User's Guide

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EUROCODES SPREADSHEETS Structural Design

Carlo Sigmund

to Excel® spreadsheet file

Verification tests

EN 1991-1-4: Eurocode 1

Edited and published by:
Carlo Sigmund

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Eurocodes - Structural Design

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Bridge: Erasmus Bridge
Location: Rotterdam, Netherlands
Length/ main span: 802 m/284 m
Pylon: 139 m
Designer: Architects Ben van Berkel, Freek Loos, UN Studio.

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Contents

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Section 1 # Eurocode 1 EN 1991-1-4 [Section 4]

1.1 General

EN 1991-1-4 gives guidance on the determination of natural wind actions for the structural design of building and civil engineering works for each of the loaded areas under consideration. This includes the whole structure or parts of the structure or elements attached to the structure, e. g. components, cladding units and their fixings, safety and noise barriers.

This Part is applicable to:

— buildings and civil engineering works with heights up to 200 m, see also (11).

— bridges having no span greater than 200 m, provided that they satisfy the criteria for dynamic response, see (12) and 8.2.

This part is intended to predict characteristic wind actions on land-based structures, their components and appendages. Certain aspects necessary to determine wind actions on a structure are dependent on the location and on the availability and quality of meteorological data, the type of terrain, etc. These need to be provided in the National Annex and Annex A, through National choice by notes in the text as indicated.

Default values and methods are given in the main text, where the National Annex does not provide information.

Guyed masts and lattice towers are treated in EN 1993-3-1 and lighting columns in EN 40. This part does not give guidance on the following aspects:

— torsional vibrations, e.g. tall buildings with a central core

— bridge deck vibrations from transverse wind turbulence

— wind actions on cable supported bridges

— vibrations where more than the fundamental mode needs to be considered.

The general assumptions given in EN 1990, 1.3 apply. The rules in EN 1990, 1.4 apply. Load and response information and terrain parameters may be obtained from appropriate full scale data. The National Annex may give guidance on design assisted by testing and measurements.

1.2 Definitions

For the purposes of this European Standard, the definitions given in ISO 2394, ISO 3898 and ISO 8930 and the following apply. Additionally for the purposes of this Standard a basic list of definitions is provided in EN 1990,1.5.

FUNDAMENTAL BASIC WIND VELOCITY. The 10 minute mean wind velocity with an annual risk of being exceeded of 0, 02, irrespective of wind direction, at a height of 10 m above flat open country terrain and accounting for altitude effects (if required).

BASIC WIND VELOCITY. The fundamental basic wind velocity modified to account for the direction of the wind being considered and the season (if required).

MEAN WIND VELOCITY. The basic wind velocity modified to account for the effect of terrain roughness and orography.

PRESSURE COEFFICIENT. External pressure coefficients give the effect of the wind on the external surfaces of buildings; internal pressure coefficients give the effect of the wind on the internal surfaces of buildings.

FORCE COEFFICIENT. Force coefficients give the overall effect of the wind on a structure, structural element or component as a whole, including friction, if not specifically excluded

BACKGROUND RESPONSE FACTOR. The background factor allowing for the lack of full correlation of the pressure on the structure surface

RESONANCE RESPONSE FACTOR. The resonance response factor allowing for turbulence in resonance with the vibration mode.

1.3 Design situations

The relevant wind actions shall be determined for each design situation identified in accordance with EN 1990, 3.2. In accordance with EN 1990, 3.2 (3)P other actions (such as snow, traffic or ice) which will modify the effects due to wind should be taken into account.(1) In accordance with EN 1990, 3.2 (3)P, the changes to the structure during stages of execution (such as different stages of the form of the structure, dynamic characteristics, etc.), which may modify the effects due to wind, should be taken into account. Fatigue due to the effects of wind actions should be considered for susceptible structures.(2)

(1) See also EN 1991-1-3, EN 1991-2 and ISO 12494.

(2) The number of load cycles may be obtained from Annex B, C and E.

1.4 Modelling of wind actions

REPRESENTATIONS OF WIND ACTIONS. The wind action is represented by a simplified set of pressures or forces whose effects are equivalent to the extreme effects of the turbulent wind.

CLASSIFICATION OF WIND ACTIONS. Unless otherwise specified, wind actions should be classified as variable fixed actions, see EN 1990, 4.1.1.

CHARACTERISTIC VALUES. The wind actions calculated using EN 1991-1-4 are characteristic values (See EN 1990, 4.1.2). They are determined from the basic values of wind velocity or the velocity pressure. In accordance with EN 1990 4.1.2 (7)P the basic values are characteristic values having annual probabilities of exceedence of 0,02, which is equivalent to a mean return period of 50 years.(3)

MODELS. The effect of the wind on the structure (i.e. the response of the structure), depends on the size, shape and dynamic properties of the structure. This Part covers dynamic response due to along-wind turbulence in resonance with the along-wind vibrations of a fundamental flexural mode shape with constant sign.

RESPONSE OF STRUCTURES. The response of structures should be calculated according to Section 5 from the peak velocity pressure, q_p, at the reference height in the undisturbed wind field, the force and pressure coefficients and the structural factor $c_s \cdot c_d$ (see Section 6). q_p depends on the wind climate, the terrain roughness and orography, and the reference height q_p is equal to the mean velocity pressure plus a contribution from short-term pressure fluctuations.

1.5 Wind velocity and velocity pressure

The mean wind velocity v_m should be determined from the basic wind velocity v_b which depends on the wind climate as described in 4.2, and the height variation of the wind determined from the terrain roughness and orography as described in 4.3. The peak velocity pressure is determined in 4.5. The fluctuating component of the wind is represented by the turbulence intensity defined in 4.4.

The National Annex may provide National climatic information from which the mean wind velocity v_m, the peak velocity pressure q_p and additional values may be directly obtained for the terrain categories considered.

BASIC WIND VELOCITY. The basic wind velocity, v_b, defined as a function of wind direction and time of year at $10\ \text{m}$ above ground for terrain category II,(4) is given by:

$$v_b = c_{dir} \cdot c_{season} \cdot c_{prob} \cdot v_{b,0} \qquad \textbf{(Eq. 1-1)}$$

(3) All coefficients or models, to derive wind actions from basic values, are chosen so that the probability of the calculated wind actions does not exceed the probability of these basic values.

(4) See Table 4.1 (EN 1991-1-4), "*Terrain categories and terrain parameters*".

where:

- $c_{dir} \cdot c_{season} \cdot v_{b,0}$ is the basic wind velocity, defined as a function of wind direction and time of year at 10 m above ground of terrain category II
- $v_{b,0}$ is the characteristic 10 minutes mean wind velocity, irrespective of wind direction and time of year, at 10 m above ground level in open country terrain with low vegetation such as grass and isolated obstacles with separations of at least 20 obstacle heights.
- c_{dir} is the directional factor
- c_{season} is the season factor
- c_{prob} is the probability factor:(5)

$$c_{prob} = \left(\frac{1 - K \cdot \ln(-\ln(1-p))}{1 - K \cdot \ln(-\ln(0,98))}\right)^n . \quad \textbf{(Eq. 1-2)}$$

The 10 minutes mean wind velocity having the probability p for an annual exceedence is determined by multiplying the basic wind velocity $c_{dir} \cdot c_{season} \cdot v_{b,0}$ by the probability factor, c_{prob} given by expression above. See also EN 1991-1-6.

MEAN WIND. The mean wind velocity $v_m(z)$ at a height z above the terrain depends on the terrain roughness and orography and on the basic wind velocity and should be determined using expression:

$$v_m(z) = c_r(z) \cdot c_0(z) \cdot v_b \quad \textbf{(Eq. 1-3)}$$

where:

- $c_r(z)$ is the roughness factor
- $c_0(z)$ is the orography factor, taken as $1,0$ unless otherwise specified.(6)

The roughness factor, $c_r(z)$, accounts for the variability of the mean wind velocity at the site of the structure due to:

- the height above ground level
- the ground roughness of the terrain upwind of the structure in the wind direction considered.

The procedure for determining $c_r(z)$ may be given in the National Annex. The recommended procedure for the determination of the roughness factor at height z is based on a logarithmic velocity profile and is given by expressions:

$$c_r(z) = k_r \cdot \ln(z/z_0) \text{ for } z_{min} \le z \le z_{max}$$

$$c_r(z) = k_r \cdot \ln(z_{min}/z_0) = \mathit{cost} \text{ for } z \le z_{min} . \quad \textbf{(Eq. 1-4)}$$

(5) The values for “K” and “n” may be given in the National Annex. The recommended values are 0,2 for “K” and 0,5 for “n”.

(6) See Section 4.3.3.

where:

- z_0 is the roughness length
- k_r is terrain factor depending on the roughness length z_0 [m] calculated using:

$$k_r = 0,19 \cdot \left(\frac{z_0}{0,05}\right)^{0,07}$$

- z_{min} is the minimum height defined in Table 4.1
- z_{max} is to be taken as 200 m.

Terrain category	z_0 [m]	z_{min} [m]
0 - Sea or coastal area exposed to the open sea	0,003	1
I - Lakes or flat and horizontal area with negligible vegetation and without obstacles	0,01	1
II - Area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights	0,05	2
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)	0,3	5
IV - Area in which at least 15% of the surface is covered with buildings and their average height exceeds 15 m	1,0	10

Table 1.1 From Table 4.1 - Terrain categories and terrain parameters.

The terrain roughness to be used for a given wind direction depends on the ground roughness and the distance with uniform terrain roughness in an angular sector around the wind direction. Small areas (less than 10% of the area under consideration) with deviating roughness may be ignored.

WIND TURBOLENCE. The turbulence intensity $I_v(z)$ at height z is defined as the standard deviation of the turbulence divided by the mean wind velocity. The recommended rules for the determination of $I_v(z)$ are given in expressions below:

$$I_v(z) = \frac{\sigma_v}{v_m(z)} = \frac{k_l}{c_0(z) \cdot \ln(z/z_0)} \quad \text{for } z_{min} < z \le z_{max}$$

$$I_v(z) = \frac{k_l}{c_0(z) \cdot \ln(z_{min}/z_0)} \quad \text{for } z < z_{min} \qquad \textbf{(Eq. 1-5)}$$

where:

- k_l is the turbulence factor. The value of k_l may be given in the National Annex. The recommended value for k_l is 1,0

- $c_0(z)$ is the orography factor
- z_0 is the roughness length, given in Table 4.1.

PEAK VELOCITY PRESSURE. The peak velocity pressure $q_p(z)$ at height z, which includes mean and short-term velocity fluctuations, should be determined. The National Annex may give rules for the determination of $q_p(z)$. The recommended rule is given in expression:

$$q_p(z) = [1 + 7 \cdot I_v(z)] \cdot 0,5 \cdot \rho \cdot v_m^2(z) = c_e(z) \cdot q_b \qquad \textbf{(Eq. 1-6)}$$

where:

- $\rho = 1,25\ kg/m^3$ is the air density
- $q_b = 0,5 \cdot \rho \cdot v_b^2$ is the basic velocity pressure
- $c_e(z) = q_p(z)/q_b$.

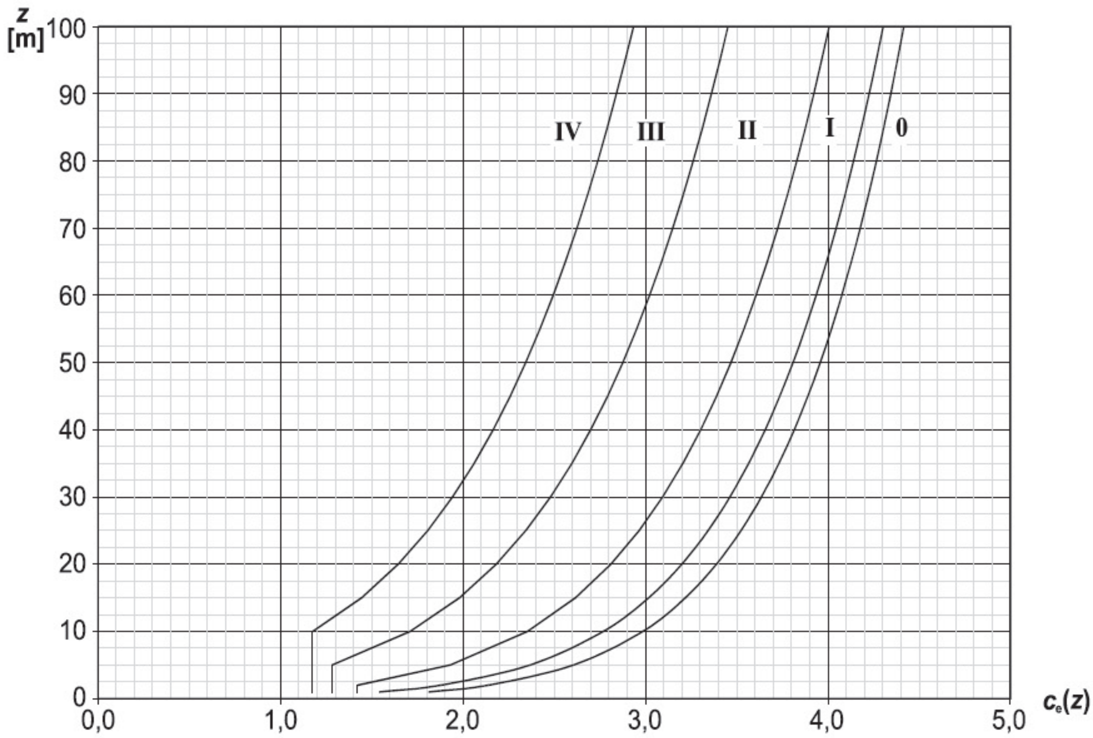

Figure 1.1 From Figure 4.2 - Illustrations of the exposure factor $c_e(z)$ for c_0=1,0; k_I=1,0.

1.6 Verification tests

EN1991-1-4_(A).XLS. 6.32 MB. Created: 12 March 2013. Last/Rel.-date: 12 March 2013. Sheets:

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— CodeSec4.

EXAMPLE 1-A- Wind velocity and velocity pressure - probability factor - **test1**

Given: Find the 10 minutes mean wind velocity having the probability $p = 0,010$ for an annual exceedence. Assume: $c_{dir} = 0,85$, $c_{season} = 0,98$ (temporary buildings erected for less than one year), $v_{b,0} = 30 \ m/s$ (fundamental value of the basic wind velocity).

[*Reference sheet:* CodeSec4]-[*Cell-Range: A37:O37-A67:O67*].

Solution: Annual probability of exceedence of $p = 0,010$ with mean return period:

$$N \approx \frac{1}{p} = \frac{1}{0,010} = 100 \ years .$$

Basic wind velocity:

$$c_{dir} \cdot c_{season} \cdot v_{b,0} = 0,85 \cdot 0,98 \cdot 30 = 24,99 \ m/s .$$

Probability factor (with $K = 0,2$ and $n = 0,5$):

$$c_{prob} = \left(\frac{1 - K \cdot \ln(-\ln(1-p))}{1 - K \cdot \ln(-\ln(0,98))}\right)^n = \left(\frac{1 - 0,2 \cdot \ln(-\ln(1 - 0,010))}{1 - 0,2 \cdot \ln(-\ln(0,98))}\right)^{0,5} = \left(\frac{1,920}{1,780}\right)^{0,5} = 1,04 .$$

Ten minutes mean wind velocity (having the probability p = 0,010 for an annual exceedence):

$$v_b = c_{dir} \cdot c_{season} \cdot c_{prob} \cdot v_{b,0} = (24,99) \cdot c_{prob} = (24,99) \cdot 1,04 = 25,99 \ m/s .$$

example-end

EXAMPLE 1-B- Mean wind - roughness factor - **test2**

Given: Find the roughness factor for an height above ground level at the site of the structure equal to $z = 5 \ m$. Assume a suburban terrain.

[*Reference sheet:* CodeSec4]-[*Cell-Range: A100:O100-A182:O182*].

Solution: From Table 4.1 ("*Terrain categories and terrain parameters*"):

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)*". With:

$z_0 = 0,3 \ m$; $z_{min} = 5 \ m$.

For $z \le z_{min}$, we get:

$$k_r = 0,19 \cdot \left(\frac{z_0}{0,05}\right)^{0,07} = 0,19 \cdot \left(\frac{0,3}{0,05}\right)^{0,07} = 0,215 .$$

Therefore, $z = 5\ \text{m} = z_{min}$:

$c_r(z) = k_r \cdot \ln(z_{min}/z_0) = 0,215 \cdot \ln(5/0,3) = 0,61\ [-]$.

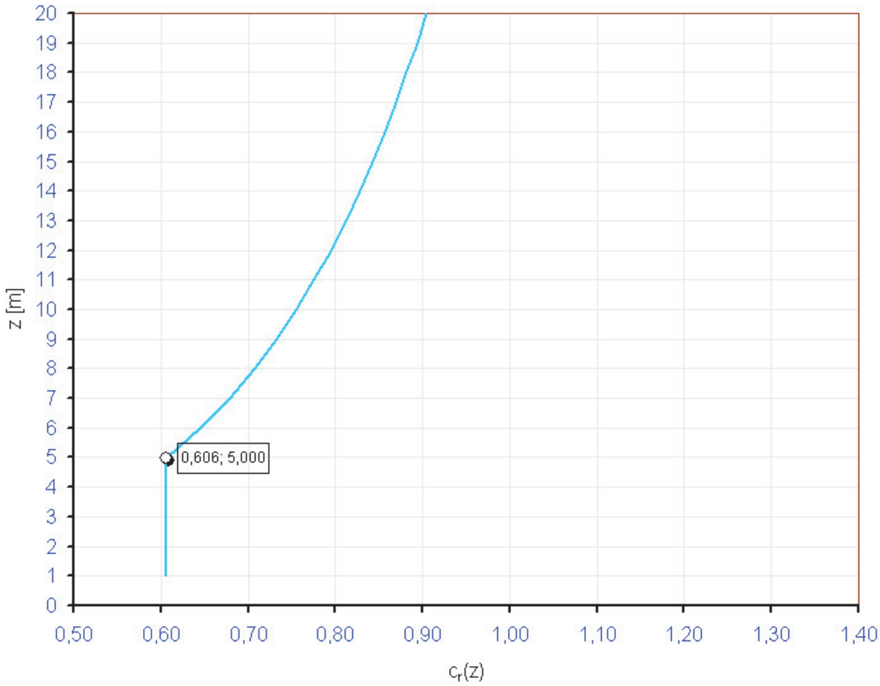


Figure 1.2 Graph of the roughness factor against "z".

For (say) $z = 9\ \text{m}$ with $z_{min} \le z \le z_{max} \quad \Rightarrow \quad 5\ \text{m} \le z \le 200\ \text{m}$:

$c_r(z) = k_r \cdot \ln(z/z_0) = 0,215 \cdot \ln(9/0,3) = 0,73$ [see *cell*: R139, *sheet*: CodeSec4].

example-end

EXAMPLE 1-C- Mean wind - flat terrain - **test3**

Given: Find the mean wind velocity at height $z = 5\ \text{m}$ above the terrain. Assume: $v_b = 25,95\ \text{m/s}$.

[*Reference sheet:* CodeSec4]-[*Cell-Range: A256:O256-A264:O264*].

Solution: Flat terrain: orography factor equal to $c_0(z) = 1 = cost$ for any "z". From which, using the results calculated in the previous example, we have:

$v_m(z) = v_m(5) = c_r(5) \cdot c_0(5) \cdot v_b \approx 0,61 \cdot 1 \cdot 25,95 = 15,8\ \text{m/s}$.

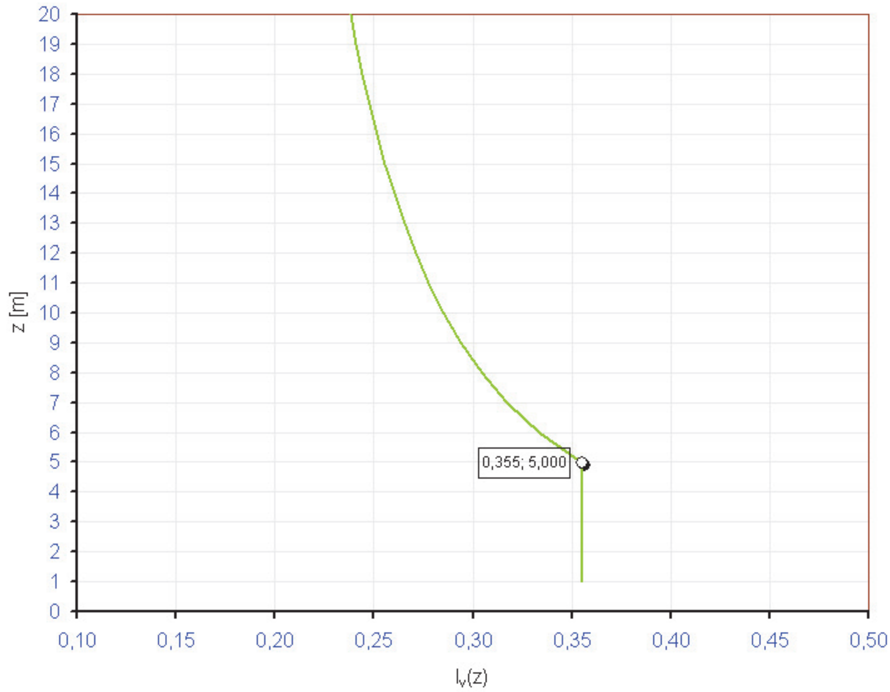


Figure 1.3 Turbolence intensity against "z" (Cat. III, c_0 = 1; k_l = 1).

NOTE $v_b = 25,9515$ [see *cell*: P66, *sheet*: CodeSec4].

$c_r(5) = 0,60598$ [see *cell*: T122, *sheet*: CodeSec4].

Therefore: $c_r(5) \cdot c_0(5) \cdot v_b = 0,60598 \cdot 1 \cdot 25,9515 = 15,72609$

[see *cell*: T258, *sheet*: CodeSec4].

example-end

EXAMPLE 1-D- Wind turbulence - **test4**

Given: Find the turbulence intensity $I_v(z)$ at height $z = 5$ m above the terrain. Let assume a turbulence factor k_l and an orography factor $c_0(z)$ both equal to unity. Terrain cat.: III.
[*Reference sheet:* CodeSec4]-[*Cell-Range: A282:O282-A364:O364*].

Solution: From Table 4.1 (terrain category III): roughness length: $z_0 = 0,30$,

$z_{min} = 5$ m, $z_{max} = 200$ m.

We have (see previous examples): flat terrain $c_0 = 1 = cost$.

For $z_{min} \le z \le z_{max} \Rightarrow 5\text{ m} \le z \le 200\text{ m}$, we find:

$$I_v(z) = \frac{k_l}{c_0(z) \cdot \ln(z/z_0)} = \frac{1}{1 \cdot \ln(5/0,30)} = 0,355 \approx 0,36.$$

For (say) $z = 17\ m$, we get:

$$I_v(z) = \frac{k_l}{c_0(z) \cdot \ln(z/z_0)} = \frac{1}{1 \cdot \ln(17/0,30)} = 0,2478$$ [see *cell*: R339, *sheet*: CodeSec4].

example-end

EXAMPLE 1-E- Peak velocity pressure - **test5**

Given: Find the peak velocity pressure at height $z = 5\ m$. Use the numerical data given in the previous examples. Assume an air density equal to $1,25\ kg/m^3$.

[*Reference sheet:* CodeSec4]-[*Cell-Range: A389:O389-A458:O458*].

Solution: From previous example, we found:

$$v_m(z) = c_r(z) \cdot c_0(z) \cdot v_b \approx 15,8\ m/s.$$

Therefore, with $I_v(5) = 0,36$, $\rho = 1,25\ kg/m^3$, we get:

$$[1 + 7 \cdot I_v(z)] \cdot 0,5 \cdot \rho \cdot v_m^2(z) = [1 + 7 \cdot 0,36] \cdot 0,5 \cdot 1,25 \cdot (15,8)^2 \cdot 10^{-3} \approx 0,55\ kN/m^2,$$

$$q_p(z) = q_p(5) = 0,55\ kN/m^2.$$

NOTE $v_m = 15,7261$ [see *cell*: T258, *sheet*: CodeSec4].

$I_v(5) = 0,35544$ [see *cell*: V310, *sheet*: CodeSec4].

Therefore:

$$[1 + 7 \cdot I_v(z)] \cdot 0,5 \cdot \rho \cdot v_m^2(z) = [1 + 7 \cdot 0,35544] \cdot 0,5 \cdot 1,25 \cdot (15,7261)^2 = 539,15\ N/m^2$$

[see *cell*: P398, *sheet*: CodeSec4].

example-end

EXAMPLE 1-F- Exposure factor - **test6**

Given: Find the exposure factor at height $z = 5\ m$. Use the numerical data given in the previous examples ($q_p(5) = 539,15\ N/m^2 = 0,539\ kN/m^2$).

[*Reference sheet:* CodeSec4]-[*Cell-Range: A544:O544-A548:O548*].

Solution: basic velocity pressure:

$$q_b = 0,5 \cdot \rho \cdot v_b^2 \approx 0,5 \cdot 1,25 \cdot (26)^2 \cdot 10^{-3} = 0,42\ kN/m^2.$$

Exposure factor: $c_e(5) = q_p(5)/q_b = (0,54)/(0,42) \approx 1,28\ [-]$.

example-end

EXAMPLE 1-G- Fundamental value of the basic wind velocity, altitude factor (UK NA) - **test7**

Given: The basic wind velocity, v_b, defined as a function of wind direction and time of year at 10 m above ground for terrain category II, called Country terrain in the UK National Annex is given by:

$$v_b = c_{dir} \cdot c_{season} \cdot c_{prob} \cdot v_{b,0}$$

where $v_{b,0}$ is the fundamental value of the basic wind velocity given by:

$v_{b,0} = v_{b,map} \cdot c_{alt}$ with $v_{b,map}$ which is given in Figure below.

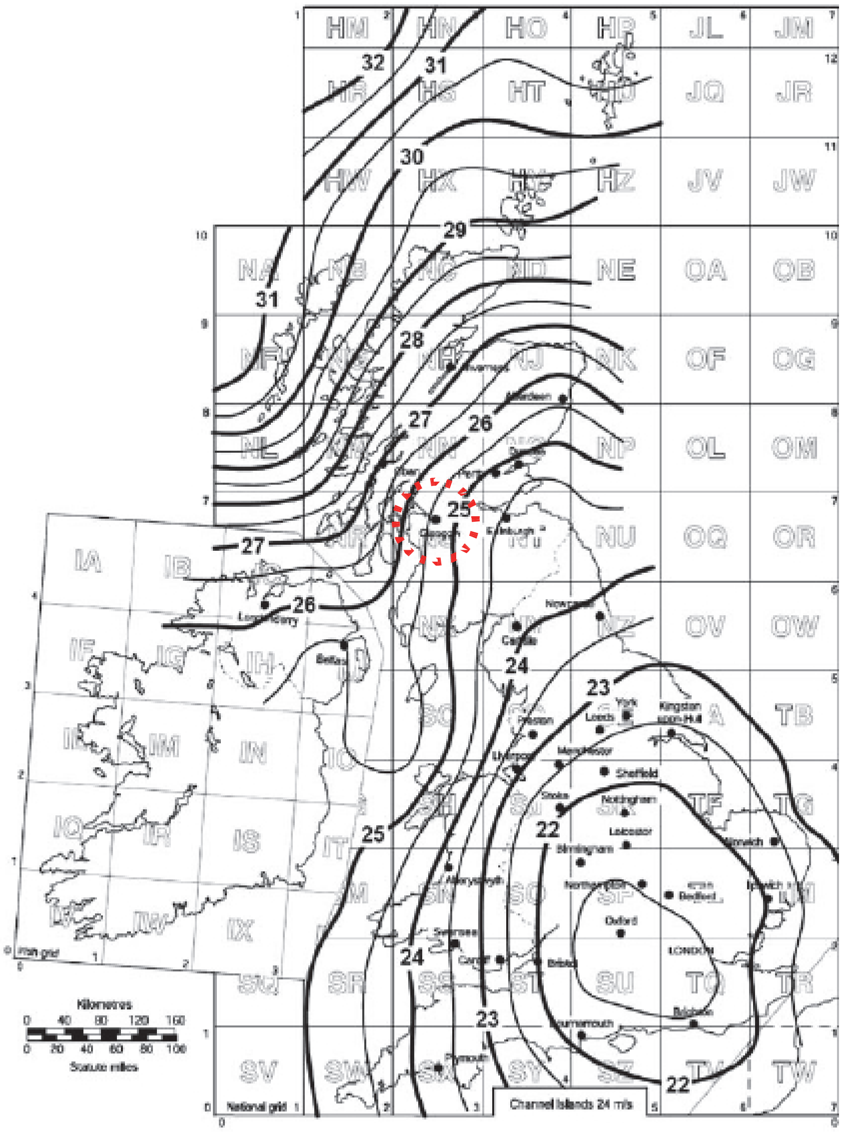


Figure 1.4 Value of $v_{b,map}$ [m/s]. Figure taken from: Manual for the design of building structures to Eurocode 1 and Basis of Structural Design April 2010. © 2010 The Institution of Structural Engineers.

The altitude factor c_{alt} is given by:

$c_{alt} = 1 + 0,001 \cdot A$ for $z \le 10$ m,

$c_{alt} = 1 + 0,001 \cdot A \cdot (10/z)^{1/5}$ for $z > 10$ m.

where A is the altitude of the site in metres above mean sea level and z is either z_s as defined in Figure 6.10 (EN 1991-1-4) or z_e the height of the part above ground as defined in Figure 7.4 (EN 1991-1-4).

Find the fundamental value of the basic wind velocity around the city of Glasgow ($A \approx 70$ mamsl) assuming an height (say as defined in Figure 6.10) equal to $z_e = z = 11$ m.

[*Reference sheet:* CodeSec4]-[*Linked Cell: I37*].

Solution: From Figure 1.4, near the city of Glasgow: $v_{b,\,map} = 25,5$ m/s. For $z > 10$ m, we get:

$c_{alt} = 1 + 0,001 \cdot A \cdot (10/z)^{1/5} = 1 + 0,001 \cdot 70 \cdot (10/11)^{1/5} = 1,069$.

Therefore: $v_{b,\,0} = v_{b,\,map} \cdot c_{alt} = 25,5 \cdot 1,069 = 27,26$ m/s.

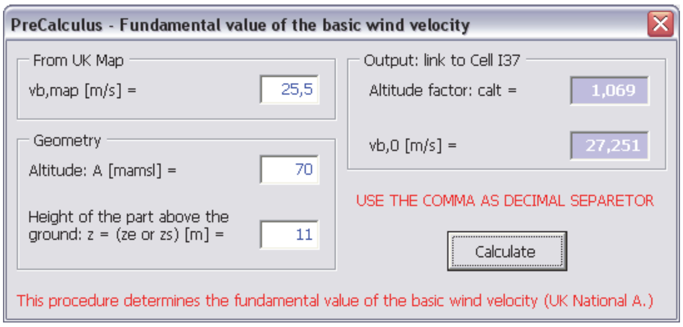


Figure 1.5 PreCalculus Excel® form: procedure for a quick pre-calculation.

PreCalculus (see Figure 1.5).

$c_{alt} = 1,068678$, $v_{b,\,0} = v_{b,\,map} \cdot c_{alt} = 25,5 \cdot 1,068678 \approx 27,251$ m/s.

example-end

1.7 References [Section 1]

EN 1991-1-4:2005/A1:2010. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, April 2010.

EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, March 2005 (DAV).

Manual for the design of building structures to Eurocode 1 and Basis of Structural Design, April 2010. © 2010 The Institution of Structural Engineers.

Section 2 **Eurocode 1**
EN 1991-1-4
Section 7 (Page 32 to 37)

2.1 Pressure and force coefficients - General

This section should be used to determine the appropriate aerodynamic coefficients for structures. Depending on the structure the appropriate aerodynamic coefficient will be:

- internal and external pressure coefficients, see 7.1.1(1)
- net pressure coefficients, see 7.1.1(2)
- friction coefficients, see 7.1.1(3)
- force coefficients, see 7.1.1(4).

Pressure coefficients should be determined for:

1. buildings, using 7.2 for both internal and external pressures, and for
2. circular cylinders, using 7.2.9 for the internal pressures and 7.9.1 for the external pressures.

Net pressure coefficients should be determined for:

1. canopy roofs, using 7.3
2. free-standing walls, parapets and fences using 7.4.

Friction coefficients should be determined for walls and surfaces defined in 5.3 (3) and (4), using 7.5.

1. force coefficients should be determined for:
2. signboards, using 7.4.3
3. structural elements with rectangular cross section, using 7.6
4. structural elements with sharp edged section, using 7.7
5. structural elements with regular polygonal section, using 7.8
6. circular cylinders, using 7.9.2 and 7.9.3
7. spheres, using 7.10
8. lattice structures and scaffoldings, using 7.11 and flags, using 7.12.

A reduction factor depending on the effective slenderness of the structure may be applied, using 7.13.

Note Force coefficients give the overall effect of the wind on a structure, structural element or component as a whole, including friction, if not specifically excluded.

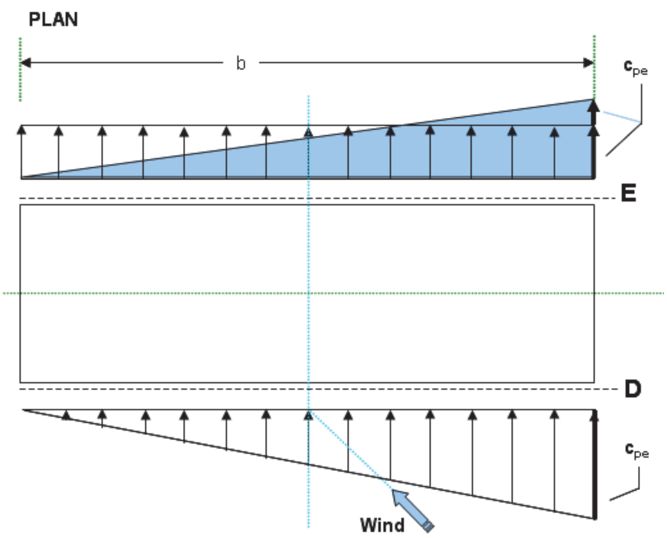
2.2 Asymmetric and counteracting pressures and forces

If instantaneous fluctuations of wind over surfaces can give rise to significant asymmetry of loading and the structural form is likely to be sensitive to such loading (e.g. torsion in nominally symmetric single core buildings) then their effect should be taken into account. For free-standing canopies and signboards, 7.3 and 7.4 should be applied.

The National Annex may give procedures for other structures. The recommended procedures are:

a. for rectangular structures that are susceptible to torsional effects the pressure distribution given in Figure 7.1 should be applied for the representation of the torsional effects due to an inclined wind or due to lack of correlation between wind forces acting at different places on the structure

b. for other cases an allowance for asymmetry of loading should be made by completely removing the design wind action from those parts of the structure where its action will produce a beneficial effect.



NOTE:

Zone **E**:
c_{pe} (UK) = 1,3 x c_{pe} (EC1)

Zone **D**:
c_{pe} (UK) = 1,3 x c_{pe} (EC1)

Note The recommended procedure in EC1 Part 1-4 to account for torsion should not be used in the UK: blue pressure distibution (zone **E**) should be used instead, the shape of the pressure distribution in zone **D** remains unchanged.

Figure 2.6 From Figure 7.1 [modified] - Pressure distribution used to take torsional effects into account.

⚠ If ice or snow alters the geometry of a structure so that it changes the reference area or shape, this should be taken into account.

2.3 Pressure coefficients for buildings

The external pressure coefficients are given for loaded areas A of 1 m^2 and 10 m^2 in the tables for the appropriate building configurations as $c_{pe,1}$, for local coefficients, and $c_{pe,10}$, for overall coefficients, respectively.

Values for $c_{pe,1}$ are intended for the design of small elements and fixings with an area per element of 1 m^2 or less such as cladding elements and roofing elements. Values for $c_{pe,10}$ may be used for the design of the overall load bearing structure of buildings. The National Annex may give a procedure for calculating external pressure coefficients for loaded areas above 1 m^2 based on external pressure coefficients $c_{pe,1}$ and $c_{pe,10}$. The recommended procedure for loaded areas up to 10 m^2 is given by expression:

$$c_{pe} = c_{pe,1} - (c_{pe,1} - c_{pe,10}) \cdot \log A \quad \text{for } 1 < A\ [m^2] < 10 \qquad \textbf{(Eq. 2-7)}$$

where A is the loaded area.

Note This recommended procedure should not be used in the UK. In the UK the $c_{pe,1}$ values should be used for all areas $\leq 1\ m^2$ and the $c_{pe,10}$ values should be used for all areas $> 10\ m^2$. The $c_{pe,1}$ values should be used for small cladding elements and fixings and the $c_{pe,10}$ values for larger cladding elements and for overall structural loads.

c_{pe} values are given for orthogonal wind directions 0°, 90° and where appropriate 180°. These represent the worst case values over the range of wind directions of ±45° about each orthogonal axis. No specific coefficients are given for overhanging or protruding roofs. In these cases the pressure on the top surface of the overhanging roof is determined from the appropriate roof zone and the pressure on the underside is taken as that on the adjacent part of the vertical wall.

2.4 Vertical walls of rectangular plan buildings

The external pressure coefficients $c_{pe,10}$ and $c_{pe,1}$ for the walls of rectangular plan buildings are defined in Figure 7.5 ("*Key for vertical walls*") and the values are given in Table 7.1 ("*Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings*").

The values of $c_{pe,10}$ and $c_{pe,1}$ may be given in the National Annex. The recommended values are given in Table 7.1, depending on the ratio h/d. For intermediate values of h/d, linear interpolation may be applied. The values of Table 7.1 also apply to walls of buildings with inclined roofs, such as duopitch and monopitch roofs.

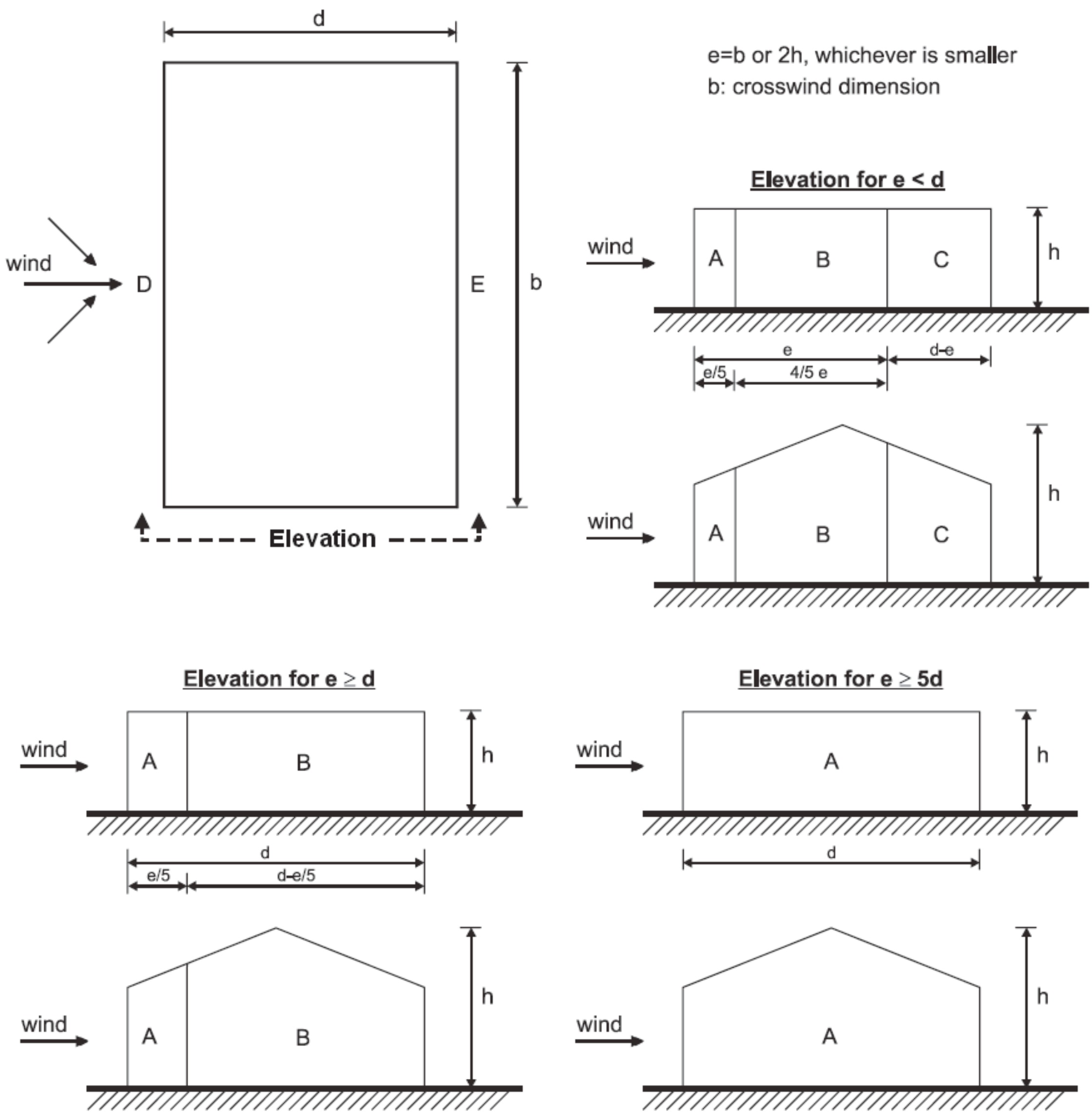


Figure 2.7 From Figure 7.5 - Key for vertical walls.

For buildings with h/d > 5, the total wind loading may be based on the provisions given in 7.6 to 7.8 and 7.9.2.

In cases where the wind force on building structures is determined by application of the pressure coefficients c_{pe} on windward and leeward side (zones **D** and **E**) of the building simultaneously, the lack of correlation of wind pressures between the windward and leeward side may have to be taken into account.

The lack of correlation of wind pressures between the windward and leeward side may be considered as follows. For buildings with h/d $\geq$ 5 the resulting force is multiplied by 1. For buildings with h/d $\leq$ 1, the resulting force is multiplied by 0,85. For intermediate values of h/d, linear interpolation may be applied.

Zone	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
5	– 1,2	– 1,4	– 0,8	– 1,1	– 0,5	– 0,5	+ 0,8	+ 1,0	– 0,7	– 0,7
1	– 1,2	– 1,4	– 0,8	– 1,1	– 0,5	– 0,5	+ 0,8	+ 1,0	– 0,5	– 0,5
≤ 0,25	– 1,2	– 1,4	– 0,8	– 1,1	– 0,5	– 0,5	+ 0,8	+ 1,0	– 0,3	– 0,3

Table 2.2 From Table 7.1 - Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings. [*For intermediate values of h/d, linear interpolation may be applied*].

2.5 Verification tests

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— CodeSec7(32to37).

EXAMPLE 2-H- External pressure coefficients for building - **test1**

Given: A 20,0 m x 25,0 m x 8,0 m at eaves, 9,0 m at apex warehouse is to be constructed. Find the external pressure coefficients $c_{pe,10}$ and $c_{pe,1}$ for vertical walls (zone A, B, C, D and E as defined in Figure 7.5). Using the recommended procedure given in Figure 7.2, find the external pressure coefficients c_{pe} for all the vertical zone. Assume a rectangular plan building.

[*Reference sheet:* CodeSec7(32to37)]-[*Cell-Range: A1:O1-A197:O197*].

Solution: We have: $d = 20,0\ m$; $b = 25,0\ m$ (crosswind dimension); $h = 9,0\ m$ (at apex) and $h_{min} = 8,0\ m$ (at eaves).

From Figure 7.5:

$e = min[b; 2h] = min[25,0; (2 \cdot 9,0)] = 18,0\ m$.

Elevation for $e < d$ applies:

$\frac{e}{5} = \frac{18}{5} = 3,6\ m$;

$\frac{4e}{5} = \frac{4 \cdot (18,0)}{5} = 14,4\ m$;

$d - e = (20,0 - 18,0) = 2,0\ m$.

Entering Table 7.1 (see Table above) with:

$\frac{h}{d} = \frac{9,0}{20,0} = 0,45$

we obtain (linear interpolation between h/d = 1 and h/d ≤ 0,25 rows) for:

Zone D

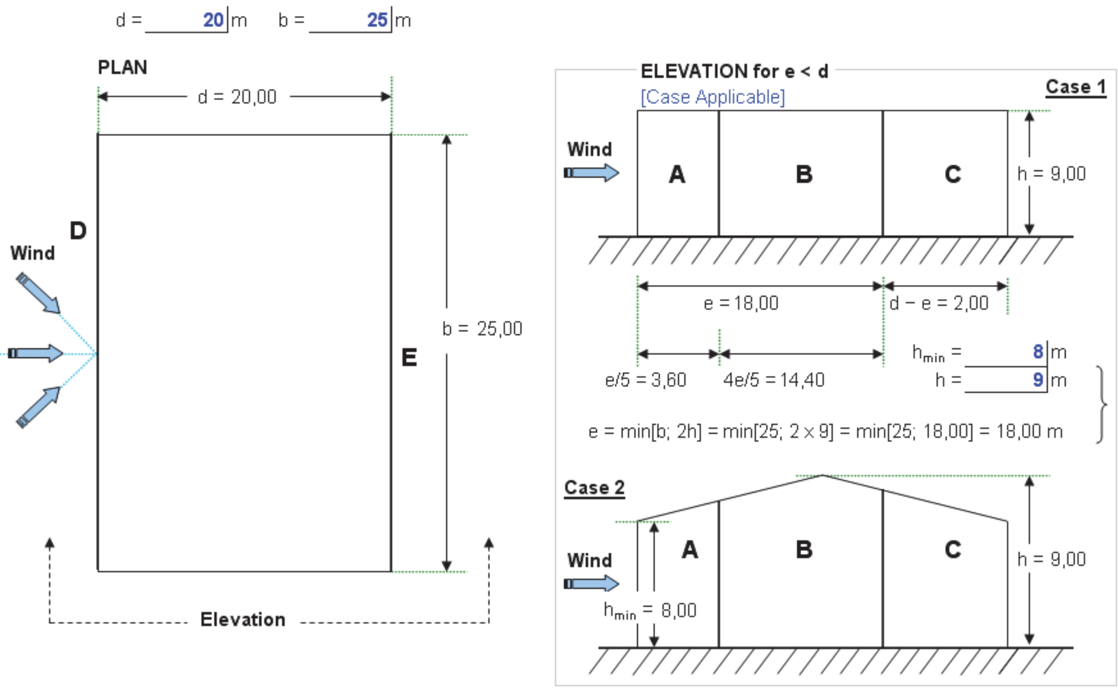

Figure 2.8 Sheet: "CodeSec7(32to37)" - Geometry Input.

$$\frac{0,8-0,7}{1-0,25} = \frac{c_{pe,10}-0,7}{0,45-0,25} \quad \rightarrow \quad c_{pe,10} = 0,73$$

Zone E (with $c_{pe,10} = c_{pe,1}$)

$$\frac{-0,5-(-0,3)}{1-0,25} = \frac{c_{pe,10}-(-0,3)}{0,45-0,25} \quad \rightarrow \quad c_{pe,10} = c_{pe,1} = -0,35\,.$$

Therefore, we get:

Zone	A		B		C		D		E	
h/d	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$	$c_{pe,10}$	$c_{pe,1}$
≤ 0,25	– 1,2	– 1,4	– 0,8	– 1,1	– 0,5	– 0,5	+ 0,73	+ 1,0	– 0,35	– 0,35

Table 2.3 From Table 7.1 - Recommended values of external pressure coefficients for vertical walls of rectangular plan buildings. [*Linear interpolation applied*].

Calculations of areas.

Zone A (with e < d and consequently e/5 < d/2):

$$\frac{h-h_{min}}{0,5\cdot d} = \frac{h_{AB}-h_{min}}{e/5} \quad \rightarrow \quad \frac{9-8}{0,5\cdot(20)} = \frac{h_{AB}-8}{3,6} \quad \rightarrow \quad h_{AB} = 8,36\ \text{m}$$

$$A(A) = \frac{(h_{AB}+h_{min})\cdot\frac{e}{5}}{2} = \frac{(8,36+8,00)\cdot(3,60)}{2} = 29,448\ \text{m}^2 > 10\ \text{m}^2\,.$$

Zone C (with e < d, it is d – e = 2 m < 0,5d):

$$\frac{h - h_{min}}{0,5 \cdot d} = \frac{h_{BC} - h_{min}}{d - e} \quad \rightarrow \quad \frac{9 - 8}{0,5 \cdot (20)} = \frac{h_{BC} - 8}{2} \quad \rightarrow \quad h_{BC} = 8,20 \text{ m}$$

$$A(C) = \frac{(h_{BC} + h_{min}) \cdot (d - e)}{2} = \frac{(8,20 + 8,00) \cdot (2,00)}{2} = 16,20 \text{ m}^2 > 10 \text{ m}^2 .$$

Total area (zones **A** + **B** + **C**):

$$A(A + B + C) = (h + h_{min}) \cdot \frac{d}{2} = (9 + 8) \cdot \frac{20}{2} = 170 \text{ m}^2 .$$

Zone B:

$$A(B) = (170 - 29,449 - 16,20) = 124,351 \text{ m}^2 > 10 \text{ m}^2 .$$

External pressure coefficients c_{pe}.

All the calculated loaded areas are above 10 m^2. Therefore $c_{pe} = c_{pe,10}$.

Zone	A	B	C	D	E
h/d	c_{pe}	c_{pe}	c_{pe}	c_{pe}	c_{pe}
≤ 0,25	– 1,2	– 0,8	– 0,5	+ 0,73	– 0,35

Table 2.4 Calculated values of external pressure coefficients for vertical walls of rectangular plan buildings. [*Linear interpolation applied*].

As it was plausible to expect all the coefficients of external pressure coincide with the values of $c_{pe,10}$.

example-end

EXAMPLE 2-I- Asymmetric and counteracting pressures and forces - **test2**

Given: Assume that short term fluctuations of wind gusts over the building's surfaces can give rise to asymmetric loading. Use the recommended procedure used in the UK to calculate the external pressure coefficient for the zone D and E. Numerical data form previous example.

[*Reference sheet:* CodeSec7(32to37)]-[*Cell-Range: A216:O216-A264:O264*].

Solution: The recommended procedure in EC1 Part 1-4 to account for torsion should not be used in the UK, Figure below should be used instead.

The zones D and E and the external pressure coefficients are given in Figure 7.5 and in Table 7.1 respectively. According to the provisions of the UK National Annex we have $c_{pe}^{(UK)} = 1,3 \cdot c_{pe}^{(EC1)}$ (with $c_{pe} = c_{pe,10}$) and pressure distributions of triangular shape (see Figure below).

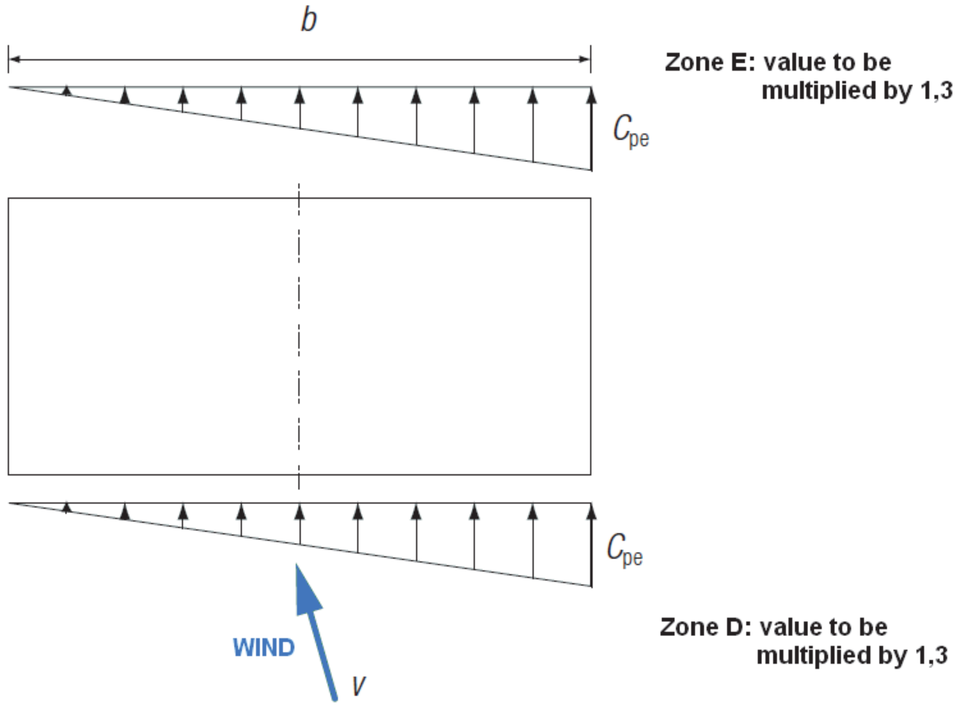

Figure 2.9 Pressure distribution used to take torsional effects into account (UK National Annex).

Zone E

$c_{pe}^{(UK)} = 1,3 \cdot (-0,35) \approx -0,45$

Zone D

$c_{pe}^{(UK)} = 1,3 \cdot (0,73) \approx 0,95$.

example-end

2.6 References [Section 2]

EN 1991-1-4:2005/A1:2010. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, April 2010.

EN 1991-1-4:2005. Eurocode 1: Actions on structures - Part 1-4: General actions - Wind actions. Brussels: CEN/TC 250 - Structural Eurocodes, March 2005 (DAV).

Manual for the design of building structures to Eurocode 1 and Basis of Structural Design, April 2010. © 2010 The Institution of Structural Engineers.