Standard 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 International Standard 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 International Standard, 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

1.1 General

This International Standard describes the general principles of determining ice load on structures of the types listed in 1.2.

In cases where a certain structure is not directly covered by this or another standard or recommendation, designers may use the intentions of this International Standard. However, the user should always consider carefully the applicability of the standard (recommendation) to the structure in question.

The practical use of all data in this International Standard is based upon certain knowledge of the site of the structure. It is necessary to have information about the degree of “normal” icing amounts (= ice classes) for the site in question. For many areas, however, no information is available.

Even in such cases this International Standard 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.

1.2 Application

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

NOTE Some typical types of structure are mentioned, but other types might be considered also. Designers should think in terms of which type of structure is sensitive to unforeseen ice, and act thereafter.

Also, in many cases only parts of structures should 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 may use this International Standard for the mast structures to overhead lines (which are not covered by IEC standards) if they so wish.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this International Standard. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

ISO 2394:1998, *General principles on reliability for structures*

ISO 4354:1997, *Wind actions on structures*

3 Terms and definitions

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

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 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
α	Angle of incidence between wind direction and the objects longitudinal axis	°
γ	Density of ice	kg/m^3
θ	Angle of wind incidence in a vertical plane	°
τ	Solidity ratio: $\dfrac{\text{exposed panel area}}{\text{total panel area within outside boundaries}}$	1
τ'	Increased value of τ caused by icing to be used in calculations	1
ϕ	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 This clause describes the way the ice loads act on a structure, and this should enable designers to understand the background and to use this International Standard, 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 International Standard 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 International Standard (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 must 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	Adhesion and cohesion	General appearance	
	kg/m^3		Colour	Shape
Glaze	900	strong	transparent	evenly distributed/icicles
Wet snow	300 to 600	weak (forming) 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 °C	Wind speed 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

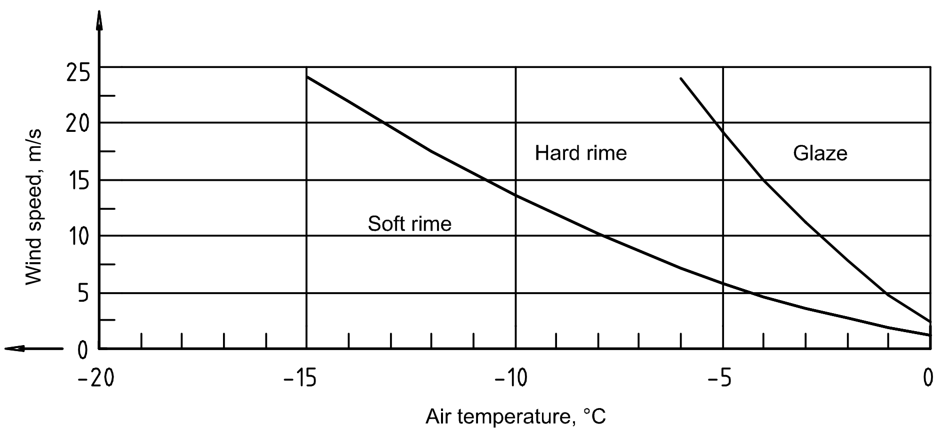
NOTE 2 When the flux of water droplets towards the object is less than the freezing rate, each droplet freezes before the next droplet impinges on the same spot, and the ice growth is said to be dry.

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).



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

Figure 1 — Type of accreted ice as a function of wind speed and air temperature

6.2.2 Glaze

Glaze is the type of precipitation ice having the highest density. Glaze is caused by freezing rain, freezing drizzle or wet in-cloud icing, and normally causes smooth evenly distributed ice accretion.

Glaze may result also in formation of icicles; in this case the resulting shape can be rather asymmetric.

Glaze can be accreted on objects anywhere when rain or drizzle occurs at temperatures below freezing point.

NOTE Freezing rain or drizzle occurs when warm air aloft melts snow crystals and forms rain drops, which afterwards fall through a freezing air layer near the ground. Such temperature inversions can occur in connection with warm fronts, or in valleys where cold air may be trapped below warmer air aloft.

The surface temperature of accreting ice is near freezing point, and therefore liquid water, due to wind and gravity, can flow around the object and freeze also on the leeward side.

The accretion rate for glaze mainly varies with the following:

— rate of precipitation;
— wind speed;
— air temperature.

6.2.3 Wet snow

Wet snow is able to adhere to the surface of an object because of the occurrence of free water in the partly melted snow crystals. Wet snow accretion therefore occurs when the air temperature is just above the freezing point.

If decreasing temperature follows wet snow accretion, the snow will freeze. The density and adhesive strength vary widely with, among other things, the fraction of melted water and the wind speed.

6.2.4 Rime

Rime is the most common type of in-cloud icing and often forms vanes on the windward side of linear, non-rotatable objects, i.e. objects which will not rotate around the longitudinal axis due to eccentrical loading by ice.

During significant icing on small, linear objects, the cross section of the rime vane is nearby triangular with the top angle pointing windward but, as the width (diameter) of the object increases, the ice vane changes its form, see clause 7.

Evenly distributed ice can also be formed by in-cloud icing when the object is a (nearly) horizontal “string” (linear shape) which is rotatable around its axis. The accreted ice on the windward side of the “string” will force it to rotate when the weight of ice is sufficient. This mechanism may continue as long as the ice accretion is going on. It results in an ice accretion more or less cylindrical around the string.

NOTE The liquid water content of the air becomes so small at temperatures below about – 20 °C that practically no in-cloud icing occurs.

The most severe rime icing occurs on freely exposed mountains (coastal or inland), or where mountain valleys force moist air through passes, and consequently both lifts the air and increases the wind speed over the pass.

The accretion rate for rime mainly varies with the following:

— dimensions of the object exposed;
— wind speed;
— liquid water content in the air;
— drop size distribution;
— air temperature.

6.2.5 Other types of ice

Hoar frost, which is due to direct phase transition from water vapour into ice, is common at low temperatures. Hoar frost is of low density and strength, and normally does not result in significant load on structures.

6.3 Topographic influences

Regional and local topography modifies the vertical motions of the air masses and hence also the cloud structures precipitation intensity and, by these, the icing conditions.

The influence of terrain is generally different for in-cloud icing than for precipitation icing. In general, topography may be the basis for defining icing zones. Most often a detailed description is necessary concerning the following:

- distance from the coast (to windward/leeward);
- elevation above sea level;
- local topography (plains, valleys);
- mountain sides facing maritime climates (to windward);
- high level areas sheltered by higher mountains;
- high mountains situated on high level areas.

The most severe icing often occurs in mountain areas, where conditions can result in a combination of in-cloud and precipitation icing, where precipitation icing will normally be of the wet snow type.

NOTE When the wind is blowing from the sea, the mountains force the moist air upwards. This leads to condensation of water vapour and droplet growth on the windward side of the mountains due to cooling of the lifted, moist air.

On the leeward side of the mountains, the cloudy air will descend and the water droplets (or ice crystals) will evaporate, resulting in dissolution of the clouds.

In a mountain area, a local face of a cliff only about 50-m height can give a significant reduction of in-cloud icing on the leeward vicinity of the cliff.

Additional lifting of the air by higher mountains, situated further inland, will cause new condensation and formation of clouds. But in this case, the passing of the coastal mountains has already reduced the liquid water content into the air. Therefore the resulting icing at inland heights usually is less severe than the icing at the coastal heights.

In valleys, where cold air can be “trapped”, severe icing due to precipitation is more frequent in the valley bottoms than on the surrounding hillsides.

6.4 Variation with height above terrain

Ice mass on a structure may vary strongly with height of the element above terrain, but so far a simple model for the distribution of ice with height has not been found.

In some cases, ice may not be observed close to ground level, but at higher levels the ice load can be significant, and also the reverse situation may be found.

If heavy ice accretions appear probable, further meteorological studies on the particular site are recommended.

NOTE Figure 2 shows a typical multiplying factor for ice masses at higher levels above terrain (not above sea level). The factor may be applied for all types of ice, if site-specific data are not available, but reality may in some cases be more complicated than Figure 2 shows.

The height effect can be expressed also by specifying different ice classes for different levels of a high structure, e.g. mast, towers, ski-lifts, etc.