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Wind actions on structures

Actions du vent sur les structures

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Foreword

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The main task of technical committees is to prepare International Standards. 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.

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ISO 4354 was prepared by Technical Committee 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 4354:1997), which been technically revised.

Introduction

This International Standard is intended for use by countries without an adequate wind loading standard and as a bridge between existing International Standards. The data in the annexes, with the exception of Annex A, whilst formally only informative, and limited to the most common usage, are intended for use within the definitions in this International Standard. Additional data will be provided from time to time in ISO Technical Reports for use on the same basis.

Wind actions on structures

1 Scope

This International Standard describes the actions of wind on structures and specifies methods of calculating characteristic values of wind loads for use in designing buildings, towers, chimneys, bridges and other structures, as well as their components and appendages. The loads are suitable for use in conjunction with ISO 2394 and other International Standards concerned with wind loads. In particular, this International Standard facilitates the conversion between peak and mean wind speed methodologies and covers the three main storm types, synoptic winds, thunderstorms and tropical cyclones (hurricanes and typhoons).

This International Standard provides the basic methods from which to determine wind loading analytically through the determination of design pressures or orthogonal along-wind and cross-wind forces and moments for structures of simple shape and wind directionality effects, and through wind tunnel or computational determinations of pressure, forces and moments for structures with complex shapes and wind directionality effects resulting in complex combinations of forces and moments.

Structures of unusual nature, size or complexity (e.g. tall buildings, long span bridges, large span roofs, guyed masts, offshore and moving structures) typically require a special engineering study; some guidance is given on the limitations of this International Standard in these cases.

Two methods of analytical determination of design wind loads are given in this International Standard, one based on a peak velocity and the other on a mean velocity. Both methods can be used when dynamic response effects are important, and where they are not important only the peak-velocity method is used in this International Standard by taking the peak dynamic response factor to be unity. To simplify presentation, the method based on the peak velocity is given in the main body of this International Standard and the method based on the mean velocity is given in a normative Annex A.

2 Normative references

The following referenced documents are indispensable for the application 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, *General principles on reliability for structures*

3 Symbols

Symbol	Term	Unit
A	Tributary or local area (area of application of pressure coefficient C_{p})	m^2
A_{ref}	Reference area for force on overall structure or part of structure	m^2
C_{dyn}	Peak dynamic response factor	1
$C_{\mathrm{dyn,\,m}}$	Mean dynamic response factor	1
C_{exp}	Peak exposure factor	1
$C_{\mathrm{exp,\,m}}$	Mean exposure factor	1
C_F	Force coefficient	1
$C_{F\mathrm{m}}$	Mean force coefficient	1
C_{p}	Pressure coefficient (time and spatially averaged)	1
$C_{\sigma F}$	Standard deviation force coefficient	1
F	Peak force	N
F_{loc}	Peak force on a tributary or local area	N
F_{m}	Mean force	N
g	Peak factor	1
g_{v}	Wind speed peak factor	1
h	Height	m
I_{v}	Wind speed turbulence intensity	1
p	Pressure	Nm^{-2}
$q_{\mathrm{ref,\,m}}$	Regional reference mean dynamic pressure	Nm^{-2}
q_{site}	Site peak dynamic pressure	Nm^{-2}
$q_{\mathrm{site,\,m}}$	Site mean dynamic pressure	Nm^{-2}
V	Peak wind speed	ms^{-1}
V_{hcr}	Critical wind speed at the top of the structure	ms^{-1}
V_{m}	Mean wind speed	ms^{-1}
V_{ref}	Regional peak reference wind speed (with return period)	ms^{-1}
$V_{\mathrm{ref,\,m}}$	Regional mean reference wind speed	ms^{-1}
V_{site}	Site peak velocity	ms^{-1}
$V_{\mathrm{site,\,m}}$	Site mean velocity	ms^{-1}
σ_{F}	Standard deviation of force	N

4 Wind actions

Wind actions that shall be considered in the design of the structure can produce the following:

a) excessive forces or instability in the structure or its structural members or elements;

b) excessive deflection or distortion of the structure or its elements;

c) repeated dynamic forces causing fatigue of structural elements;

d) aeroelastic instability, in which motion of the structure in wind produces aerodynamic forces augmenting the motion;

e) excessive dynamic movements causing concern or discomfort to occupants or onlookers;

f) effects of interference from existing and potential future buildings.

NOTE Wind pressure and force given in this International Standard are equivalent static wind loads and not pure external excitations. As the equivalent static wind loads are essentially based on linear elastic building and structure behaviour, it is necessary to give careful attention if they are applied to design in the plastic region.

5 Wind pressure

For the actions referred to in Clause 4 a), b), c) and e), the effective wind pressure, p, shall be determined from a relationship incorporating the site dynamic pressure, q_{site}, defined in Clause 7 and Clause 8, a pressure coefficient, C_p, and a dynamic response factor, C_{dyn}, of the general form of Equation (1):

$$p = q_{site} \times C_p \times C_{dyn} \tag{1}$$

The wind pressure is assumed to act statically in a direction normal to the surface of the structure or element, except where tangential frictional forces are specifically identified. Both internal and external pressures shall be considered. Integration of pressures shall be undertaken to obtain global forces or forces for defined tributary areas.

The effects of wind from all directions shall be considered.

6 Wind force

For some structures, it may be appropriate to represent the wind forces, F, by their resultants. These resultants shall include along-wind (drag), cross-wind (lift), torsional and overturning actions. Different magnitudes and distributions of the wind force can be necessary to evaluate the actions described in Clause 4 a), b), c) and e).

The derivation of effective wind forces on an element, or resultant forces and moments, shall be determined by using either the peak reference dynamic pressure given here, or the mean reference dynamic pressure given in Annex A.

The peak reference pressure method assumes that the dynamic effects can be represented by a maximum or peak loading effect based on a peak reference pressure combined with a mean pressure coefficient, (or mean pressure coefficient modified for local effects relating to area of application and statistical characteristics), and a peak dynamic response factor, C_{dyn}, from the general relationships given in Equations (2) and (3):

$$F_{loc} = q_{site} \times C_p \times C_{dyn} \times A \tag{2}$$

$$F = q_{site} \times C_F \times C_{dyn} \times A_{ref} \tag{3}$$

Equation (2) is used for the force on a tributary or local area, A. Equation (3) is used for the total force on the whole structure or part of the structure. The value of C_{dyn} can be taken as 1,0 except where the structure is dynamically wind-sensitive, as described in Annex E.

In many cases total loads on whole structures will be determined from loads determined for various components, or facades, or from along-wind and cross-wind components. These forces contribute simultaneously but are not usually well correlated. Methods for determining load combinations are given in Annex G.

It is important when using the dynamic method that the ways in which the equivalent static wind forces are distributed include not only the mean and fluctuating (background) wind forces acting on the structure's exterior, but also the inertial forces due to motions of the structure's mass.

7 Site peak dynamic pressure

The site peak dynamic pressure, q_{site}, shall be determined from the regionally derived reference wind speed, V_{ref}, along with appropriate exposure factors, C_{exp}, relating to wind speed for the site defined by the expression:

$$q_{site} = 0{,}5 \times \rho \, (V_{site})^2 \quad (4)$$

In Equation (4) the peak design wind speed locally at the site, adjusted for local exposure conditions, is given by Equation (5):

$$V_{site} = V_{ref} \, C_{exp} \quad (5)$$

where the exposure factor is determined as described in Clause 8.

The reference wind speed is normally the specified value of the wind speed for the geographical area in which the structure is located. It refers to a standard exposure (i.e. roughness, height and topography), averaging time and probability of excedence in one year (which can be approximated by an average return period for design application as required from serviceability to ultimate limit state determinations). In some situations, the reference wind speed can be specified as varying with direction. In the annexes of this International Standard the standard exposure is at 10 m height in open country terrain and q_{site} is based on a maximum 3 s mean gust wind speed, V.

Analysis procedures and values are given in Annex B and Annex C.

In certain cases, critical loading can occur at wind speeds differing from, and perhaps lower than, that specified above (e.g. due to vortex shedding). These critical wind speeds (with reference to height h) are denoted V_{hcr} and substituted for V_{site}. These cases are discussed in Annex E.

8 Exposure factor

The exposure factor, C_{exp}, relating to wind speed, accounts for the variability of the wind speed at the site of the structure for each storm type, due to

a) the height above ground level,

b) the roughness of the terrain (including change of roughness), and

c) the topography.

Values of the exposure factor are given in Annex C, and can vary with wind direction. Further guidance on the application of directional design wind speeds is given in Annex C.

9 Pressure and force coefficients

A pressure coefficient, C_p, is an aerodynamic wind-induced pressure expressed as a fraction of the reference pressure. A force coefficient, C_F, is an aerodynamic wind-induced force expressed as a ratio of the aerodynamic force exerted on a structure or its parts to a reference pressure multiplied by a reference area.

Pressure coefficients are specified as appropriate fractile values of the respective extreme actions. The fractile value to be used is defined in Annex D.

Pressure and force coefficients are influenced by the shape of the structure, the exposure, the relative wind direction, the Reynolds number and the averaging time. Values of pressure and force coefficients are presented in Annex D in tables as non-simultaneous values for the design of cladding or parts of the structure and in figures as simultaneous distributions for the design of the load-bearing structure.

Enclosed structures are subject to internal pressures determined by the size and distribution of the openings in the building envelope and by any pressurization, mechanical or otherwise. Allowance shall be made for these by combining pressure coefficients for the external pressures with those for the internal pressures.

Pressure and force coefficients shall be determined from one of the following sources:

a) Annex D;

b) appropriate wind tunnel tests, as described in Annex H;

c) appropriate computationally based data, as described in Annex I;

d) other codes or standards, provided that appropriate adjustment is made for any discrepancies, e.g. in averaging time and exposure from those used in this International Standard, and provided that adequate provision is made for a dynamic response factor.

10 Dynamic response factor

The dynamic response factor, C_{dyn}, accounts for the following actions of the wind:

a) fluctuating pressures due to random wind gusts acting over all or a part of the surface area of the structure;

b) fluctuating pressures in the wake of the structure (vortex shedding forces), producing resultant forces acting cross-wind, as well as torsionally and along-wind;

c) fluctuating pressures induced by the motion of the structure due to wind.

Information on these effects and appropriate values of the dynamic response factor is given in Annex E.

11 Criterion for aeroelastic instability

For structures affected by the wind actions specified in Clause 4 d) that cause aeroelastic instability, it is necessary to show that the performance of the structure, without further application of a load factor, is acceptable up to a wind speed somewhat higher than the design peak wind speed for the structure. Unless alternative rational procedures are available, this wind speed shall be taken as no less than the ultimate limit state site peak velocity, V_{site}, or 1,5 times the ultimate limit state 10-min mean design wind speed for the site location and height of the structure.

12 Methods of determination of wind loads

Two methods of determining design wind loads are given in this International Standard, one based on a peak velocity pressure and the other on a mean velocity pressure. Both methods are intended for use in a detailed way when dynamic response effects are important with an appropriate value of either a peak or mean dynamic response factor, guidance for which is given in Annex E. When dynamic response effects are not important, such as for the design of cladding for most typical structures and the design of the main structural systems of small- to medium-sized structures with little dynamic response effect, the peak velocity pressure method is intended for use in a simplified way by taking the peak dynamic response factor, C_{dyn}, to be unity.

For certain wind-sensitive structures specialist supplementary studies are recommended. Structures sensitive to wind include those which are particularly flexible, slender, tall or of light weight and those within complex surroundings. Unusual geometry is able to also give rise to an unexpectedly large response to wind. In these instances, supplementary studies by an expert in the field are recommended and these typically include wind tunnel tests. These tests can be used to establish details of the overall structural loads and the distribution of external local pressures. Details of suitable testing procedures are given in Annex H.

Both methods of analysis are intended for use with performance-based and limit state design methods, the requirements for which are introduced at the choice of an appropriate probability of excedance for the regional reference wind speed, defined in Clause 7.

This International Standard may be used to interpret between national and regional wind loading standards by using the relationships given in Annex B and Annex C. In using this International Standard or interpreting between national standards, it is essential that account be taken of the storm type most applicable to both the ultimate limit state and the serviceability design.

Alternative methods of analysis to those recommended in this International Standard may be permitted provided it can be demonstrated that the level of safety achieved is generally equivalent to that achieved in this International Standard. Guidance on the level of safety is given in Annex J.

Annex A
(normative)

Mean velocity method

A.1 General

Two methods for analytical determination of design wind loads are given in this International Standard, one based on a peak velocity that has been presented in the main body of this International Standard, and the other on a mean velocity that is to be presented in this normative Annex A. The mean velocity method has its main application in the determination of dynamic response effects because it transparently represents the response of the structure in terms of mean and fluctuating components, which is a more accurate description of the response process and more appropriate when considering complex structures requiring load distributions with height and load combinations as used in determinations based on wind tunnel model measurements.

A.2 Wind force analysis procedures

The mean velocity method assumes that the dynamic effects can be represented by a general expression for the peak loading effect, F, made up from the addition of a mean force component, F_m, and a fluctuating force component made up from the product of a peak factor, g, and the standard deviation of the force, σ_F, as given in Equation (A.1):

$$F = F_m + g \times \sigma_F \tag{A.1}$$

where the mean and standard deviation forces can be obtained using mean and standard deviation force coefficients, C_{Fm} and C_{σ_F} , as given in Equations (A.2) and (A.3):

$$F_m = q_{site,\ m} \times C_{Fm} \times A_{ref} \tag{A.2}$$

and

$$\sigma_F = q_{site,\ m} \times C_{\sigma m} \times A_{ref} \tag{A.3}$$

To facilitate the conversion to the peak dynamic response factor, C_{dyn}, a mean dynamic response factor, $C_{dyn,\ m}$, (often referred to as a gust effect factor for along-wind forces) can be given as Equation (A4):

$$C_{dyn,\ m} = F/F_m = 1 + g \times \sigma_F/F_m \tag{A.4}$$

And for local force, F_{loc}, on tributary or local area, A, as Equation (A.5):

$$F_{loc} = F_m \times C_{dyn,\ m} = q_{site,\ m} \times C_p \times C_{dyn,\ m} \times A \tag{A.5}$$

NOTE C_p in this application is the actual mean value and not a modified mean value.

For overall force, F, on a structure with reference area, A_{ref}, Equation (A.6) is used as follows:

$$F = F_m \times C_{dyn,\ m} = q_{site,\ m}\ C_{Fm} \times C_{dyn,\ m} \times A_{ref} \tag{A.6}$$

The peak and mean dynamic response factors can be linked through the relationship between the peak and mean wind speeds with the introduction of a wind speed peak factor, g_v, and turbulence intensity, I_v, as given in Equations (A.7) and (A.8):

$$V = V_m (1 + g_v I_v) \tag{A.7}$$

$$C_{dyn} = C_{dyn, m} / (1 + g_v I_v)^2 \tag{A.8}$$

[and as an approximation, for low turbulence intensity, $C_{dyn} = C_{dyn, m} / (1 + 2g_v I_v)$]

A.3 Site mean dynamic pressure

The site mean dynamic pressure, $q_{site, m}$, shall be determined from regionally derived mean reference wind speed, $V_{ref, m}$, along with appropriate exposure factors, $C_{exp, m}$, relating to wind speed, for the site defined using Equation (A.9):

$$q_{site, m} = 0{,}5 \times \rho \, (V_{site, m})^2 \tag{A.9}$$

where

$$V_{site, m} = V_{ref, m} \times C_{exp, m} \tag{A.10}$$

In Equation (A.10), $V_{site, m}$ is the mean design wind speed relating to the local exposure conditions and height of the structure as described in A.4.

The reference wind speed is normally the specified value of the wind speed for the geographical area in which the structure is located. It refers to a standard exposure (i.e. roughness, height and topography), averaging time and probability of excedence in one year (which can be approximated by an average return period for design application as required from serviceability to ultimate limit state determinations). In some situations, the reference wind speed can be specified as varying with direction. In the Annexes of this International Standard the standard exposure is at 10 m height in open country terrain and $q_{ref, m}$ is based on a maximum 10-min mean wind speed, $V_{ref, m}$.

Analysis procedures and values are given in Annex B and Annex C.

In certain cases, critical loading can occur at wind speeds differing from that specified above (e.g. due to vortex shedding). These critical wind speeds (with reference to height, h) are denoted V_{hcr} and are substituted for V_{ref}. These cases are discussed in Annex E.

A.4 Mean exposure factor

The mean exposure factors, $C_{exp, m}$, relating to mean wind speed account for the variability of the mean wind speed at the site of the structure, for each storm type, due to

a) the height above ground level,

b) the roughness of the terrain (including change of roughness), and

c) the topography.

Values of the mean exposure factor are given in Annex C and can vary with wind direction. Further guidance on the application of directional design wind speeds is given in Annex C.

Annex B
(informative)

Determination of reference wind speed

B.1 General

Clause 7 defines site peak and mean dynamic pressures in terms of reference wind speeds and exposure factors. The reference wind speeds for any probability of excedance in one year (average return period) shall be determined from regionally derived reference wind speeds, and for use in this International Standard the two reference wind speeds will be referenced to standard averaging times and exposure, defined as follows:

— V_{ref} is the maximum wind speed averaged over 3 s referenced to a height of 10 m over flat open country terrain;

— $V_{ref,\,m}$ is the maximum mean wind speed averaged over 10 min referenced to a height of 10 m over flat open country terrain.

Many national standards are based on annual extremes which can be appropriate where a single storm type causes the extremes. However, generally, yearly extremes do not form an appropriate basis for the extreme value analysis of wind speeds. This is especially true if the respective storm phenomenon tends to occur in families or clusters. Then, in a specific (calendar) year more than one event corresponding to the analysed storm type might be obtained, while in another year no event of the analysed storm type has occurred. In such cases, the ensemble of yearly extremes contains irrelevant data and neglects other relevant data. The ensemble therefore should consist of independent extremes above an appropriate threshold for each storm type.

B.2 Analysis procedures

The defined reference wind speeds shall be obtained from regional wind speeds, which, if not referenced as given in the definitions in Clause B.1, shall be converted by the following procedures.

a) Conversion for wind speeds referenced to different terrain roughness or height, $V_{tr,\,z}$, shall use the exposure factors, C_{exp}, $C_{exp,\,m}$, given in Annex C for the appropriate storm type as given in Equations (B.1) and (B.2):

$$V_{ref} = \frac{V_{tr,\,z}}{C_{exp}} \tag{B.1}$$

$$V_{ref,m} = \frac{V_{tr,\,z,\,m}}{C_{exp,\,m}} \tag{B.2}$$

b) Conversion to wind speeds, V_T, referenced for different averaging times, T, shall use an averaging time factor, k_T, which is based on a peak factor, g_v, and the turbulence intensity, I_v, as given in Equations (B.3) and (B.4):

$$V_T = k_T V_{T = 3\,600\text{ s}} \tag{B.3}$$

$$k_T = 1 + g_v I_v \tag{B.4}$$