

Annex A: Wind actions on tent structures

A.1 Background

Following the publication of *Guidance on certification schemes and management of construction projects for portable tents and structures, August 2014*, discussions with the parties involved have shown that there is a need for clarifying the guidance with respect to the safety of the structures in question. In addition, a need has been identified for specifying more precise wind actions that include the effect of the compliance of structures when determining the characteristic values, which is an issue that the present provisions of the Eurocode do not deal with consistently.

The design is based on the Eurocode system, including the safety provisions given in EN 1990 and the Eurocode on wind actions, EN 1991-1-4, and their National Annexes. The following clauses deal with the determination of the overall wind actions on tents and the associated safety and wind load factors, and provide a proposal for a documentation format.

A.2 Wind actions

The overall design wind force, F_w , acting on the structure is determined using the expression, see the Eurocode:

$$F_{w,d} = \gamma_F \cdot q_p \cdot c_f \cdot c_s c_d \cdot A_{ref}$$

where γ_F is the force partial factor, q_p is the peak velocity pressure, c_f is the force coefficient, $c_s c_d$ is the structural factor, and A_{ref} is the reference area of the structure.

The peak velocity pressure is taken as

$$q_p = q_{p,0} \cdot c_{season}^2$$

where $q_{p,0}$ is the peak velocity pressure without the season variation, and c_{season}^2 is the seasonal factor.

The force coefficient, c_f , is taken as

$$c_f = c_{pe,10} - c_{pi}$$

where $c_{pe,10}$ is the external pressure coefficient for loaded areas of 10 m² and c_{pi} is the internal pressure coefficient.

A.3 Load classes

The calculation of the structure can be based on load classes. Table A.3.1 illustrates the choice of peak evacuation speeds, seasonal factors and partial factors for the 5 load classes.

In the table, the second row from the bottom describes the basis of the calculation of the peak velocity pressure.

Load class 1 covers normal safety and loading; load class 2 covers normal safety for a structure set up during the period from May to September.

The peak velocity pressure depends in addition of the roughness of the surrounding terrain. The Eurocode divides the terrain into 4 terrain categories, I-IV, see clause A.4.

Table A.3.1 Load classes and associated coefficients

	No evacuation		Evacuation is necessary		
	1. All year	2. May-September	3. Hurricane	4. Violent storm	5. Storm
Peak evacuation speed, $v_{p,evak}$ [m/s]*	-	-	32,7	28,5	24,5
Seasonal factor, c_{season}^2 [-]	1,0	0,8	1,0	1,0	1,0
Partial factor, γ_F [-]	1,5	1,5	1,2	1,2	1,2
Peak velocity pressure q_p based on	Return period of 50 years	Return period of 50 years	$v_{p,evak}$	$v_{p,evak}$	$v_{p,evak}$
Evacuation frequency	-	-	Approx. once every 10 years	Approx. once every year	Several times every year

* based on an agricultural country corresponding to terrain category II according to the Eurocode and at a height of 10 m.

Where load classes 3 to 5 are applied, monitoring of wind conditions by means of weather reports and/or an anemometer will be necessary. Monitoring is combined with an emergency evacuation plan. If the weather report predicts that the permissible wind force will be exceeded, the tent shall be evacuated and constructive measures shall be taken to ensure that the tent does not present a danger to the surroundings.

Examples of constructive measures include

- reducing wind actions: opening of the sides of the tent;
- increasing the strength: addition of extra guy lines and improvement of tent anchorages.

With respect to the items specified above, it is necessary to identify who is responsible for monitoring, evacuation and constructive measures. The measures shall be described in detail in the documentation of the structure and the documentation intended for the user.

A.4 Terrain categories – Extracts from Eurocode 1

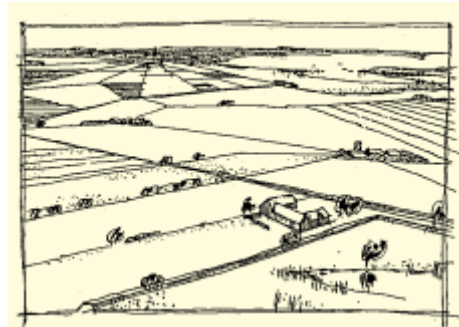
The value of the peak velocity pressure, q_p , depends on the roughness of the surrounding terrain, see the Eurocode. The terrain roughness is considered by assigning the area where the structure is set up to terrain categories I to IV. A description of the 4 different terrain categories is given below.

Description

Illustration

Terrain category I

Lakes or flat and horizontal area with negligible vegetation and without obstacles.



Terrain category II

Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights.



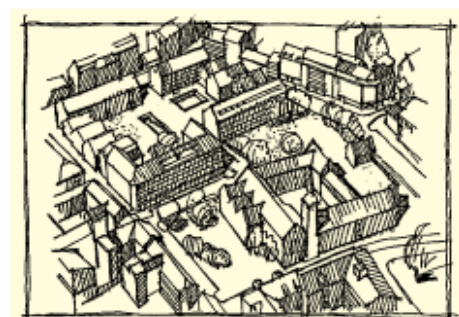
Terrain category III

Area with regular cover of vegetation or buildings or with isolated obstacles with separations of maximum 20 obstacle heights (such as villages, suburban terrain, permanent forest).



Terrain category IV

Area in which at least 15 % of the surface is covered with buildings and their average height exceeds 15 m.



A.5 Peak velocity pressure

The peak velocity pressure depends on the terrain category and the reference height, see Eurocode 1. The peak velocity pressure may be divided according to load classes, see Table A.5.1 for the reference height $z = 10$ m.

Table A.5.1 Peak velocity pressure, q_p [kN/m²], at a height of 10 m

Terrain category <i>y</i>	No evacuation		Evacuation is necessary		
	1. All year	2. May- September	3. Hurricane	4. Violent storm	5. Storm
I	1,00	0,80	0,79	0,60	0,44
II	0,85	0,68	0,67	0,51	0,38
III	0,62	0,49	0,49	0,37	0,27
IV	0,42	0,34	0,33	0,25	0,19

For other reference heights than $z = 10$ m, the peak velocity pressure is multiplied by the factor derived from Figure A.5.1 for the specific terrain category in Eurocode 1. The highest point of the tent is typically taken as the reference height.

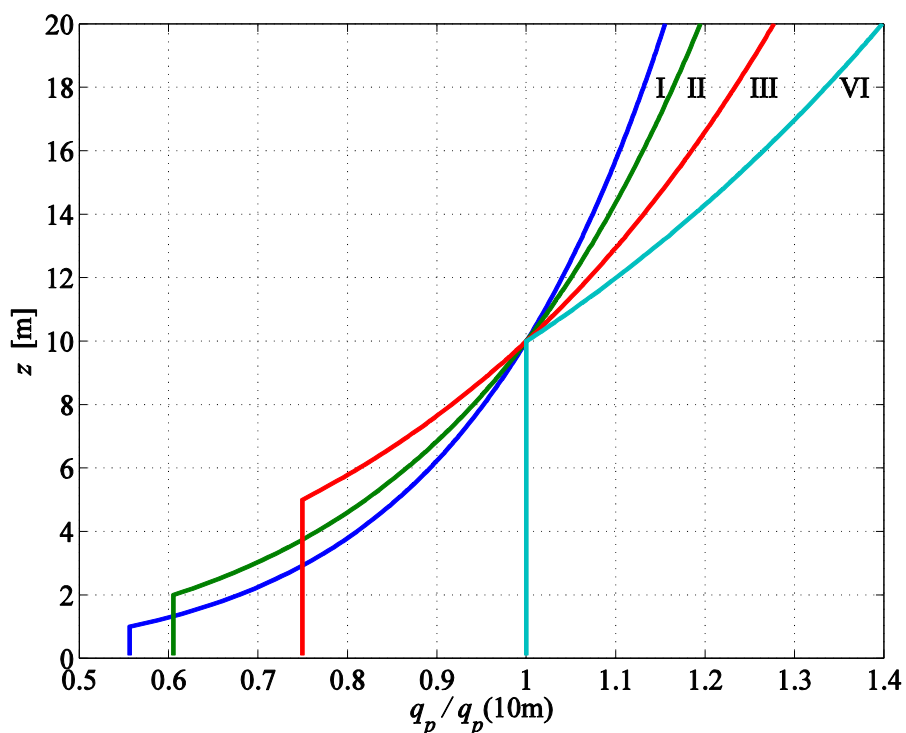


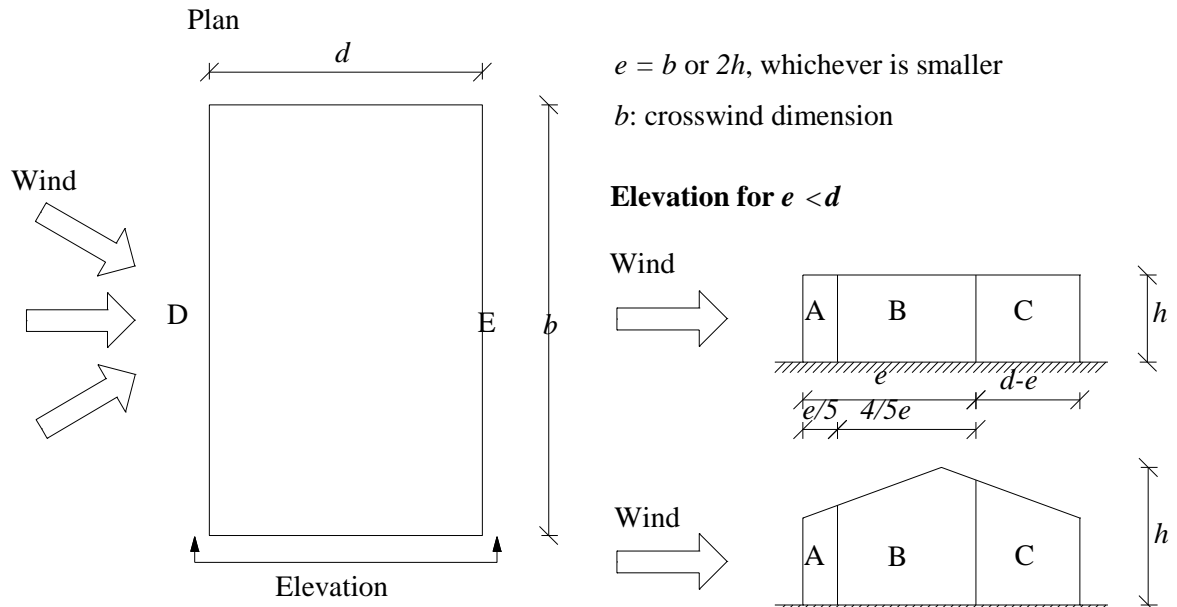
Figure A.5.1 Correction factor depending on the reference height, z , and the terrain category

A.6 Force coefficients – Extracts from Eurocode 1

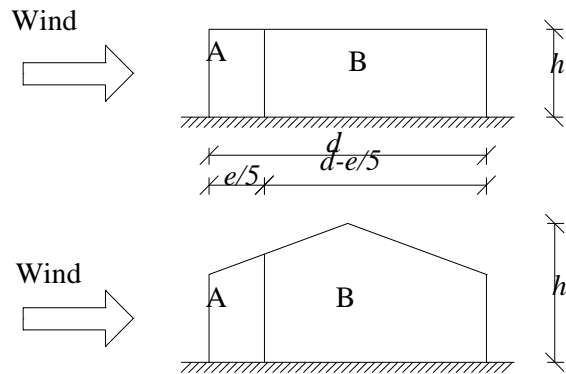
The force coefficients given in this clause are based on Eurocode 1.

Wind acting on facades

The force coefficient is based on rectangular plan structures.



Elevation for $e \geq d$



Elevation for $e \geq 5d$

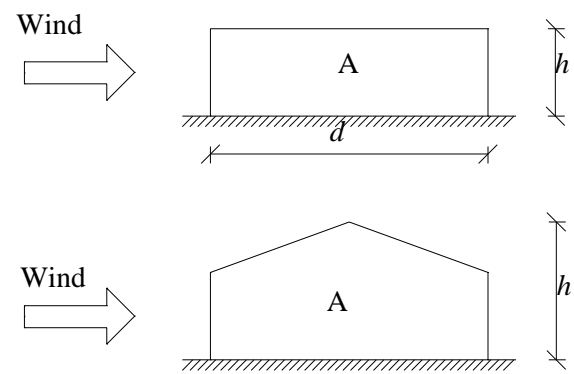


Table A.6.1 Recommended values of external pressure coefficients, $c_{pe,10}$ [-], for vertical facades of rectangular plan structures

h/d	Zone				
	A	B	C	D	E
5	-1,2	-0,8	-0,5	+0,8	-0,7
1	-1,2	-0,8	-0,5	+0,8	-0,5
$\leq 0,25$	-1,2	-0,8	-0,5	+0,7	-0,3

Wind acting on duopitch roofs

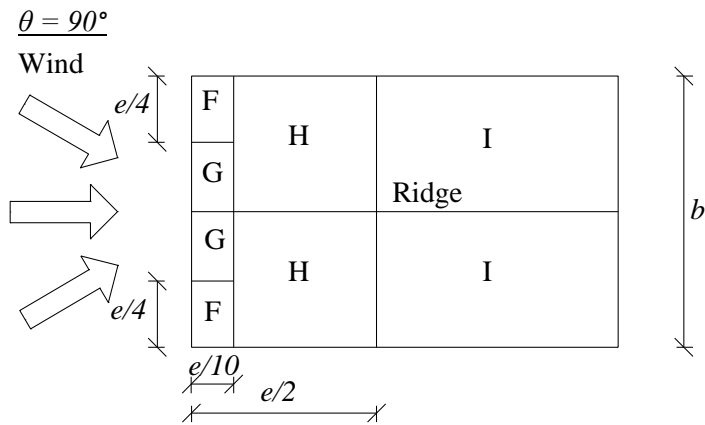
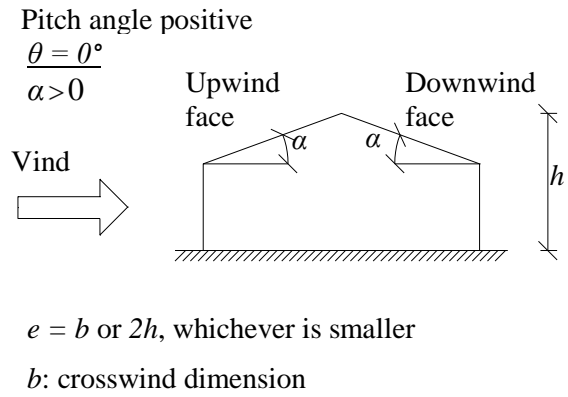
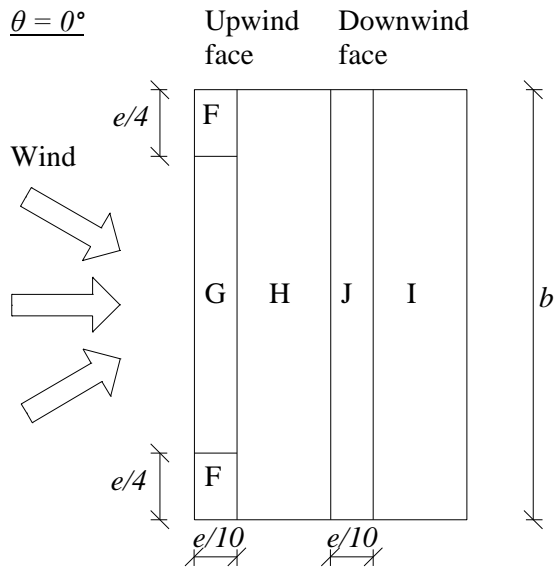


Table A.6.2 External pressure coefficient, $c_{pe,10}$ [-], for duopitch roofs

Pitch angle α	Zone for $\theta = 0^\circ$					Zone for $\theta = 90^\circ$			
	F	G	H	I	J	F	G	H	I
5°	-1,7	-1,2	-0,6	-0,6	+0,2	-1,6	-1,3	-0,7	-0,6
	+0,0	+0,0	+0,0	-0,6	-0,6				
15°	-0,9	-0,8	-0,3	-0,4	-1,0	-1,3	-1,3	-0,6	-0,5
	+0,2	+0,2	+0,2	+0,0	+0,0				
30°	-0,5	-0,5	-0,2	-0,4	-0,5	-1,1	-1,4	-0,8	-0,5
	+0,7	+0,7	+0,4	+0,0	+0,0				
45°	+0,0	+0,0	+0,0	-0,2	-0,3	-1,1	-1,4	-0,9	-0,5
	+0,7	+0,7	+0,6	+0,0	+0,0				
60°	+0,7	+0,7	+0,7	-0,2	-0,3	-1,1	-1,2	-0,8	-0,5
75°	+0,8	+0,8	+0,8	-0,2	-0,3	-1,1	-1,2	-0,8	-0,5

Linear interpolation for intermediate pitch angles of the same sign may be used between values of the same sign.

At $\theta = 0^\circ$ the pressure changes rapidly between positive and negative values on the windward face around a pitch angle of $\alpha = +5^\circ$ to $+45^\circ$, so both positive and negative values are given. For those roofs, four cases should be considered where the largest or smallest values of all areas F, G and H are combined with the largest or smallest values in areas I and J. No mixing of positive and negative values is allowed on the same face.

The internal pressure coefficient, c_{pi} , is taken as the more onerous of +0,2 and -0,3, when the structure does not have dominant openings.

A.7 Structural factor

The structural factor takes into account both the load reducing effect of the non-simultaneous occurrence of the peak wind pressures on the surfaces of the structure and the vibrations of the structure. For the structures considered, vibrations are not decisive and in this case the structural factor accounts primarily for the effect of the non-simultaneous occurrence of the largest wind pressures on the surfaces of the structure and the effect of the compliance of the structure.

When wind load on the windward face is combined with that on the leeward face, the structural factor also takes into account the non-simultaneous occurrence of windward pressures and leeward suction. The non-simultaneous occurrence of windward pressures and leeward suction contributes considerably to the load reduction included in the structural factor. The compliance of the structure will result in reduced effects of wind.

For the design of frame structures and lift of the structure, the structural factor is underestimated by not applying $c_s c_d = 0,80$.

A.8 Proposal for a documentation format

The conclusion of the calculation of the tent may be based on verification of the resistance

$$R_d \geq E_d$$

where R_d is the design resistance, and E_d is the load effect which includes the wind load.

Table A.8.1 specifies the conformity of the resistance of the tent with the load classes. The colours indicate when the design resistance of the tent, R_d , is larger or smaller, respectively, than the design load effect, E_d .

Table A.8.1 Conclusion for certification of the tent structure

Terrain category	No evacuation		Evacuation is necessary		
	1. All year	2. May- September	3. Hurricane	4. Violent storm	5. Storm
I	$R_d < E_d$	$R_d < E_d$	$R_d < E_d$	$R_d < E_d$	$R_d > E_d$
II	$R_d < E_d$	$R_d < E_d$	$R_d < E_d$	$R_d > E_d$	$R_d > E_d$
III	$R_d < E_d$	$R_d < E_d$	$R_d > E_d$	$R_d > E_d$	$R_d > E_d$
IV	$R_d < E_d$	$R_d > E_d$	$R_d > E_d$	$R_d > E_d$	$R_d > E_d$

The load effect may include special design situations, such as rolled-up tent sides and directional factors, but this will not be a typical situation.

In addition to Table A.8.1 where the tent structure is approved, minimum values of the load capacity for all tent anchorages to the ground are given. The load capacity can e.g. be given as the mass of ballast or the number, size and angle of ground anchors. Table A.8.2 contains an example of the communication of minimum values of the anchorage load capacities. Anchorages $f_1 - f_N$ may indicate guy lines and frame legs. f_1 may e.g. indicate all anchorages at frame legs at the corners of the tent structure. The table may be supplemented by figures illustrating the positions and types of anchorages.

Table A.8.2 Minimum load capacities for anchorages according to the load classes in Table A.8.1 for $R_d > E_d$

Load class	Terrain category	f_1	f_2	f_3	f_N
1.	I	-	-	-	-
	II	-	-	-	-
	III	-	-	-	-
	IV	-	-	-	-
2.	I	-	-	-	-
	II	-	-	-	-
	III	-	-	-	-
	IV	xx kg	xx kg	xx kg	xx kg
3.	I	-	-	-	-
	II	-	-	-	-
	III	xx kg	xx kg	xx kg	xx kg
	IV	xx kg	xx kg	xx kg	xx kg
4.	I	-	-	-	-
	II	xx kg	xx kg	xx kg	xx kg
	III	xx kg	xx kg	xx kg	xx kg
	IV	xx kg	xx kg	xx kg	xx kg
5.	I	xx kg	xx kg	xx kg	xx kg
	II	xx kg	xx kg	xx kg	xx kg
	III	xx kg	xx kg	xx kg	xx kg
	IV	xx kg	xx kg	xx kg	xx kg

In addition to documentation in the form of static calculations, it may contain guidance on setting up the tent and other information.