Macau Regulamento de Segurança e Acções em Estruturas de Edifícios e Pontes

Wind Action Revision (Consultation Document)

Revision of Chapter III - Wind Action - of
Regulamento de Segurança e Acções em Estruturas de Edifícios e Pontes
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Chapter III
Wind Action

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Chapter III

Wind Action

Article 17°

(Wind action and their effects on structures)

1. Characterization of wind action and methods of design analysis

Macau region shall be qualified as exposed to severe typhoon wind occurrences, as it happens in the close Hong Kong region.

Wind action is a complex phenomenon not only in the wind approaching the structures but also in the flow pattern generated around the building (distortion of the mean flow, flow separation, formation of vortices, and development of the wake).

This induces large wind pressure fluctuations on the wrapping surfaces of the structures, resulting in large aerodynamic forces and localized fluctuating forces. So the structure tends to vibrate in planar and torsional modes, with oscillation amplitudes depending namely on the aerodynamic nature of the relevant wind-induced forces, on the dynamic characterization of the envelope surfaces, and on the response behavior of the structure.

The determination of wind action and the analysis of their effects on structures, and on their attached elements, may be assessed either by simplified analytical or experimental methodologies, taking consideration, with an increasing strictness, the previously mentioned nature of the aerodynamic random wind forces and the dynamic nature of the corresponding structural response effects.

In the context of these wind code provisions, only the simplified and deterministic procedures are specified either for the characterization and definition of the wind-induced actions, or for the modelization and structural analysis of their effects on buildings and other structures.

This simplified modelization of the structural behavior consider the application of simplified, dynamic equivalent, static methods of analysis, henceforth called as *simplified static analysis*, to determine the corresponding internal member forces, and assuring full consistency with the RSA criteria for structural integrity and serviceability, during the expected life-time of the structures.

However, in some rather flexible and special structures, such code simplified methodologies, can become inappropriate, as the dynamic effects of the wind random excitation become more relevant, and full dynamic analysis and experimental wind tunnel testing will be required.

2. Scope

The main objective of these wind code specifications is the definition, for the Macau region, of the adequate characteristic values of wind action that, affected by the relevant coefficients, shall be considered in the analysis and design of structures, under a *simplified static analysis* concept.

Considering that this simplified modelization concept is to be used both, on the wind action evaluation and on the corresponding analysis of their structural response effects, the scope of these code specifications includes, in general, the following types of the more usual and ordinary structures:

- regular building structures, with heights up to 200 meters; their components (e.g. walls, roofs) and attached secondary elements (e.g. chimneys, canopies, balconies);
- bridge structures, other than the cable-supported ones, and having spans up to 200 meters.

The above specified building structures also include the ones with moderate flexibility (first mode fundamental frequency within 0.2 Hz to 1 Hz). In these cases the building structures should be classified as *dynamic sensitive* and an adequate dynamic response coefficient (C_{dyn}>1) should be applied to calculation of wind forces such that the *simplified static analysis* can still be used.

However, these code specifications do not give guidance for the following special structural situations:

- flexible structures, with their first mode fundamental frequencies less than 0.2 Hz;
- special flexible structures, such as cables, masts, chimneys, lattice towers, and cable-supported bridges, characterized by the occurrence of aero-elastic type of response behavior (vortex, flutter, galloping);
- irregular building structures, such as those with unusual or complex geometry, where significant eccentricities and torsional vibration effects could occur;
- structures where vibration modes other than the fundamental mode needs to be considered;
- structures under “shielding effects” resulting from closely spaced buildings or obstacles,
- structures for which, in addition to the *alongwind response* dynamic force component, also the *crosswind response* component could be significant.

All the above special situations will require the use of more refined analytical modelization or experimental analyses, employing wind tunnel testing of aero-elastic building models, together with a full spectral definition of the dynamic wind actions.

3. Units and definitions

For the purposes of these wind code provisions, the SI units system is adopted and the following definitions shall be applied:

- *Characteristic value (wind pressure or speed)* – a gust wind pressure (or speed) value (or profile values), having a return period of 50 years.
- *Return period (of an event)* – or *average recurrence interval of an event* – is the inverse (expressed in years) of its annual probability of exceedance (expressed in decimal format). For example: an event with a return period of 50 years, will occur on average once in every 50 years, and will have an annual probability to be exceeded of 2%.
- *Annual probability of exceedance (of an event)* – the probability that an event will be exceeded in any one year (inverse of the return period). For example: an event with an annual probability of exceedance of 0.002, have a return period of 500 years, or it will occur, on average, once in every 500 years.

- *Life-time (or reference) period of a structure* – intended period of time that a structure is to be exposed to a particular wind action, complying with all the intended safety and serviceable conditions, with anticipated routine maintenance, but without requiring any significant major structural repair.
- *Profile (wind speed or pressure)* – variation of wind speed or pressure value with height above ground.
- *Enclosed building* – building with roof and full wrapping walls not permeable to the wind (opposite to an “open” building).
- *Open framework* – structure without wrapping walls.
- *Breadth (of a building)* – horizontal dimension of a building, normal to wind direction.
- *Structure envelope* – external wrapping surfaces (or cladding) of a structure, exposed to wind action.

4. Statistical and experimental analysis concepts for evaluation of wind action

The quantification of the wind action was based on a detailed statistical analysis of the available wind records in Macau, performed at The University of Hong Kong, based on their staff expertise in wind code research, including intense use of their wind-tunnel resources.

The initial wind data base of Macau comprise the continuous wind records, from the year 1952 up to the year 2005, collected by Macau Direcção dos Serviços Meteorológicos e Geofísicos, available from the following meteorological stations of: Guia, Fortaleza do Monte, Taipa Grande and Ponte de Amizade. These original wind records of the hourly mean wind speeds were affected by the topographic and local effect of each anemometer station, so compelling to perform initial normalization of all the available wind data information, based on the adequate modelization of Macau region and recurring to the wind-tunnel experimental research.

The conclusion of the extreme wind statistical analysis, in terms of mean and gust wind speed, for wind blowing over the sea surface at a height of 250m, considering various annual probabilities of exceedance, and assuming an adequate confidence level of 99.5%, is shown in the following Table III.1:

Table III.1 - Mean and gust wind speeds, referred to a height of 250 m, over sea surface, for various return periods.

Return Period (year)	10	20	50	100	200	500
Mean Wind Speed (m/s)	48.1	52.0	56.6	59.8	62.9	66.7
Gust Wind Speed (m/s)	60.7	65.6	71.9	75.5	79.4	84.2

5. Characteristic value of gust wind speed and corresponding reference period

The Macau wind code provisions restrict their applicability to the situations where simplified static equivalent procedures can be adopted, as detailed in n^{o}. 2 of this article.

Under this context, the present specifications assume, as its "reference-base criterion", that the characteristic value of a gust wind speed, for wind blowing over a sea surface and acting on structures under any horizontal direction, is specified as 71.9m/s, referred to an altitude of 250m.

This specified characteristic gust wind speed value corresponds to an annual probability of exceedance of 2%, which is equivalent to a return period of R=50 years, occurring in a structure, during a reference period of 50 years (or a structure life-time period of 50 years).

The following two relevant considerations shall be pointed out to complete this important wind code specification for the Macau region:

a. The above wind action, specified in terms of a characteristic intensity and a probability of occurrence of a gust wind speed value, should be understood as always acting horizontally on construction structures, irrespectively of its particular horizontal incidence direction. In fact all the horizontal wind directions have been included in the previously performed statistical extreme wind analysis.

b. Only one type of "terrain roughness" is to be considered for all the Macau territory, corresponding to a wind blowing horizontally over the sea surface. In fact, since Macau always presents small geographic plan dimension in all the directions, any change of terrain roughness is not able to induce modification on the characteristics of wind flow over the territory.

6. Definition of characteristic gust wind pressure profile

The distribution in height above the ground of the wind gust characteristic values, if expressed in their corresponding pressures effects on a building façade, roof or exposed structure, can be graphically described as a *gust wind pressure profile*. The configuration of this profile follows a pattern depending on (1) the variation of mean speed and turbulence intensity with height above the ground, and (2) the local topographic conditions near the ground level.

The characteristic values of the gust wind pressure profile, w_{kh}, are related with the characteristic gust wind speed profile, v_{kh}, by the following expression:

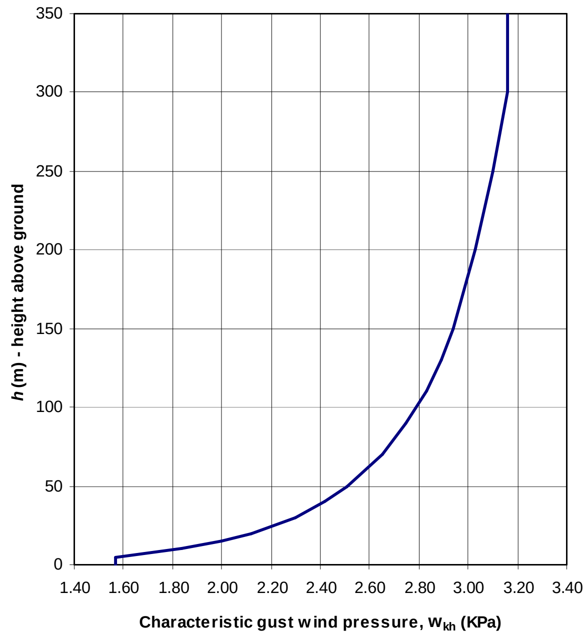
$$w_{kh} = \frac{1}{2}\delta\, v_{kh}^2$$

where: δ = density of air, taken as 1.20 kg/m^3, for 20° C

The graphic representation and the corresponding tabulated values for the characteristic gust wind pressures profile are shown in Table III.2:

Table III.2 - Graphic representation and tabulated values of the characteristic gust wind speeds and pressures profile

***h* (m)**	**Characteristic gust wind**	
	Speed, V_{kh} (m/s)	**Pressure, W_{kh} (kPa)**
≥300	72.6	3.16
250	**71.9**	**3.10**
200	71.1	3.03
150	70.0	2.94
130	69.4	2.89
110	68.6	2.83
90	67.7	2.75
70	66.5	2.65
50	64.7	2.51
40	63.5	2.42
30	61.9	2.30
20	59.5	2.12
15	57.8	2.00
10	55.4	1.84
≤5	51.2	1.57



Note 1: For intermediate height values, a linear interpolation could be done.

Note 2: Exception for constructions with open framework near the ground level, in all the other full enclosed cases, a constant value shall be used for the characteristic gust wind pressure profile over the lower part of the construction. The height up to which this constant value occurs should be the breadth or the full height of the construction, whichever is lesser, and its constant pressure value shall be the wind pressure at that level (see n°. 1.1.1 of Appendix B to Annex 3).

7. Safety verification on structures exposed to wind action

To ensure a reliable consistency with the RSA specifications for safety verification of structures (Articles 6° to 10°), the following should be pointed out, under the wind action point of view:

- The safety verification, under the *serviceability limit state*, shall be performed based on characteristic values of gust wind pressure, corresponding to a return period of *R* = 50 years. The safety verification, under the *ultimate limit state*, shall be performed based on design values of gust wind pressure (characteristic values scaled up by a partial safety factor of $\gamma_q=1.5$), corresponding to a return period near to *R* = 1000 years.
- If the wind is not the basic variable action of a load combination, the reduced wind pressure values shall be obtained through the following combination coefficients: $\psi_0 = 0.4$; $\psi_1 = 0.2$; $\psi_2 = 0$. For structures with utilization referred in n°. 3 and n°. 5 of Article 27°, and where the live-load is the basic action of the combination, shall be assumed $\psi_0 = 0.6$.
- Return periods (*R*) and/or structure reference life-time (*L*), others than the code's reference-base ones, could be enabled, in well

justified situations, according to Appendix D to Annex 3 of this Chapter III. Normally the requirement to change the return period, only, is related to a modification of a collapse probability, but the demand to change a structure reference life-time, only, could be justified to take in account its social-economic importance level, under the point of view of very severe damage occurrences.

8. <u>Pressures, forces and friction forces on structures or in part of structures</u>

a - To obtain the complete definition of the wind pressures acting on a structure or its parts, the characteristic gust wind pressure profile, defined in the previous n^{o}. 6, should take in account the effects of the local topographic conditions, the shape configuration and permeability of the exposed surfaces, and the dynamic response of the structure.

These effects, defined as multiplier coefficients $\boldsymbol{C_t}$, δ_p or δ_f and $\boldsymbol{C_{dyn}}$, shall be successively applied to the characteristic values of the gust wind pressure profile, w_{kh}, and will be defined in the following Articles 18°, 19° and 20°. The characteristic wind action (pressure and force) shall be determined as follows:

$$p_h = [\ w_{kh} \times C_t\ ] \times \delta_p \times C_{dyn}$$
$$F_h = [\ w_{kh} \times C_t\ ] \times \delta_f \times C_{dyn} \times A_h$$

where:
- p_h wind pressure acting normal to the surface (kPa), at height *h*;
- F_h wind force acting normal to the surface (kN), at height *h*;
- w_{kh} characteristic gust wind pressure values (kPa), at height *h*;
- C_t topographic coefficient, as defined in Article 18°;
- δ_p or δ_f pressure or force coefficients, as defined in Article 19°;
- C_{dyn} dynamic response coefficient, as defined in Article 20°;
- A_h effective projected area (m^2) at height *h*, upon which the pressure w_{kh} acts.

b - If the effect of wind friction, on the surfaces parallel to the wind, is significant when compared with the pressure forces, and cannot be disregarded, then the corresponding friction force (F_{fr}) should be considered, in the addition to the previous wind pressure or force on the surfaces normal to the wind. This friction force shall be determined as follows:

$$F_{fr} = [\ w_{kh} \times C_t\ ] \times \delta_{fr} \times C_{dyn} \times A_{fr}$$

where:
- δ_{fr} friction coefficient, as defined in Article 19°;
- A_{fr} reference area (m^2) of the external surface parallel to the wind;
- w_{kh}, C_t and C_{dyn} see previous item 8.a.

Usually this effect of wind friction on the surfaces could be disregarded when the total area of all surfaces parallel (or with a small angle) to the wind is equal to or less than 4 times the total area of all external surfaces normal to the wind.

Article 18°

(Topographic effect)

Since wind increases its speed - wind “speed-up” effect – if it moves up the windward slope of a hill or a ridge, when a building or a structure is located on this topographic condition and if this could be qualified as significant, according to the criteria defined in Appendix A to Annex 3, the characteristic gust wind pressure profile values w_{kh} shall be multiplied by a topographic coefficient, $C_t > 1$.

If the topographic conditions are qualified as not significant, then $\boldsymbol{C_t} = 1$.

In general the EuroCode EN 1991-1-4:2005 concepts are used, namely on its "Annex A.3 – Numerical calculation of orographic coefficients". However, the coefficient values have been adjusted to apply on the effective gust wind pressure values as defined, in these code specifications, for the Macau region.

If a more complex topographic condition occurs, the approach given in these code specifications may underestimate the "speed-up" effect and is hence not applicable. In these situations, more refined studies are recommended; such as wind tunnel testing of those particular topographic situations.

Article 19°

(Shape coefficients)

1. Introduction

To determine the wind action over on a building or a structure it is required to consider the shape configuration and the wind permeability of the external wrapping surfaces (or envelopes) of those constructions, directly exposed to the wind action. This is obtained through the application of the shape coefficients to the gust wind pressures, as it is described in this article and defined in Appendix B to Annex 3, for the more usual shape configuration cases.

Three types of shape coefficients are considered: pressure coefficient, force coefficient, and friction coefficient.

2. Pressure coefficients δ_p

The pressure coefficients, δ_p, are defined for a particular surface (globally and in singular localized parts), and the corresponding wind pressures are obtained, acting on the surfaces, in perpendicular direction.

For buildings the wind pressure acting on their exposed wrapping surfaces consists of external and internal components. The external coefficient, δ_{pe}, depends on the shape configuration of the surfaces and the wind direction. The internal coefficient, δ_{pi}, depends on the air permeability of the building façades (ratio of openings areas to the total area and their distribution).

The pressure coefficients, δ_{pe} and δ_{pi}, will be positive or negative, depending on their "pressure effect" or "suction effect", normally related to the relevant exposed or not exposed or roof surface side of the façade. Combinations from the possible positive and negative internal and external pressures should be considered to obtain the most severe condition for design.

Furthermore in localized areas, usually close to edges of walls and roofs, local actions are developed and in Appendix B to Annex 3 are presented the respective external pressure coefficients – the localized coefficients.

Values of local pressure coefficients are intended for the design of small elements and fixings located in some sensitive areas, such as purlins and roof plate connections (in roof structures) and balconies and windows (in buildings façades). These localized pressures are to be used only in the design of those secondary elements, and should not be added to the external wind pressures acting in the whole structure.

3. **<u>Force coefficients δ_f</u>**

The overall wind induced loads on buildings or structures can be obtained from the spatial distribution of their elementary pressures and areas, using pressure coefficients (δ_p). Alternatively, a force coefficient can be used (δ_f), to define the corresponding global (resultant) wind force.

4. **<u>Friction coefficients δ_{fr}</u>**

When the tangential wind effects in surfaces or protrusions (e.g. ribs or corrugations) parallel to the wind direction are significant – friction forces - the friction coefficient, δ_{fr}, should be used, as described in the Article 17•, n^{o}.8.b.

Article 20°

(Dynamic response of structures)

1. **<u>Dynamic sensitive concept and criteria</u>**

In *dynamic sensitive* structures, a dynamic response coefficient C_{dyn} (>1) shall be applied to the characteristic gust wind pressure profile values, to account for the relevant dynamic behavior of these structures, when induced by wind.

To assess if the building structure is either *dynamic sensitive* or *dynamic non-sensitive* its first mode fundamental frequency, n_a, should be determined, and the dynamic response coefficient, C_{dyn}, shall be determined, if applied.

- If n_a is greater than 1 Hz then the structure (or structural element) is *dynamic non-sensitive* and $\boldsymbol{C_{dyn}}$ is equal to 1;
- If n_a is within 1 Hz and 0.2 Hz then the structure is *dynamic sensitive* and $\boldsymbol{C_{dyn}}$ shall be defined according to Appendix C to Annex3 for *alongwind response*;
- If n_a is less than 0.2 Hz then the structure is out of the scope of this wind code specification.

An alternative method to assess the dynamic sensibility of structures, which does not require the calculation of the first mode fundamental frequency, could be the following simplified criteria - a building structure shall be qualified as *dynamic sensitive* if it has either of the following properties:

- height of structure exceeds 100 meters, or
- height of structure exceeds 5 times the least plan dimension (the smaller dimension of the rectangular envelope, enclosing the main vertical structural elements of the structure).

2. **<u>Applicability condition</u>**

It should be noted that the applicability criteria of this simplified qualification of structures, as *dynamic sensitive* or *dynamic non-sensitive*, are inherent to the wider applicability concept of the present wind code provisions as a whole, where only models and simplified analysis methodologies are specified.

This means that the above qualification is not applicable to structures out of the scope defined in Article 17•, n^{o}.2, such as the more flexible ones with significant dynamic response and torsional effects. In these cases the relevant dynamic effects should be investigated according to recommendations given in published literature and/or through model testing in the wind tunnel. The accurate dynamic response of such structures should usually be obtained from the modal combination of responses corresponding to more than one vibration mode, under a full dynamic definition of the wind actions.

Annex 3 – Wind Action

Appendix A – Topographic coefficient (C_t)

As it happens frequently, some localized orography situations occur that could affect and modify the characteristic gust wind pressure profile (as defined in n°.6 of Article 17° for a planar, horizontal, and over the sea, approach condition).

The situation considered in this appendix corresponds to the “speed-up” effect that could occur when the wind flow intersects a localized upwind or downwind slope situation that could induces important modifications to the corresponding gust wind pressure profile, namely near the bottom levels. In the following Figure III.A.-1, it is represented, in a schematic way, the resultant effect of upwind type interference.

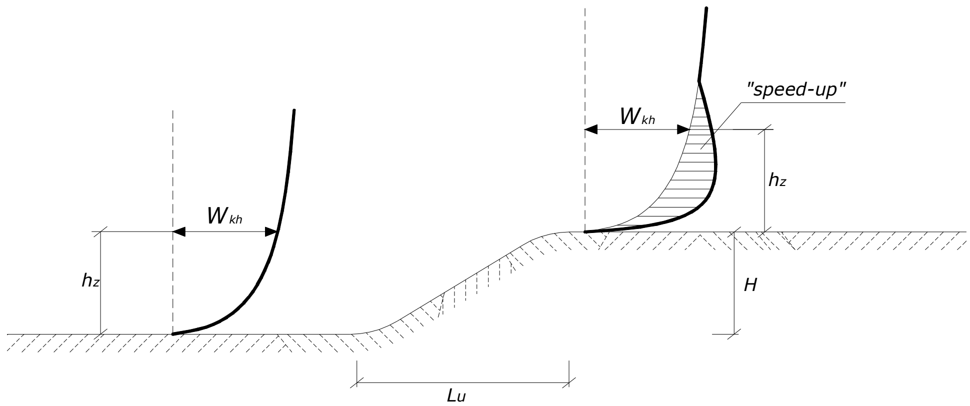


Figure III.A.1 – Illustration of the topographic effect – wind “speed-up”

This appendix aims to quantify this effect in terms of a corrective factor to the gust wind pressure characteristic profile, defining first the topographic singularity relevance and second to determine the topographic coefficient, C_t, value that shall be multiplied to the characteristic wind profile.

1. To assess the relevant topographic parameters and to decide if a particular topographic feature should be considered as significant, it is required to determine the corresponding cross-sectional shape of the topographic feature, along the wind direction plan.

   The key parameters to consider are: the upwind slope ($\phi = H/L_u$), and the relative position of the structure to the crest, as shown in Figures III.A.2 and III.A.3.

2. A particular topographic condition shall be qualified as significant in the following situations:

   a) For sites on upwind slopes of hills and ridges:
   - where $0.05 < \phi \leq 0.3$ and $|X| \leq L_u/2$

   b) For sites on downwind slopes of hills and ridges:
   - where $\phi < 0.3$ and $X < L_d/2$
   - where $\phi \geq 0.3$ and $X < 1.6\,H$

   c) For sites on upwind slopes of cliffs and escarpments:
   - where $0.05 < \phi \leq 0.3$ and $|X| \leq L_u/2$

   d) For sites on downwind slopes of cliffs and escarpments:
   - where $\phi < 0.3$ and $X < 1.5\,L_e$
   - where $\phi \geq 0.3$ and $X < 5\,H$

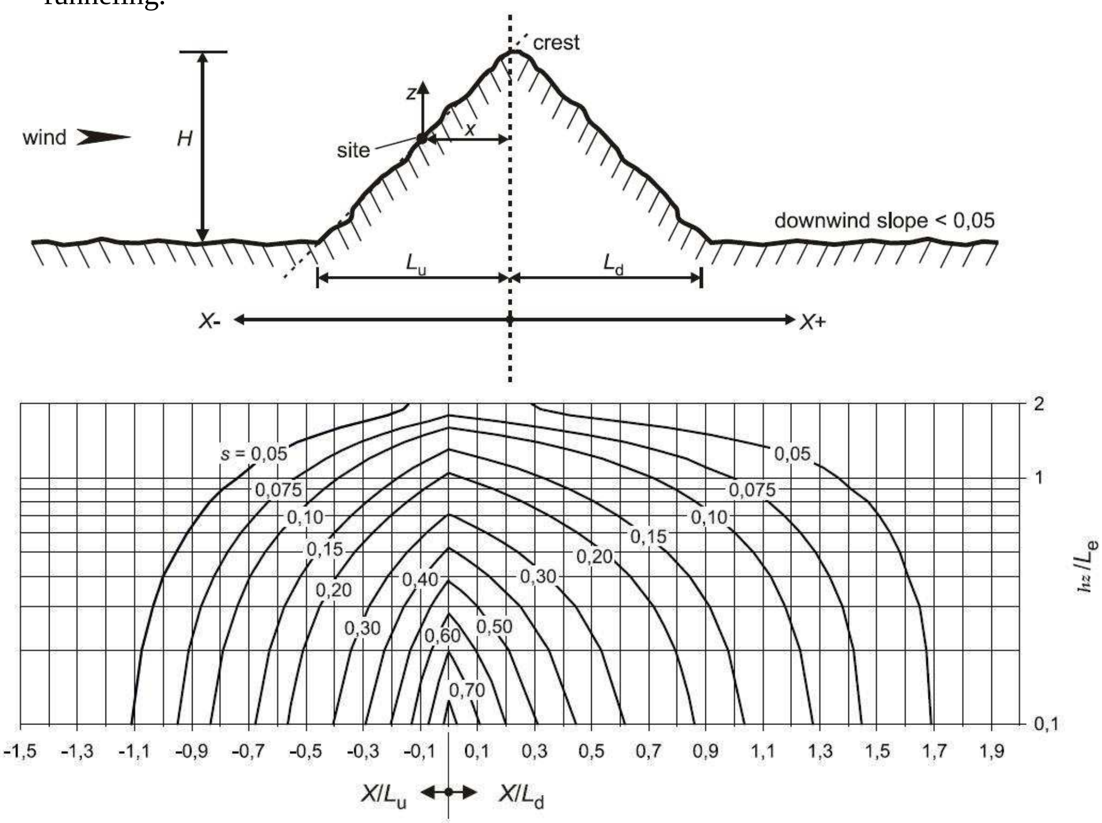
3. The topographic coefficient ($\boldsymbol{C_t}$) is defined, for gust wind pressure, as follows:

$C_t = 1$	for	$\phi < 0.05$
$C_t = (1 + 1.50 \times s \times \phi)^2$	for	$0.05 < \phi < 0.3$
$C_t = (1 + 0.45 \times s)^2$	for	$\phi > 0.3$

where:

- s topographic location factor, to be obtained from Figure III.A.2 or III.A.3 scaled to the length of the effective upwind slope length, L_e
- ϕ upwind slope H/L_u in the wind direction (see Figure III.A.2 and II.A.3)
- L_e effective upwind slope length, defined as follows:
  - if $0.05 < \phi < 0.3$ (shallow slope) …….… $L_e = L_u$
  - if $\phi > 0.3$ (steep slope) ………………….. $L_e = H/0.3$
- L_u actual length of the upwind slope in the wind direction
- L_d actual length of the downwind slope in the wind direction
- H effective height of the feature
- X horizontal distance of the site from the top of the crest
- h_z variable height (along z direction), above ground level, where the topographic coefficient is to be applied to the characteristic gust wind pressure profile

4. In valleys C_t may be set to 1.0 if no speed up due to funneling effects is to be expected. For structures situated within, or for bridges spanning steep-sided valleys care should be taken to account for any increase of wind speed caused by funneling.



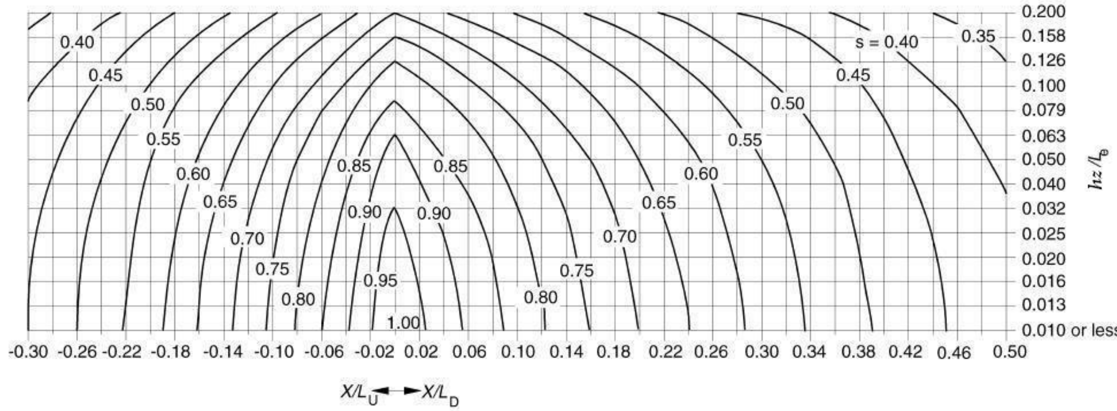


Figure III.A.2 – Topographic location factor (***s***) for hills and ridges

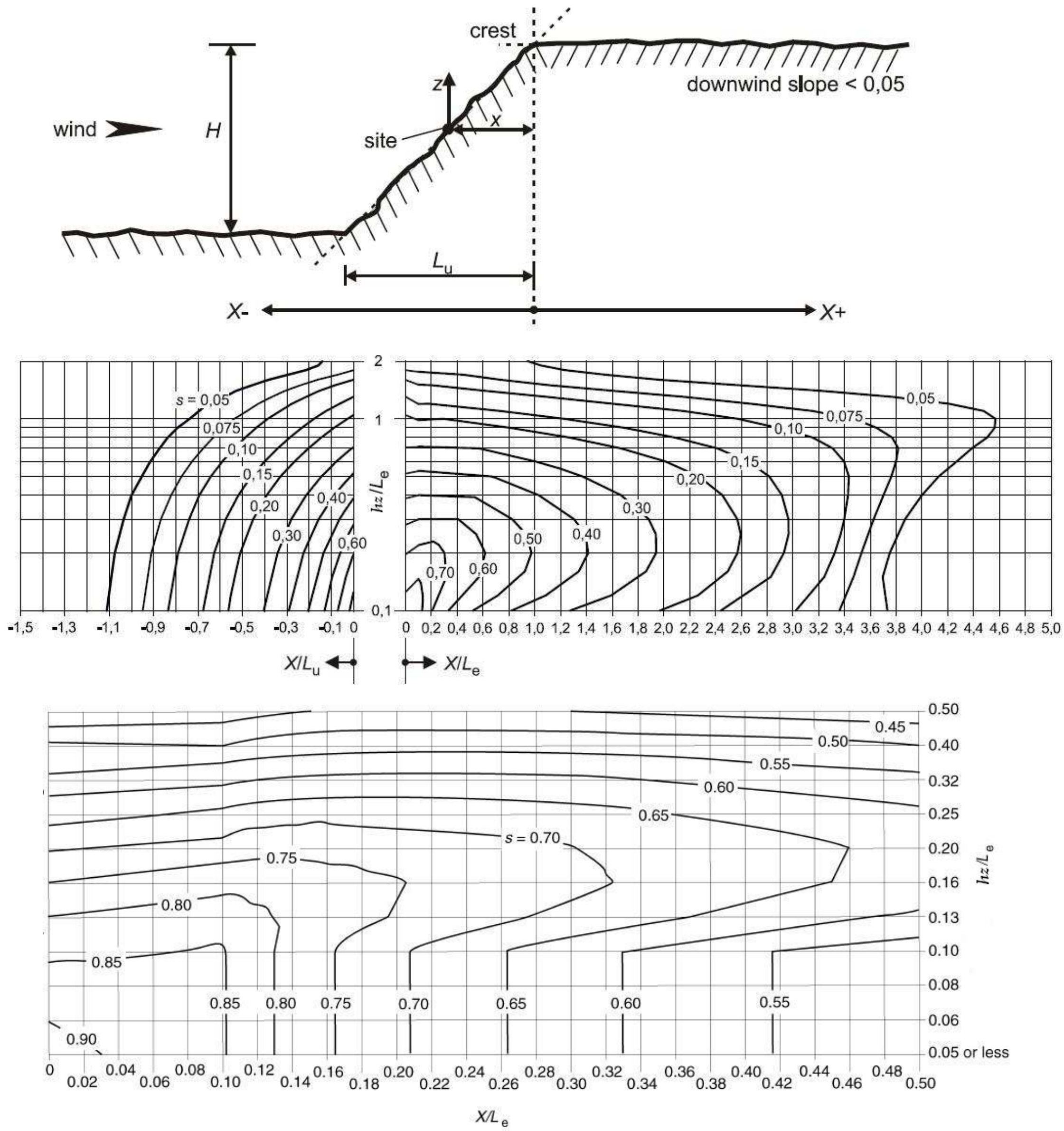


Figure III.A.3 – Topographic location factor (***s***) for cliffs and escarpments

Acknowledgement: Figures III.A.2 and III.A.3 in this Appendix A have been extracted from British Standards with the permission of BSI under license number 2007ET00200, dated on 20 July 2007.

Appendix B – Pressure and friction coefficients (δ_p and δ_{fr})

The more usual shape configuration cases are presented, for pressure and friction coefficients, following in general the Portuguese RSA Regulation 1983 and the EN 1991-1-4:2005 concepts.

Other pressure and friction coefficients, for more special configuration cases, and also force coefficients (not included in these specifications) could be found either in other code provisions or by appropriate modelization and testing in wind-tunnel laboratories. However adequate adjustments shall be made for any discrepancies concerning the relevant concepts assumed in these code specifications.

1. Pressure coefficients, δ_p, for buildings

Values are defined for the external, δ_{pe} , and the internal, δ_{pi} , pressure coefficients to be applied to usual buildings with a rectangular plan.

1.1 External pressure coefficients, δ_{pe}

1.1.1 Vertical walls of rectangular plan buildings

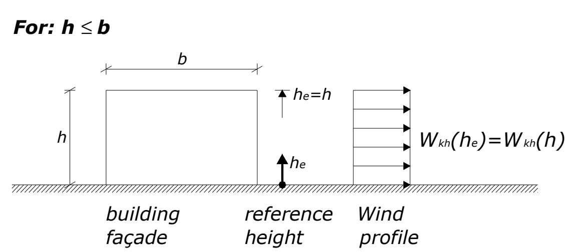
The pressure coefficients in the windward walls, leeward walls and sidewalls of rectangular plan buildings (zones A, B, C, D and E, see Table III.B.1) depend on the aspect ratio *h/d*, where *h* is always the upper height of the wall and *d* is the dimension of the building plan parallel to wind direction.

To assess the adequate wind profile for the windward walls it is necessary to define the reference height, h_e. This reference height depends on the ratio *h/b*, where *b* is the breath, and three cases can occur as shown in Figure III.B.1.

Note that, in general, the pressures in the exposed surface of a building can be considered uniform, though for the sidewalls this simplification is not acceptable. Therefore, according to the definition of parameter *e*, a subdivision of the sidewalls surface into zones (zones A, B and C) is presented in Figure III.B.2, and the corresponding pressure coefficients are accessible in Table III.B.1.

Also note that for the leeward wall (zone E) and sidewalls (zones A, B and C) the reference height, h_e, should always be the building height, *h*, and so the previous three cases considered in Figure III.B.1 are not applicable.

An equivalent overall pressure coefficient in the wind direction can be obtained by the vector summation of the windward and leeward pressure coefficients. Nevertheless, when this equivalent overall pressure coefficient is used, due to the lack of correlation of wind pressures between windward and leeward side, a reduction factor is allowed to be multiplied to this external net coefficient. So as follows: for buildings with $h/d \geq 5$ should be multiplied by 1; for buildings with $h/d \leq 1$ should be multiplied by 0.85; and for intermediate values of *h/d*, a linear interpolation may be applied. However, for example in portal frame structures, such net coefficient can not be used and the corresponding windward and leeward external coefficients have to be considered separately.



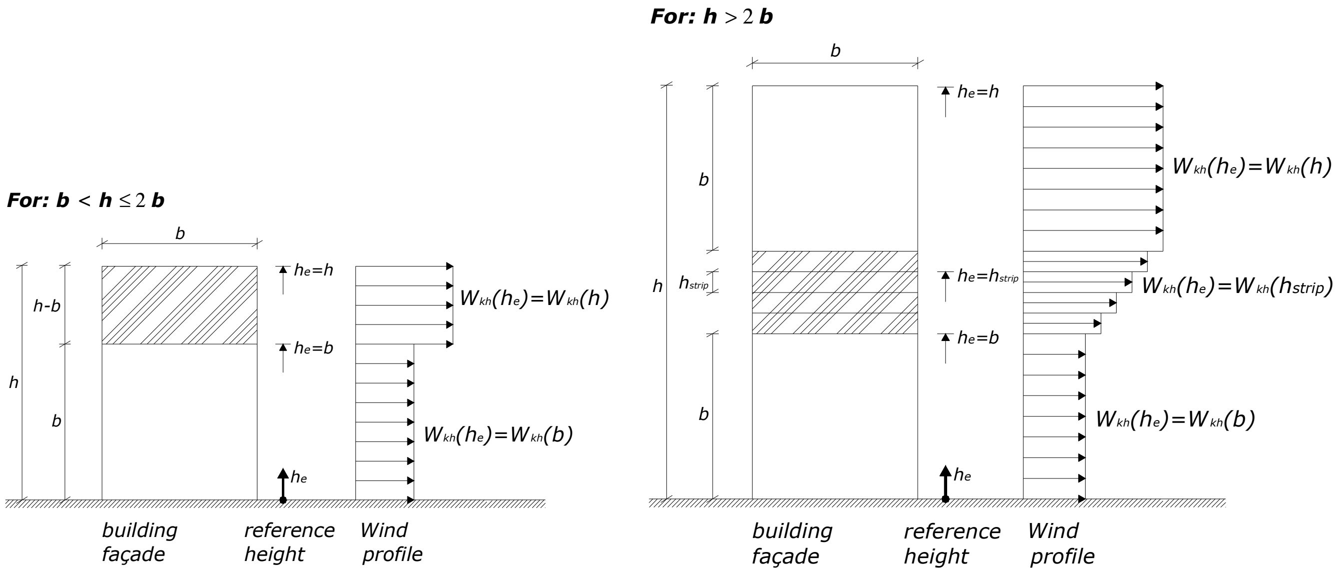


Figure III.B.1 - Reference height, h_e, and corresponding pressures profile for the windward walls of rectangular plan buildings

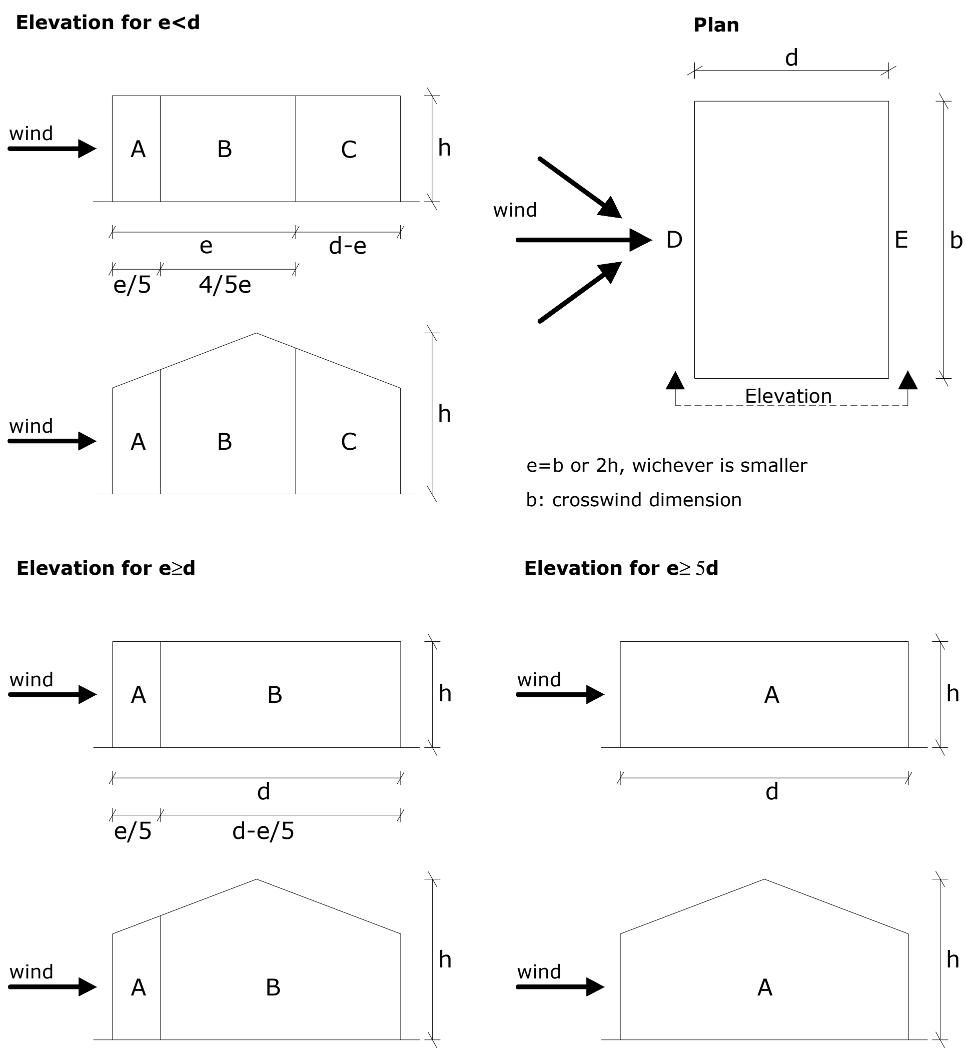


Figure III.B.2 - Zoning subdivision for the sidewalls surfaces

The external pressure coefficients are divided into overall coefficients and local coefficients, depending on the size of the loaded areas. Overall coefficients give the pressure for loaded areas larger than 10 m^2, and local coefficients give the pressure for loaded areas smaller than 10 m^2.

The following Table III.B.1 presents the external pressure coefficient for a loaded area of 10 m^2, $\delta_{pe,10}$, for zone A, B, C, D and E to be considered for vertical walls of rectangular plan buildings.

Table III.B.1 - External pressure coefficients values for vertical walls of rectangular plan buildings

Zone	A	B	C	D	E
h/d	$\delta_{pe,10}$				
5	-1.2	-0.8	-0.5	+0.8	-0.7
1	-1.2	-0.8	-0.5	+0.8	-0.5
≤0.25	-1.2	-0.8	-0.5	+0.7	-0.3

Note 1: For intermediate values of *h/d*, linear interpolation may be applied. The values also apply to walls of buildings with inclined roofs, such as duopitch and monopitch roofs.

Note 2: Tall buildings, *h/d* >5, are assumed likely to be highly dynamic so, normally, falling out of the scope of this code. However for the ones within the scope of this code, then the EN 1991-1-4:2005 presents alternative provisions for this situation, *h/d* >5, and may be followed. It is important to note that a proper understanding of the relevant concepts to this matter has to be accomplished to be correctly used.

External pressure coefficients for loaded areas of different sizes can be obtained from the multiplication of $\delta_{pe,10}$ with an area correction factor. The area correction factors are listed in Table III.B.2.

Table III.B.2 - Area correction factor

Action types	Loaded area (m^2)	Area correction factor
Local Actions	1	1.20
	5	1.06
Overall Actions	10	1.00
	50	0.95
	100	0.93
	500	0.88
	1000	0.86
	5000	0.82
	≤10000	0.80

Note: For intermediate values of loaded areas, linear interpolation may be applied.

1.1.2 External pressure coefficients for duopitch roofs

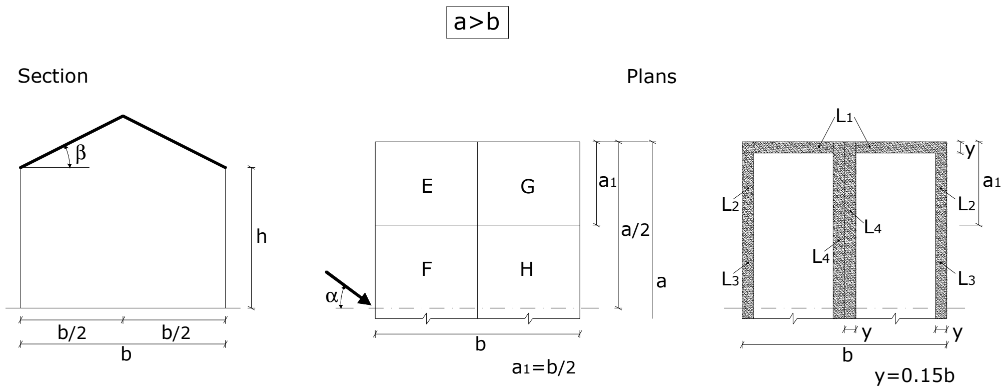


Table III.B.3 – External pressure coefficients for duopitch roofs

Building geometrical relations h/b	β (degrees)	Overall Actions				Local Actions			
		Wind direction							
		α=0°		α=90°					
		E,F	G,H	E,G	F,H	L_1	L_2	L_3	L_4
$\frac{h}{b} \le \frac{1}{2}$	0	-0.8	-0.4	-0.8	-0.4	-2.0	-2.0	-2.0	
	5	-0.9	-0.4	-0.8	-0.4	-1.4	-1.2	-1.2	-1.0
	10	-1.2	-0.4	-0.8	-0.6	-1.4	-1.4		-1.2
	20	-0.4	-0.4	-0.7	-0.6	-1.0			-1.2
	30	0	-0.4	-0.7	-0.6	-0.8			-1.1
	45	+0.3	-0.5	-0.7	-0.6				-1.1
$\frac{1}{2} < \frac{h}{b} \le \frac{3}{2}$	0	-0.8	-0.6	-1.0	-0.6	-2.0	-2.0	-2.0	
	5	-0.9	-0.6	-0.9	-0.6	-2.0	-2.0	-1.5	-1.0
	10	-1.1	-0.6	-0.8	-0.6	-2.0	-2.0	-1.5	-1.2
	20	-0.7	-0.5	-0.8	-0.6	-1.5	-1.5	-1.5	-1.0
	30	-0.2	-0.5	-0.8	-0.8	-1.0			-1.0
	45	+0.2	-0.5	-0.8	-0.8				
$\frac{3}{2} < \frac{h}{b} \le 6$	0	-0.7	-0.6	-0.9	-0.7	-2.0	-2.0	-2.0	
	5	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.0
	10	-0.7	-0.6	-0.8	-0.8	-2.0	-2.0	-1.5	-1.2
	20	-0.8	-0.6	-0.8	-0.8	-1.5	-1.5	-1.5	-1.2
	30	-1.0	-0.5	-0.8	-0.7	-1.5			
	40	-0.2	-0.5	-0.8	-0.7	-1.0			
	50	+0.2	-0.5	-0.8	-0.7				

Note: There is no need to consider the particular values for the local action in the cases where in the table the corresponding coefficients are not indicated.

1.1.3 External pressure coefficients for monopitch roofs

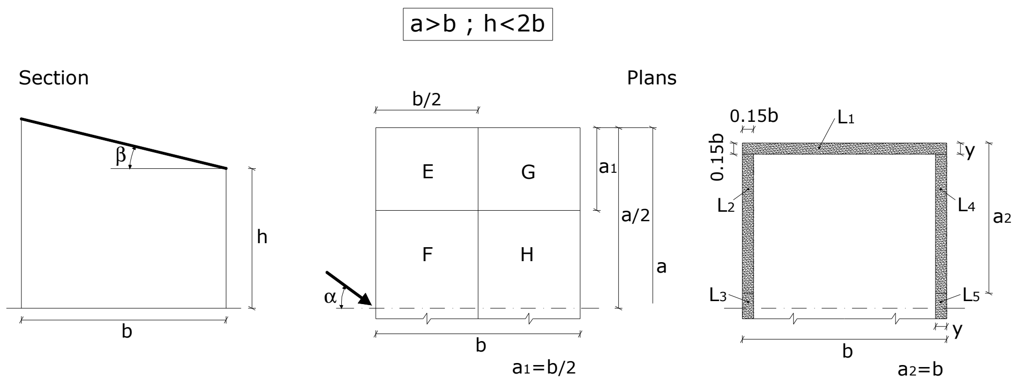


Table III.B.4 – External pressure coefficients for monopitch roofs

β (degrees)	Overall Actions										Local Actions				
	Wind direction, α														
	0°		45°		90°		135°		180°						
	E,F	G,H	E,F	G,H	E,G	F,H	E,F	G,H	E,F	G,H	L_1	L_2	L_3	L_4	L_5
5 to 10	-1.0	-0.5	-1.0	-0.9	-1.0	-0.5	-0.9	-1.0	-0.5	-1.0	-2.0	-2.0	-1.5	-2.0	-1.5
15	-0.9	-0.5	-1.0	-0.7	-1.0	-0.5	-0.6	-1.0	-0.3	-1.0	-2.0	-1.8	-0.9	-1.8	-1.4
20	-0.8	-0.5	-1.0	-0.6	-0.9	-0.5	-0.5	-1.0	-0.2	-1.0	-2.0	-1.8		-1.8	-1.4
25	-0.7	-0.5	-1.0	-0.6	-0.8	-0.5	-0.3	-0.9	-0.1	-0.9	-2.0	-1.8			
30	-0.5	-0.5	-1.0	-0.6	-0.8	-0.5	-0.1	-0.6	0	-0.6	-2.0	-1.8			

Note: There is no need to consider the particular values for the local action in the cases where in the table the corresponding coefficients are not indicated.

1.1.4 External pressure coefficients for cylindrical roofs with a circular, or elliptical, or parabolic directrix

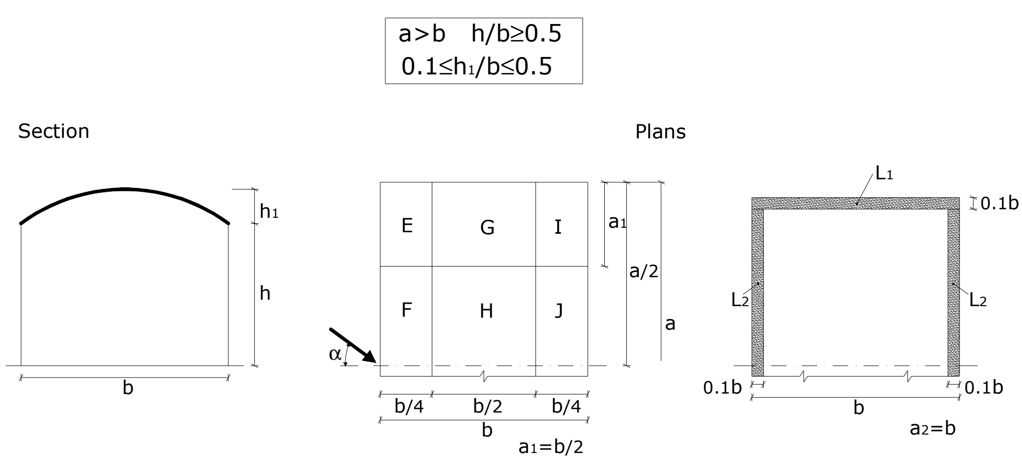


Table III.B.5 – External pressure coefficients for cylindrical roofs with a circular, or elliptical, or parabolic directrix

Decay h_1/b	Overall Actions					Local Actions	
	Wind direction, α						
	0°			90°			
	E, F	G, H	I, J	E, G, I	F, H, J	L_1	L_2
0.1	-0.9	-0.8	-0.5	-0.8	-0.6	-1.6	-1.8
0.2	-0.9 or 0(*)	-0.9	-0.5	-0.8	-0.6	-1.6	-1.8
0.3	-0.3 or +0.2(*)	-1.0	-0.5	-0.8	-0.6	-1.6	-0.6
0.4	+0.4	-1.1	-0.5	-0.8	-0.6	-1.6	
0.5	+0.7	-1.2	-0.5	-0.8	-0.6	-1.6	

(*) The worst situation must be considered.
Note: There is no need to consider the particular values for the local action in the cases where in the table the corresponding coefficients are not indicated.

1.1.5 External pressure coefficients for multispan roofs of duopitch

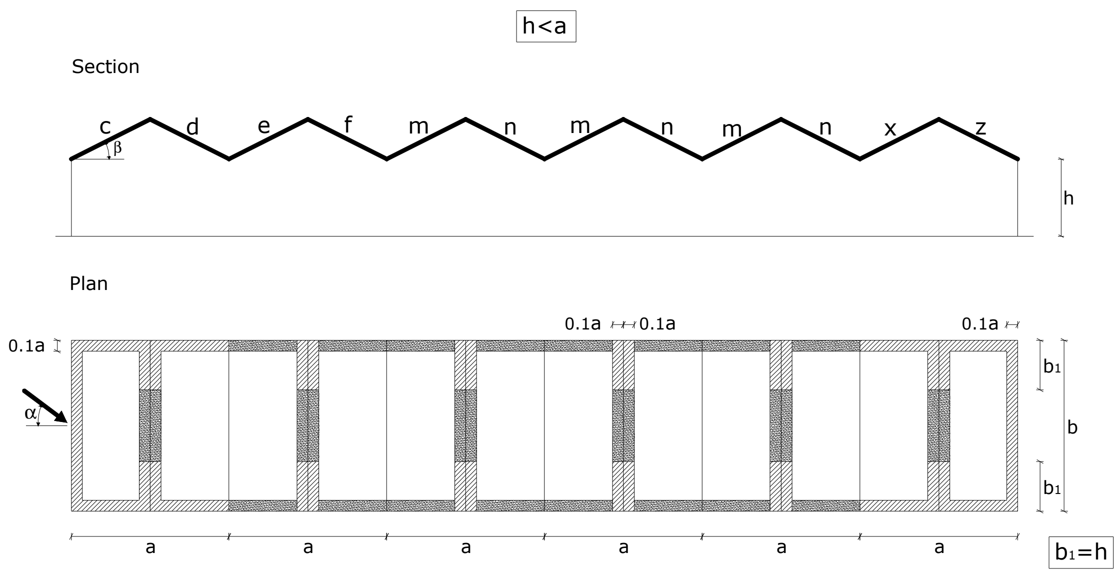
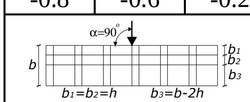


Table III.B.6 – External pressure coefficients for multispan roofs of duopitch

- Overall Actions

β (degrees)	Wind direction α=0°								Wind direction α=90°		
	Pitch δ_{pe} coefficients								Strip δ_{pe} coefficients		
	c	d	e	f	m	n	x	z	b_1	b_2	b_3
5 to 10	-1.1	-0.6	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.8	-0.6	-0.2
20	-0.7	-0.6	-0.4	-0.3	-0.3	-0.3	-0.3	-0.5			
30	-0.2	-0.6	-0.4	-0.3	-0.2	-0.3	-0.2	-0.5			
45	+0.3	-0.6	-0.6	-0.4	-0.2	-0.4	-0.2	-0.5			

- Local Actions

The δ_{pe} coefficients witch define the local actions to take in consideration in the areas signed in the figure are the following:
Striped Areas .... -2.0
Shaded Areas .... -1.5

1.1.6 External pressure coefficients for multispan roofs of monopitch

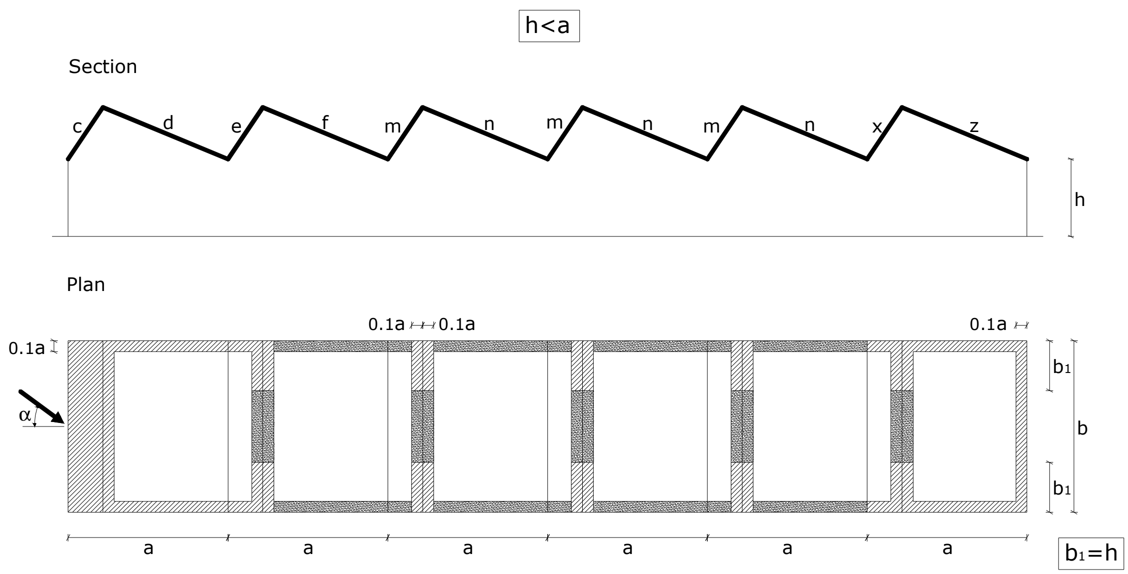
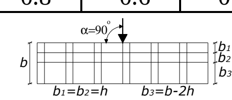


Table III.B.7 – External pressure coefficients for multispan roofs of monopitch

- Overall Actions

Pitch δ_{pe} coefficients								Wind direction α=90^o		
c	d	e	f	m	n	x	z	Strip δ_{pe} coefficients		
Wind direction α=90^o								b_1	b_2	b_3
+0.6	-0.7	-0.7	-0.4	-0.3	-0.2	-0.1	-0.3	-0.8	-0.6	-0.2
Wind direction α=180^o										
-0.5	-0.3	-0.3	-0.3	-0.4	-0.6	-0.6	-0.1			

- Local Actions

The δ_{pe} coefficients witch define the local actions to take in consideration in the areas signed in the figure are the following:
Striped Areas .... -2.0
Shaded Areas .... -1.5

1.2 Internal pressure coefficients, δ_{pi}

Note that when the building envelope surfaces totally blocks the wind flow to its interior (no permeability), or has partitions that prevent the internal air flow, then the internal pressure coefficients are not applied.

For buildings considered in the previous point 1.1.1 where there are no internal partitions or if their presence does not block the air flow then, the internal pressure coefficients may be obtained by the following simplified rules. These rules take into account the characteristics and distribution of the openings in the external walls (building envelope).

The simplified rules are as follows:

- Buildings with a small probability to have openings in the façade during the occurrence of strong winds. So the permeability of the building façade is mainly due to the, for example, gap in windows, vents, etc (so called leakage paths).

  Two situations in general can occur to which correspond the following internal pressure coefficients:

  - two opposite façades with permeability and the other two façades are impermeable:
    - wind normal to the permeable façades $\delta_{pi} = + 0.2$
    - wind normal to the impermeable façades $\delta_{pi} = - 0.2$
  - the four façades with equal permeability $\delta_{pi} = - 0.3$

- Buildings with openings in one or several façades, as long as one of the façade is much more predominant than the others, during the occurrence of strong winds. So for this case the internal pressure coefficient, δ_{pi}, must be taken as 0.75 of the external pressure coefficients values, δ_{pe}, corresponding to the façade with clearly predominant openings. But if the openings are in zones of the façades where special pressure coefficients, δ_{pe}, are defined (local actions), then these should be the values to be considered in the determination of δ_{pi}.

2. Pressure coefficients, δ_p, for canopy roofs

A canopy roof is defined as the isolated roof structure without permanent walls that presents an obstacle to the air flow. For this case the wind action acts directly and normally to the superior and inferior faces of the roof pitch. The pressure coefficients indicated in Table III.B.8 already take into account the combined effect of wind acting on both the upper and lower surfaces of the canopies for all wind directions. The positive values correspond to force acting from up to down direction and the opposite case, down to up direction, correspond to the negative values.

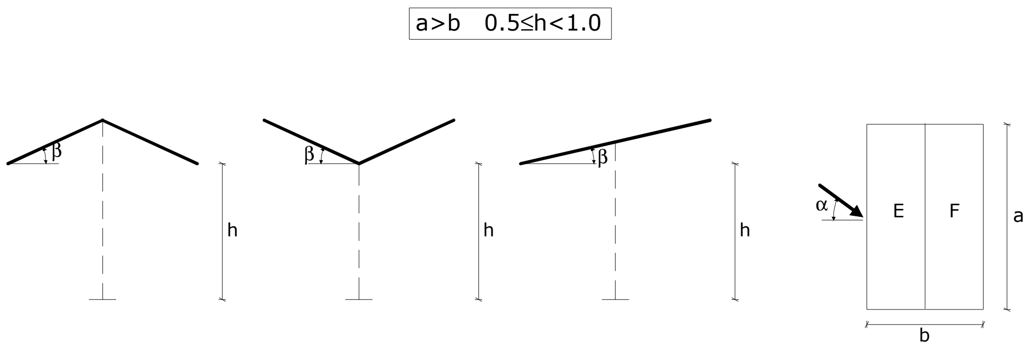
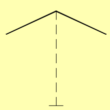
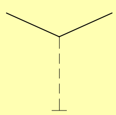
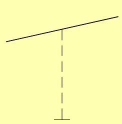


Table III.B.8 - Pressure coefficients for canopy roofs

Roof Type	β (degrees)	Wind direction α (degrees)	Pitch δ_p coefficients (*)	
			E	F
	5	0	-1.1 or +1.2	-1.0
	10		-1.1 or +1.4	-1.0
	15		-0.7 or +1.6	-1.0
	20		-0.3 or +1.8	-1.0
	25		-0.2 or +2.0	-0.8
	30		0 or +2.0	-0.7
	5	0	-1.2 or +0.8	-0.8 or +1.0
	10		-1.4 or +0.6	-0.6 or +1.0
	15		-1.6 or +0.4	-0.6 or +1.0
	20		-1.8 or +0.2	-0.6 or +0.7
	25		-2.0 or 0	-0.6 or +0.2
	30		-2.0 or 0	-0.6 or 0
	0	0 (lower side in windward)	-1.5 or +1.5(**)	-0.5 or +0.5(**)
	5		-1.5 or +1.5(**)	-0.55 or +0.55(**)
	10		+1.55	+0.65
	15		+1.55	+0.7
	20		+1.6	+0.75
	25		+1.6	+0.85
	30		+1.65	+0.95
	0	180 (lower side in leeward)	-0.5 or +0.5(**)	-1.5 or +1.5(**)
	5		-0.55 or +0.55(**)	-1.5 or +1.5(**)
	10		-0.65	-1.55
	15		-0.7	-1.55
	20		-0.75	-1.6
	25		-0.85	-1.6
	30		-0.95	-1.65

(*) When, with the corresponding β and α, are indicated two values for δ_p in the same pitch then the worst situation should be considered.
(**) The coefficients to be considered at the same time in the E and F pitch should have the same sign.

3. Friction coefficients, δ_{fr}

For the cases referred in Article 17°, n°.8.b – when the total area of all surfaces parallel (or with a small angle) to the wind is more than 4 times the total area of all external surfaces perpendicular to the wind - then it is recommended that the friction effect should be considered. The friction coefficients, δ_{fr}, for walls and roof surfaces are given in Table III.B.9.

Table III.B.9 - Friction coefficients, δ_{fr} , for walls, parapets and roof surfaces

Surface	Friction coefficient (δ_{fr})
Smooth (i.e. steel, smooth concrete)	0.01
Rough (i.e. rough concrete, tar-boards)	0.02
Very rough (i.e. ripples, ribs, folds)	0.04

A reference area should be assessed to take into account this effect – A_{fr}.

In the case of an isolated vertical elements (e.g. walls, panels) or horizontal elements (e.g. slabs, roofs) supported by elements that present no blockage to the air flow then the reference area should be considered on both sides.

In the case of enclosed buildings the reference area for the determination of the friction forces to be applied in the external surfaces parallel to the wind is located beyond a distance from the upwind eaves or corners, equal to the smallest value of 2 times the breadth (*b*) or 4 times the height (*h*) of the building, see Figure III.B.3.

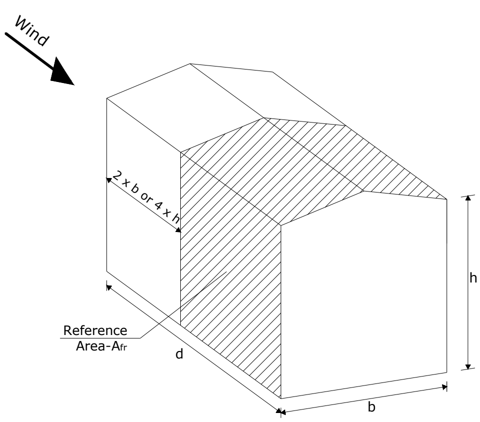


Figure III.B.3 – Reference area for friction

Appendix C – Dynamic response coefficient ***(C_{dyn})***

1. For the definition of the dynamic response coefficient, to be applied to *dynamic sensitive* structures, the present wind code specifications follow closely the concepts and methods expressed in the Australian and New Zealand Standards AS/NZS 1170.2:2002, in its Section 6, Clause 6.2.

2. Besides the scope of application of this simplified static equivalent methodology, defined in Articles 17° and 20°, it is important to point out that this multiplier coefficient (C_{dyn}) can only be used in structures with the natural first mode fundamental frequencies of values between 1 Hz and 0.2 Hz, and only the *alongwind* component action is considered, reserving more elaborated analytical methodologies for the consideration of the other cases.

3. As stated in the above referred AS/NZS Clause 6.2, this coefficient mainly depends upon the turbulence intensity, the gust wind pressure value at the roof level, the height and breadth of the building structure, its first mode fundamental frequency and the corresponding damping coefficient.

4. Assuming the concept expressed on AS/NZS, Clause 6.2.2, which is herewith transcribed:

   "For calculation of action effects (bending moments, shear forces, member forces) at a height (s) on the structure, the wind pressures on the structure at height (z) shall be multiplied by a response factor (C_{dyn}). This factor is dependent on both (z) and (s) and s<z<h. For calculation of base bending moments, deflections and acceleration at the top of structure, a single value of (C_{dyn}) shall be used, with (s) taken as zero".

   It should be noted that where this text refers the variable *(z)*, it should be understood as *(h_z)*, according to the symbology used in the present Macau specifications.

5. Under this context, the coefficient C_{dyn} is determined by the following expression:

$$C_{dyn} = \frac{1 + 2I_h\left[g_v^2 B_s + \frac{H_s g_R^2 SE}{\zeta}\right]^{0.5}}{\left(1 + 2g_v I_h\right)} \quad \text{(with } C_{dyn} \geq 1.0\text{)}$$

where:

- s height (m) above the ground level at which the corresponding dynamic coefficient is being calculated and so the related action effects in the structure;
- h height of the structure (m);
- I_h turbulence intensity at the top of the structure which shall be taken as:

$$I_h = \left(0.093\left(\frac{h}{250}\right)^{-0.14}\right) / \sqrt{C_t}$$

  where:

  C_t topographic coefficient, as defined in Appendix A to this Annex 3;

- g_v peak factor for the upwind velocity fluctuations, which shall be taken as 3.7;
- B_s background factor, which is a measure of the slowly varying background component of the fluctuating response, caused by low frequency wind speed variations, given as follows: $B_s = \dfrac{1}{1 + \dfrac{\left[0.26(h-s)^2 + 0.46b_{sh}^2\right]^{0.5}}{L_h}}$

where:

b_{sh} average breadth of the structure between heights *s* and *h*;

L_h integral turbulence length value scaled at height *h* equal to:

$$L_h = 325(h/250)^{0.39};$$

H_s height factor for the resonant response (= $1+(s/h)^2$);

g_R peak factor for resonant response (10 min period) given by:

$$g_R = \sqrt{[2\ln(600\, n_a)]}$$

where:

n_a first mode fundamental frequency of the structure for the alongwind direction, in Hz, and estimated as $n_a = 46/h$ or determined by a more detailed analysis;

S size reduction factor, given as follows:

$$S = \frac{1}{\left[1+\dfrac{3.5 n_a h(1+g_v I_h)}{\sqrt{w^*_{kh}/0.0006}}\right]\left[1+\dfrac{4 n_a b_{0h}(1+g_v I_h)}{\sqrt{w^*_{kh}/0.0006}}\right]}$$

where:

b_{0h} average breadth of the structure between heights 0 and *h;*

w^*_{kh} characteristic gust wind pressure at level *h* (kPa) already affected with the topographic coefficient, defined as $w^*_{kh} = w_{kh} \times C_t$ *;*

E equal to (π/4) times the spectrum of turbulence in the approaching wind stream, given as follows:

$$E = \frac{\pi N}{(1+70.8N^2)^{5/6}}$$

where:

N reduced frequency given by: $n_a L_h[1+(g_v I_h)]/(\sqrt{w^*_{kh}/0.0006})$;

ζ damping coefficient of the structure.

As an example, the next table shows the dynamic response coefficient determination for several buildings according to their height (*h*), depth (*d*) and breadth (*b*) values, assuming that:

- the damping coefficient of the structure is: ζ = 2.0%,
- the building is a square plan (*b*=*d*),
- the section being studied is the base of the structure (*s*=0),
- the structure has no variation of breadth over height (i.e. $b=b_{sh}=b_{0h}$),
- the n_a is assumed as 46/*h*, and
- the topographic effect is not significant.

Breadth = Depth (m) Height (m)	30	40	50
200	(1.035)*	1.026	1.018
180	(1.031)*	1.022	1.014
160	(1.027)*	1.018	1.010
140	1.021	1.012	1.004
120	1.017	1.008	1.0**
100	1.011	1.001	1.0**

(*) As *h*/*d* > 5 then see note 2 to Table III.B.1 in Appendix B.

(**) A value of C_{dyn} less than 1.0 occurred so, it is possible to assume, in a conservative way, the structure as *dynamic non-sensitive* and to adopt $\boldsymbol{C_{dyn}}$ **=** 1.0 instead, or perform a more accurate analysis, non-simplified and out of scope of these code specifications. These situations could arrive in tall and wide structures, where a direct application of the simplified method could suggest a reduction in gust wind pressures values, on the façades normal to the wind direction (see *A Guide to AS/NZS 1170.2:2002 – Wind Actions*).

Appendix D – Probability factor C_{prob} for other, than the code specified, life-time period of a structure and/or return period

1. As a reference-base criterion, the present code specifications assume a gust wind pressure characteristic value with a return period of R=50 years, during a structure reference life-time of L=50 years, then resulting in a probability of exceedance of the selected characteristic wind pressure at ρ = 0.64, during the mentioned 50 years reference period.

2. The relationship between the probability (ρ), the return period (R) and the life-time (L) of the structure, following the well known geometric distribution probabilistic concept, can be expressed as: $\rho = 1-(1-1/R)^L$

   The statistical analysis previously performed on the normalized Macau wind records, being the sound basis of the present code specifications in the definition of their characteristic mean and gust wind speeds, also make it possible to modify the specified reference life-time or the specified return period, changing the related characteristic gust wind speed or pressure values, and compelling the Macau wind characterization.

   This could be done by multiplication of a probabilistic factor (C_{prob}) to the specified gust wind pressure characteristic values (defined for a return period of 50 years), occurring in a structure during its life-time of 50 years, so modifying the corresponding probability of exceedance (ρ), during the same, or other, life-time period (L). This probabilistic factor (C_{prob}), for Macau, is expressed as:

$$C_{prob} = \frac{2.02+\ln(L)-\ln(-\ln(1-\rho))}{2.02+\ln(50)}$$

   where: L reference period (years);
   ρ probability of exceedance during the reference period L.

3. If in a structure it is required only to modify the reference period (expected life-time) from the specified in this code (L=50 years), but maintaining the specified probability of failure (defined with a return period close to R =1000 years – see Article 17°, n° 7), then the specified characteristic gust wind pressure profile values should be multiplied by the corresponding probability factor (C_{prob}), determined by the above mentioned formulation with ρ =0.64, as shown in Table III.D.1:

Table III.D.1: Probability factor (C_{prob})

Building or structure category	Target reference period (L) in years	Probability factor (C_{prob})
Temporary structures	10	0.73
Replaceable structural components, bearings, girders	10 to 25	0.73 - 0.88
Agricultural and simple storage structures	15 to 30	0.80 - 0.91
Current buildings and structures	50	1.00
Structures with post-disaster functions, nuclear facilities, bridges	100	1.12

Note: No linear interpolation allowed. If other reference period is to be adopted, then it should be used the following expression: $C_{prob} = \left(\frac{2.02+\ln(L)-\ln(-\ln(1-0.64))}{2.02+\ln(50)}\right)$