CHAPTER III - WIND ACTIONS

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Summary

In this chapter the determination of wind effects on structures according to the European draft standard EN 1991-1-4 is explained. The following practical examples show the application of operational rules for the determination of the wind pressure and wind actions on:

- a simple rectangular multi-storey frame building with flat roof
- a simple rectangular building with duopitch roof
- a rectangular tower block
- a glazing panel
- an industrial hall
- a cylindrical tower block
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The excel-sheet 'windloads.xls' helps to determine characteristic wind velocity and pressure coefficients according to EN 1991-1-4 for buildings.

1 INTRODUCTION

1.1 General

General principles for the classification of actions on structures, including environmental impacts and their modelling in verification of structural reliability, are introduced in Eurocode 0, EN 1990 [2]. In particular EN 1990 [2] defines various representative values (characteristic and design values) used in design calculation (see also Designers' Handbook [3]). Detailed description of individual types of actions is given in various parts of Eurocode 1, EN 1991.

Part 1.4 of EN 1991 [1] covers wind actions and gives rules and values for the following topics:

- design situations;
- nature and classification of wind actions;
- wind velocity and velocity pressure;
- effect of wind on the structure;
- pressure and force coefficients.

For the effect of wind on the structure three types of response are covered. From these three types of response only the quasi-static response will be discussed in this chapter. Dynamic and aeroelastic responses are not covered herein because the calculation of these types of response is not needed for most types of buildings.

1.2 Background documents

Part 1.4 of EN 1991 [1] was initially based on an ISO TC98 document and was developed using inputs from the latest wind engineering practice introduced into national standards in European countries.

1.3 Status

Part 1.4 of EN 1991 [1] is not yet available. Hence, this paper is based on its predecessor prEN 1991-1-4 according to the draft of June 2004.

2 BASIS OF APPLICATION

2.1 Characteristics of prEN 1991-1-4

Part 1.4 of EN 1991 [1] enables the assessment of wind actions for the structural design of buildings and civil engineering structures up to a height of 200 m. The wind actions are given for the whole or parts of the structure, e.g. components, cladding units and their fixings.

Part 1.4 of EN 1991 [1] does not cover all possible aspects of wind actions. Special conditions which are not common for most types of structures, like local thermal effects on the characteristic wind, torsional vibrations, vibrations from transverse wind turbulence, vibrations with more than one relevant fundamental mode shape and some aeroelastic effects are not covered. Wind actions on structures like lattice towers, tall buildings with a central core, cable stayed and suspension bridges, guyed masts and offshore structures are not fully covered. If possible, a reference is made to other more specific codes. Otherwise specialist's advice is needed and wind tunnel experiments might be useful.

The application range of the European wind load standard is much larger than compared to some older national standards. Particularly the specification of wind loads for high-rise buildings and for structures which are susceptible to wind induced vibrations is described in detail.

Table 1. Application range of prEN 1991-1-4

Structure	Limitation of EN 1991-1-4
Buildings	Height: max. 200 m
Viaducts	Span: max. 200 m
Suspension Bridge/Stay Cable Bridge	Particular Investigations
Pedestrian Bridge	Span: max. 30 m

For this broad application range an extensive set of pressure coefficients and force coefficients as well as a sufficiently accurate description of the characteristics of the natural wind must be provided. Consequently these advantages lead to a more complex application of the new European wind load standard compared to older national standards. Due to its comprehensiveness the modern European standard demands more skills to determine the relevant wind loading than the simple rules of some national standards, particularly in case of small, simple structures.

Table 2. Advantages and Disadvantages of prEN 1991-1-4

Comparison of prEN 1991-1-4 with national standards	
+	New extensive set of pressure and force coefficients
+	More accurate description of wind loads
+	Suitable for lightweight structures
+	Additional investigations of experts is in many cases avoidable
-	Application demands more skills than simple standards
-	Difficult identification of the relevant information in case of simple structures

2.2 General principles

According to EN 1990 [2] actions shall/should be classified according to their variation in time, spatial variation, origin and their nature and/or structural response.

Considering their variation in time and space, wind actions are classified as variable fixed actions. It means that the wind actions are not always present and the wind actions have for each considered wind direction fixed distributions along the structure. The classification to the origin of wind actions can be direct as well as indirect: Direct for external surfaces and internal surfaces of open structures; indirect for internal surfaces of enclosed structures.

The last classification of wind actions is done according to their nature and/or structural response. This classification depends on the response of the structure due to wind actions. For wind actions the following responses are covered in Part 1.4 of EN 1991 [1]:

- quasi-static response
- dynamic and aeroelastic response

For structures when the lowest natural frequency is so high that wind actions in resonance with the structure are insignificant, the wind action is called quasi-static. The dynamic response is significant for structures, if the turbulence (or gust effect) of the wind is in resonance with the structure's natural frequency whereas the aeroelastic response occurs if an interaction between the movement of a particular structure and the circumfluent wind flow exists.

Due to these different types of wind loading the European wind load standard is subdivided into two parts. The main part gives information and load assumptions for common structures which are not susceptible to wind induced vibrations, i.e. here the rules for determining the quasi-static wind loading are defined. In the annex to prEN 1991-1-4 rules are given for the determination of wind loading for slender, lightweight structures susceptible to vibrations due to turbulence and for structures susceptible to aeroelastic effects due to vortex shedding (e.g. steel chimneys) and due to galloping and flutter (e.g. bridge decks). Concerning the dynamic response due to turbulence prEN 1991-1-4 covers only the along wind vibration response of a fundamental mode shape with constant sign. Structural response of higher vibration modes can not be taken into account using prEN 1991-1-4.

The following text and examples deal only with topics of the main part of prEN 1991-1-4, i.e. only the quasi-static response will be discussed herein. According to prEN 1991-1-4 the quasi-static response needs to be calculated for all structures, while for most buildings it is not needed to take account of the dynamic and aeroelastic response.

If special considerations are necessary for dynamic and aeroelastic response wind tunnel tests should be performed.

3 WIND VELOCITY AND WIND PRESSURE

3.1 General

One of the main parameters in the determination of wind actions on structures is the characteristic peak velocity pressure q_p. This parameter is in fact the characteristic pressure due to the wind velocity of the undisturbed wind field. The peak wind velocity accounts for the mean wind velocity and a turbulence component. The characteristic peak velocity pressure q_p is influenced by the regional wind climate, local factors (e.g. terrain roughness and orography/terrain topography) and the height above terrain.

3.2 Wind climate

The wind climate for different regions/countries in Europe is described by values related to the characteristic 10 minutes mean wind velocity at 10 m above ground of a terrain with low vegetation (terrain category II). These characteristic values correspond to annual probabilities of exceedence of 0,02 which corresponds to a return period of 50 years. In prEN 1991-1-4 this variable is denoted as the *fundamental value of the basic wind velocity* $v_{b,0}$. Values for the wind climate in different regions/countries are given in the National Annex to prEN 1991-1-4. The *basic wind velocity* v_b in a region in Europe can be determined with the formula:

$$v_b = c_{dir}\, c_{season}\, v_{b,0} \tag{1}$$

where: $v_{b,0}$ = fundamental value of basic wind velocity
v_b = basic wind velocity
c_{dir} = directional factor
c_{season} = seasonal factor

The directional factor c_{dir} accounts for the fact that for particular wind directions the velocity v_b could be decreased, whereas the seasonal factor c_{season} takes into account that in case of temporary structures for particular periods the probability of occurrence of high wind velocities is relatively low. For simplification the directional factor c_{dir} and the seasonal factor c_{season} are in general equal to 1,0. A global overlook of the wind maps for Europe is given in Figure 1 (which is not included in prEN 1991-1-4).

The following relationship exists between the basic velocity and the basic pressure:

$$q_b = \rho/2 \cdot v_b^2 \tag{2}$$

where: ρ = density of air (can be set to 1,25 kg/m^3)

Thus this value represents the mean velocity pressure (averaging interval 10 min.), i.e. the turbulence of the wind is not included, at a reference height of 10 m in open terrain with a return period of 50 years.

The basic value of the velocity pressure has to be transformed into the value at the reference height of the considered structure. Velocity at a relevant height and the gustiness of the wind depend on the terrain roughness. The roughness factor describing the variation of the speed with height has to be determined in order to obtain the mean wind speed at the relevant height:

$$v_m(z) = c_r(z) \cdot c_o(z) \cdot v_b \tag{3}$$

where: $v_m(z)$ = mean velocity
$c_r(z)$ = roughness factor
$c_o(z)$ = orography factor (usually taken as 1,0)

In case of structures that are located on elevations like hills etc. the increase of the velocity can be taken into account by defining a particular orography factor $c_o(z)$. In general this factor is set to 1,0.

The roughness factor related to a minimum height z_{min} for the calculation is:

$$c_r(z) = k_r \cdot \ln(z/z_0)\ , \ \text{but } z \geq z_{min} \tag{4}$$

$$k_r = 0{,}19 \cdot (z_0/z_{0,II})^{0{,}07} \tag{5}$$

where: k_r = terrain factor
z_0 = roughness length
z_{min} = minimum height

Figure 1. Overlook of the European wind map for basic wind velocities $v_{b,0}$
(indicative values only)

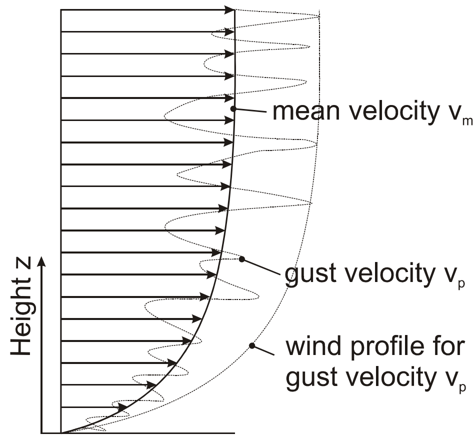


Figure 2. Variation of wind velocity depending on height *z*

The input parameters of the formulae above are defined in dependence of the relevant terrain roughness:

Table 3. Terrain categories

Terrain category	Characteristics of the terrain	z_0 [m]	z_{min} [m]
0	sea or coastal area	0,003	1,0
I	lakes; no obstacles	0,01	1,0
II	low vegetation; isolated obstacles with distances of at least 20 times of obstacle heights	0,05	2,0
III	regular vegetation; forests; suburbs; villages	0,3	5,0
IV	at least 15% of the surface covered with buildings with average height of at least 15 m	1,0	10,0

The gust velocity (or peak velocity) $v_p(z)$ at the reference height of the considered terrain category is calculated with the mean velocity and the gust factor G:

$$v_p(z) = v_m(z) \cdot G \tag{6}$$

where:

$$G = \sqrt{c_e(z)} = \sqrt{1 + 7 \cdot I_v(z)} = \sqrt{1 + 7 \cdot \frac{\sigma_v(z)}{v_m(z)}} = \sqrt{1 + \frac{7 \cdot k_I}{c_o(z) \cdot \ln(z/z_0)}} \quad \textit{with} \quad z \geq z_{min} \tag{7}$$

where: k_I = turbulence factor (usually taken as 1,0)

As indicated above the gust factor represents the square root of the exposure coefficient. Hence the following expression for the gust pressure in the relevant reference height is obtained:

$$q_p(z) = q_b(z) \cdot [c_r(z)]^2 \cdot [c_o(z)]^2 \cdot \left[1 + \frac{7 \cdot k_I}{c_o(z) \cdot \ln(z/z_0)}\right] \tag{8}$$

which is simplified in case of the general assumption of $c_o(z) = k_I = 1{,}0$:

$$\underbrace{q_p(z)}_{\text{peak pressure}} = \underbrace{q_b}_{\text{basic pressure}} \cdot \underbrace{\left[c_r(z)\right]}_{\text{wind profile}}{}^2 \cdot \underbrace{\left[1+\frac{7}{\ln(z/z_0)}\right]}_{\text{squared gust factor}} \tag{9}$$

4 WIND PRESSURE FOR DETERMINATION OF QUASI-STATIC RESPONSE

4.1 General

In prEN 1991-1-4 regulations are given not only for the determination of the external wind pressure w_e on the structure's cladding but also for the application of the internal wind pressure w_i in case of openings in the cladding. Both types of wind pressure depend on the geometry of the considered structure. In addition to that the internal pressure varies with the permeability of the building:

$$w_e = q_{b,0} \cdot c_e(z_e) \cdot c_{pe} \tag{10}$$

$$w_i = q_{b,0} \cdot c_e(z_i) \cdot c_{pi} \tag{11}$$

where: w_e = external pressure
w_i = internal pressure
$q_{b,0}$ = basic value of velocity pressure
$c_e(z)$ = exposure factor
$c_{pe}(z)$ = external pressure coefficient
$c_{pi}(z)$ = internal pressure coefficient
z_e; z_i = reference height of the considered building

Both, external and internal wind pressure, are defined as acting orthogonally to the surface of the building.

4.2 Pressure coefficients

Due to the fact that an increase of the gust pressure is related to a decrease of the surface area loaded by the corresponding gust in prEN 1991-1-4 external pressure coefficients are given as a function of the size of the relevant cladding: In some cases the pressure coefficients are decreased for smaller sizes.

For the external wind load as well as for the internal wind load the term "pressure" includes also suction: a positive wind load stand for pressure whereas a negative wind load stands for suction on the surface. If both, internal and external wind pressure, have to be applied, they have to be superposed if their effect is unfavourable for the design.

The pressure coefficient c_{pe} for the external pressure has to be chosen in dependence of the structure's geometry. The pressure coefficient c_{pi} has to be applied depending on the permeability of the structure's surface. If it is not possible to estimate the building's permeability then c_{pi} should be taken as the more onerous of +0,2 and –0,3 (see 7.2.9 (6) NOTE 2).

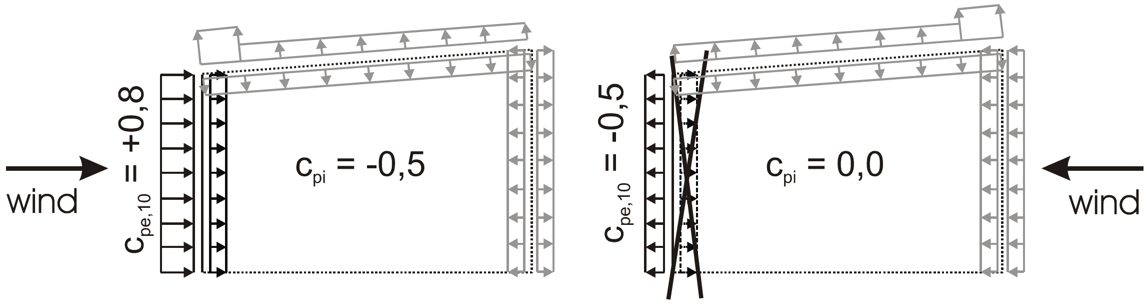


Figure 3. Wind load on cladding:
Superposition of external pressure with unfavourable internal pressure:
wind load on cladding (when cladding windward, c_{pi} is unfavourable - when cladding is leeward, c_{pi} has to be taken as 0,0)

5 DETERMINATION OF THE WIND INDUCED FORCE

5.1 General

The resulting wind force can be determined by integration of the wind pressure over the whole surface or by applying appropriate force coefficients that are given in prEN 1991-1-4 for different kinds of structures. It is noted here, that for many structures force coefficients result into more accurate results than integration of pressure coefficients. The wind force F_w is determined using the following equation:

$$F_w = c_s\, c_d \cdot c_f \cdot q_p(z_e) \cdot A_{ref} \tag{11}$$

where: F_w = wind force
c_s = size factor
c_d = dynamic factor for structures susceptible to wind induced vibrations
c_f = force coefficient
A_{ref} = reference area
z_e = reference height (maximum height of the structure above ground level)

For structures which are not susceptible to turbulence induced vibrations, the quasi-static structural response is crucial. Then the size factor and the dynamic factor are fixed at $c_s\, c_d = 1{,}00$. As mentioned above, only this quasi-static case is treated in this text.

Particularly in case of complex structures like e.g. trusses or in case of structures where the pressure distribution on the surface depends on the Reynolds Number (i.e. the ratio of the inertia force to the frictional force of the flow) as it is for curved shapes like cylinders, spheres, the application of force coefficients instead of integration of pressure coefficients is recommendable. Then the consideration of force coefficients in the calculation leads to a time saving and more accurate determination of wind effects.

5.2 Force coefficients

In prEN 1991-1-4 besides values for particular constructions a distinction is made between force coefficients for elements with rectangular/polygonal shapes and with curved shapes.
For rectangular/polygonal shapes force coefficients are determined by:

$$c_f = c_{f,0} \cdot \Psi_r \cdot \Psi_\lambda \tag{12}$$

where: $c_{f,0}$ = force coefficient for shapes with sharp corners
ψ_r = reduction factor for rounded corners at rectangular structures
ψ_λ = end-effect factor

The ψ_r-value makes allowance for the fact that the wind pressure at rounded corners is lower than at sharp corners that represents a higher obstacle to the flow. In turn it leads to a decreased wind force at structures with rounded corners. Furthermore, independend on the shape of the corner, with the ψ_λ-factor it is taken into account that at the top of structures the resulting wind pressure is lower than the average value at the inner surface. This effect, i.e. this reduction, decreases relatively with higher slenderness of structures.

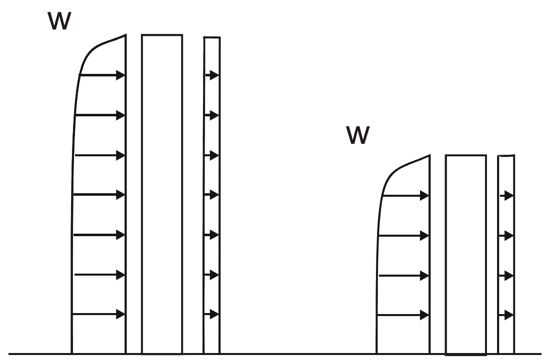


Figure 4. Relative influence of the flow at the edge of the structure on the resulting wind force is for slender structures smaller than for compact structures

The force coefficient for cylinders is defined as:

$$c_f = c_{f,0} \cdot \psi_\lambda \tag{13}$$

where: $c_{f,0}$ = force coefficient for cylinders without free-end flow
ψ_λ = end-effect factor

The force coefficient for spheres has to be determined according to the relevant Reynolds Number $Re = b \cdot v(z_e) / \nu$ (where b = diameter, ν = viscosity of air – $15 \cdot 10^{-6}$ m^2/s).

In addition to the general shapes mentioned above, force coefficients are given for structural elements like:

Table 4: Particular structural elements force coefficients are available for

Structure	c_f depends on
Lattice Structures	End-effect, *Re*-No., solidity ratio*, cross section of members
Flags	End-effect, mass per unit area
Bridges	Ratio height of section/width of section, inclination to the vertical, shape of section, permeability of road restraint system
Sharp edged sections	End-effect

*ratio of impermeable area and overall area of a structure

6 EXAMPLES

6.1 Wind pressure on an industrial hall

The wind pressure is relevant for the design of frames of the following typical structure for an industrial hall and has to be determined:

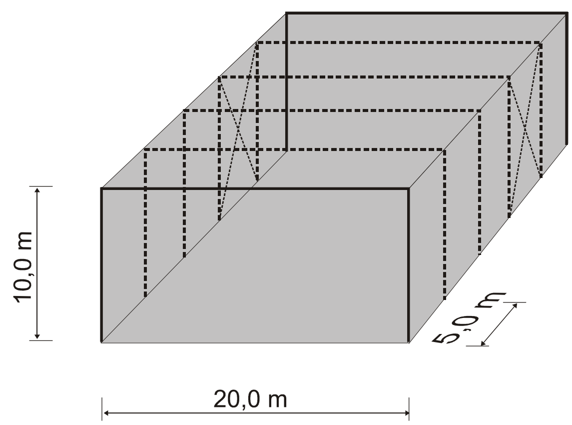


Figure 5. Example: system of an industrial hall

The main structure consists of six frames with a spacing of 5,0 m. The length of the hall is 25,0 m. Each frame is 10,0 m high and has got a bay width of 20,0 m. It is assumed, that in case of a storm there is no opening in the surface of the hall, so that the internal pressure can be neglected, i.e. $c_{pi} = 0,0$.

The hall shall be erected in an industrial area in Aachen, Germany corresponding to wind load zone II and related to a basic value of velocity pressure of

$$q_{b,0} = 0,39 \text{ kN/m}^2$$

With the input data according to terrain category III (see table 3) the following roughness coefficient is determined with the reference height 10 m:

$$k_r = 0{,}19 \cdot (0{,}3/0{,}05)^{0{,}07} = 0{,}22$$

$$c_r(z) = 0{,}22 \cdot \ln(10{,}0/0{,}3) = 0{,}77$$

Furthermore the exposure factor is:

$$c_e(10{,}0) = 1 + \frac{7{,}0}{1{,}0 \cdot \ln(10{,}0/0{,}3)} = 3{,}00$$

The peak velocity pressure is:

$$q_p(10{,}0) = 0{,}77^2 \cdot 3{,}00 \cdot 0{,}39 = 0{,}69 \text{ kN/m}^2$$

From **Table 7.1** ("External pressure coefficients for vertical walls of rectangular plan buildings") and **Table 7.2** ("External pressure coefficients for flat roofs") of prEN 1991-1-4 the following application of c_{pe}-values are obtained:

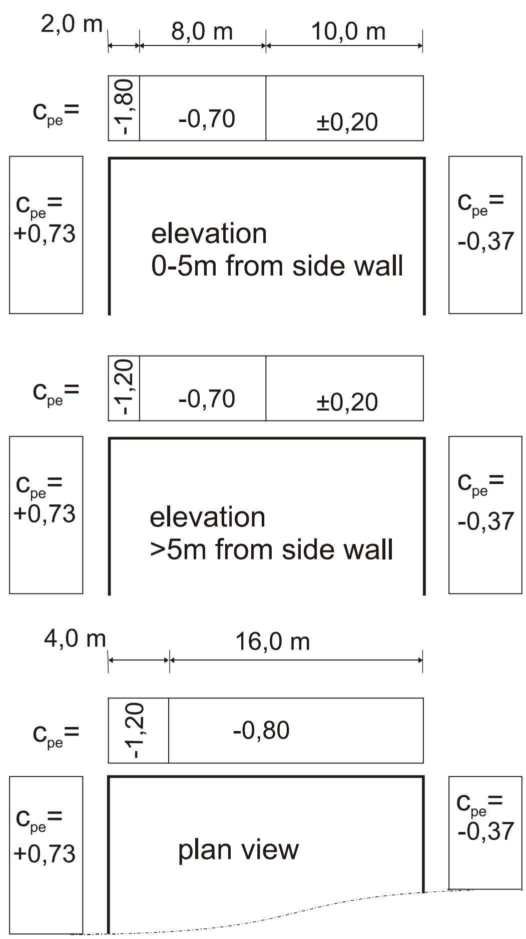


Figure 6. External pressure coefficients according to prEN 1991-1-4

The following characteristic values of the wind loading are obtained from the combination of the pressure coefficients with the peak velocity pressure:

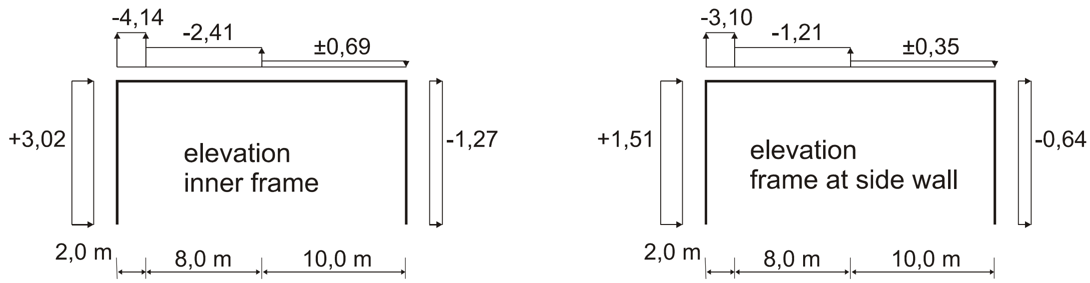


Figure 7. Characteristic values of wind loading in [kN/m] for inner frames (left) and for frames at the side wall (right)

6.2 Wind pressure on a rectangular building with flat roof

A simple rectangular building with flat roof is shown in Figure 6. The dimensions of the building are: height 12 m, width 30 m and depth 15 m. The building is situated in flat terrain of terrain category II. The basic wind velocity $v_{b,0}$ is equal to 26 m/s. The wind forces on the main structure for the wind direction as given in figure 6 will be considered in detail.

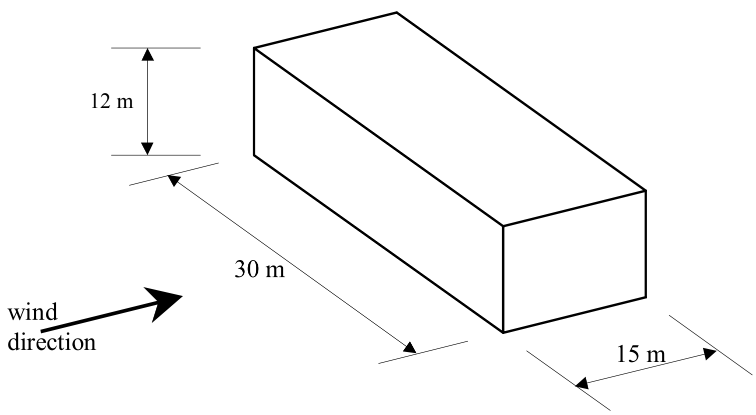


Figure 8. Simple rectangular building with flat roof

The wind forces on the building's main structure in case of a quasi-static response have to be calculated according to section 5.3 of prEN 1991-1-4. The coefficients for the distribution of wind forces on buildings are given as pressure coefficients. The friction forces F_{fr} are neglected. Therefore the resulting wind force, F_w, on the structure is determined with the following equations:

For external pressures: $$F_{w,e} = c_s\, c_d\, \Sigma\, w_e(z)\, A_{ref}(z) \tag{13}$$

For internal pressures: $$F_{w,i} = \Sigma\, w_i(z)\, A_{ref}(z) \tag{14}$$

The summation must be carried out vectorial by taking into account the spatial distribution of the wind pressures $w_e(z)$ and $w_i(z)$. Reference is made to clause 5.1 of prEN 1991-1-4 for the calculation of the wind pressures. This results in the following equations for the wind forces:

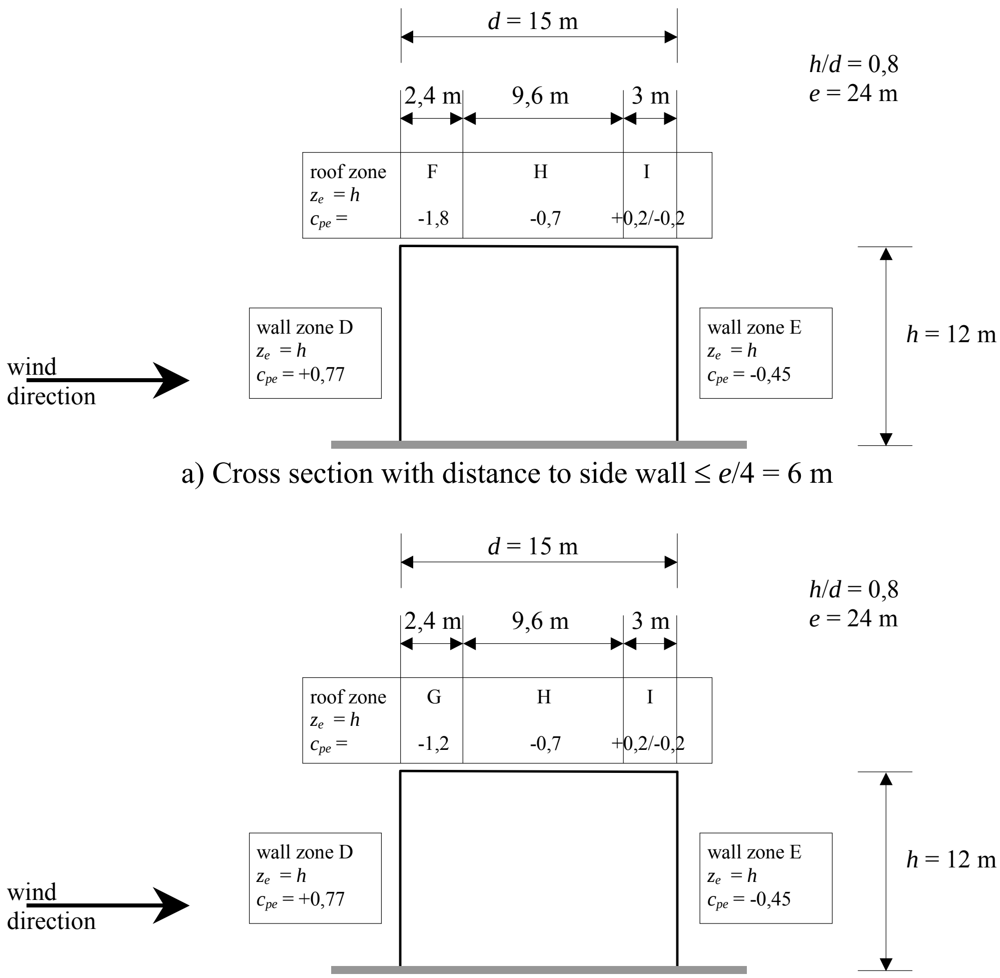
For external pressures: $$F_{w,e} = c_s\, c_d\, \Sigma\, q_p(z_e)\, c_{pe}\, A_{ref}(z) \tag{15}$$

For internal pressures: $$F_{w,i} = \Sigma\, q_p(z_i)\, c_{pi}\, A_{ref}(z) \tag{16}$$

$c_s\, c_d$ is the structural factor. Clause 6.2 (1) a) states that for buildings with a height of less than 15 m the value of $c_s\, c_d$ may be taken as 1 which is conservative.

The pressure coefficients c_{pe} and c_{pi} are given in section 7 of prEN 1991-1-4. In the general clause for buildings it can be seen that the wind forces needs to be calculated in four orthogonal wind directions perpendicular to the side walls, because the pressure coefficients represent the most unfavourable values in a range of wind directions. Also it is given that the pressure coefficient $c_{pe} = c_{pe,10}$ because the loaded area A for the main structure is larger than 10 m^2.

The external pressure coefficients and accompanying reference height can now be determined for the walls and the flat roof. The results are given in Figure 9 for the wind direction given in Figure 8.



a) Cross section with distance to side wall ≤ $e/4$ = 6 m

b) Cross section with distance to both side walls > $e/4$ = 6 m

Figure 9. External pressure coefficients and accompanying reference heights

For the determination of the resulting force on the main structure the lack of correlation between the windward and leeward side (which means that the peak wind pressures do not appear at the same time) may be taken into account. For this example ($h/d = 0{,}8 < 1$) the resulting force from the external pressures on the walls may be multiplied by 0,85 for the verification of the overall stability.

The internal pressure coefficient and the accompanying reference height are determined in the next step. Assuming uniformly distributed permeability the ratio μ is 0,74 (see chapter 3.2). The results are given in Figure 10. For the reference height the conservative value $z_i = z_e$ is chosen.

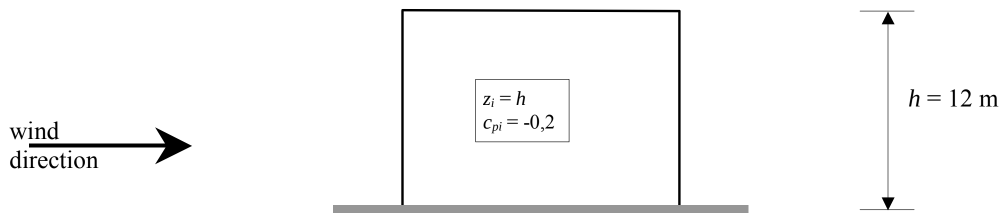


Figure 10. Internal pressure coefficients and accompanying reference height

For all the pressure coefficients the reference height is taken equal to $z_e = z_i = 12$ m. The characteristic peak velocity pressure is $q_p(z = 12 \text{ m})$ for flat terrain of terrain category II with $v_{b,0} = 26$ m/s and is equal to $q_p = 1043$ N/m^2.

If the distance between the frames is equal to 7,5 m, the distributed forces on the frame are according to Figure 11.

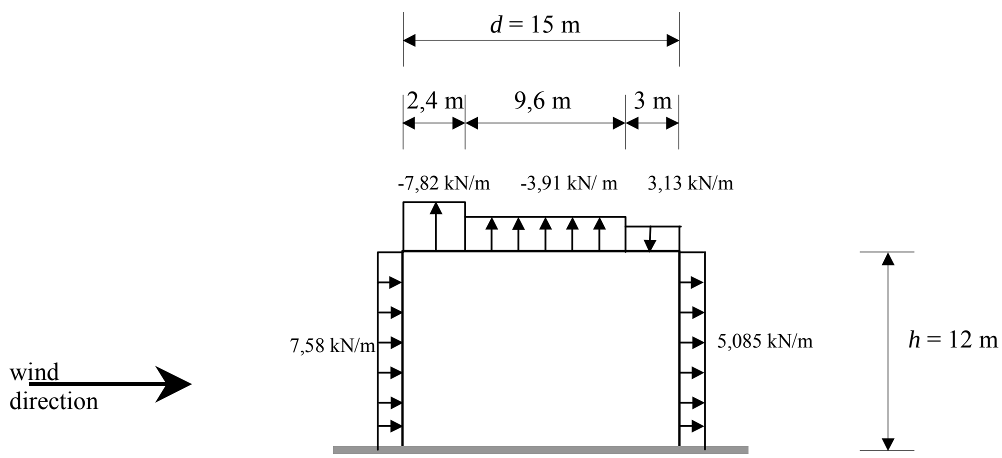


Figure 11. Wind force on the central frames (not influenced by roof zone F)

6.3 Simple rectangular building with duopitch roof

A simple rectangular building with duopitch roof is shown in Figure 12. The dimensions of the building are: Ridge height 6 m, gutter height 2 m, width 30 m and depth 15 m. The building is situated in flat terrain of terrain category II in an area where the basic wind velocity $v_{b,0}$ is equal to 26 m/s. For this building only the pressure coefficients for the wind direction as given in figure 12 will be considered in detail.

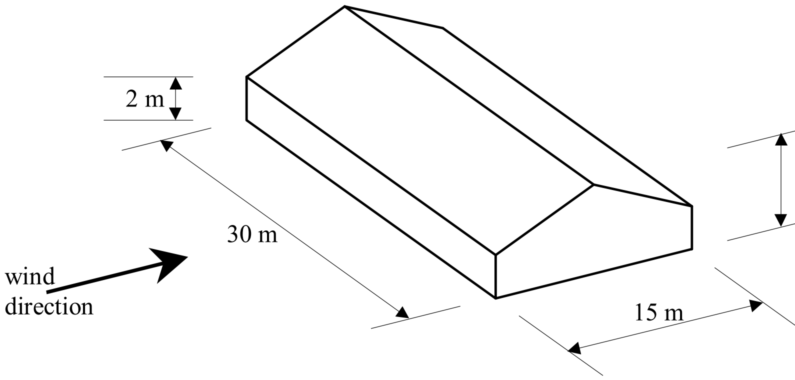


Figure 12. Simple rectangular building with duopitch roof

The procedure for the determination of the wind forces on the main structure (frames) of the building with duopitch roof is nearly equal to the previous example. Only the pressure coefficients and reference heights differ.

The external pressure coefficients and accompanying reference height are presented in Figure 13.

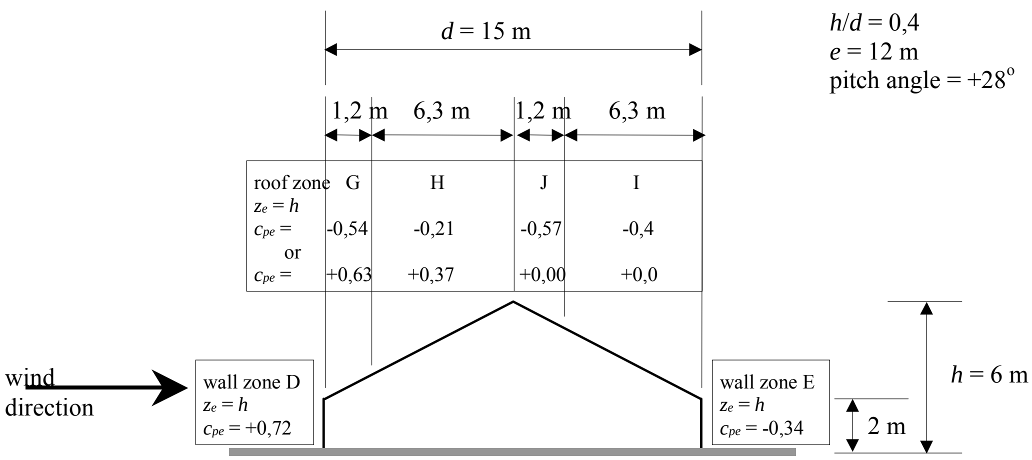


Figure 13. Pressure coefficients and accompanying reference heights (distance to side wall > 3 m)

The reference height for the wall is equal to the height of the building. For the pressure coefficients on the roof two sets of c_{pe} values are given. Combinations with partial suction and overpressure for the roof zones G and H need not be taken into account.

The internal pressure coefficient and accompanying reference height should be determined in the next step. For buildings with uniformly distributed permeability and d/h = 2,5 the internal pressure coefficient should be taken as c_{pi} = -0,35 or c_{pi} = +0,25.

For the given wind direction four loadcases due to wind should be considered. These are the two load case due to the external wind pressure (suction on first pitch or overpressure on first pitch) each combined with the two load cases due to internal pressure (suction or overpressure).

6.4 Wind force on a cylindrical tower block

The wind force which acts on the foundation of a tower block with circular plan has to be determined.

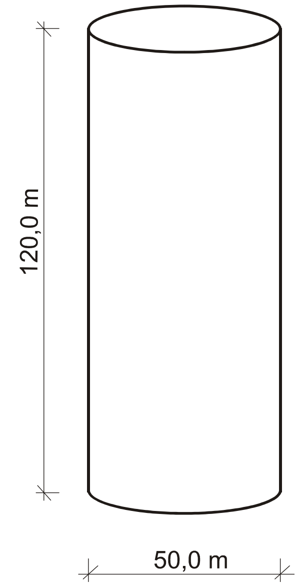


Figure 14. Example: tower block with circular plan

It is assumed that the building will be erected in Dresden, Germany corresponding to wind zone III, so that a basic value of the velocity pressure

$$q_{b,0} = 0{,}47 \text{ kN/m}^2$$

has to be applied.

The tower will be located in a suburb, which belongs to the terrain category II. For the reference height z_e = 120,0 m the following roughness coefficient ist obtained:

$$k_r = 0{,}19 \cdot (0{,}3/0{,}05)^{0{,}07} = 0{,}22$$

$$c_r(z) = 0{,}22 \cdot \ln(120{,}0/0{,}3) = 1{,}32$$

With table 3 the exposure factor is

$$c_e(120{,}0) = 1 + \frac{1{,}0}{1{,}0 \cdot \ln(120{,}0/0{,}3)} = 1{,}17$$

resulting into a peak velocity pressure of

$$q_p(120) = 1{,}32^2 \cdot 1{,}17 \cdot 0{,}47 = 0{,}96 \text{ kN/m}^2$$

For the calculation of the relevant force coefficient the Reynolds-Number has to be determined. The wind speed corresponding to the peak velocity pressure is:

$$v = (2 \cdot q_p(z) / \rho)^{1/2} = (2 \cdot 0{,}96 \cdot 1000 / 1{,}25)^{1/2} = 39 \text{ m/s}$$

resulting into a Reynolds-Number of

$$Re = 50\text{m} \cdot 39\text{m/s} / (15 \cdot 10^{-6}\text{m}^2\text{/s}) = 13 \cdot 10^7 \text{ [-]}$$

In addition to the Reynolds-Number the surface roughness has to be known. It is assumed that it consists of a glass façade. From table 7.13 of prEN 1991-1-4 the equivalent roughness is obtained:

$$k = 0{,}0015 \text{ mm}$$

With the Reynolds-Number and with the ratio

$$k/b = 3 \cdot 10^{-8}$$

from figure 7.28 of prEN 1991-1-4 the basic value of the force coefficient is:

$$c_{f,0} = 0{,}68$$

The reference area for the cylindrical structures is

$$A_{ref} = l \cdot b = 120 \cdot 50 = 6000 \text{ m}^2$$

In order to calculate the end-effect factor according to table 7.16 of prEN 1991-1-4 the smallest of the values $\lambda = 0{,}7 \cdot l/b = 1{,}68$ and $\lambda = 70$ has to be chosen as the effective slenderness. It serves as an input value of figure 7.36 of prEN 1991-1-4. From that diagram the following end-effect factor is derived:

$$\psi_\lambda = 0{,}65$$

Then the resulting characteristic value of the wind induced force on the foundation of the tower block is:

$$F_w = 0{,}96 \cdot 0{,}65 \cdot 6000 = 3744 \text{ kN}$$

6.5 Wind pressure on a rectangular tower block

A simple rectangular high-rise building with flat roof is shown in Figure 15. The dimensions of the building are: Height 55 m, width 20 m and depth 15 m. The building is situated in flat terrain of terrain category II in an area where the basic wind velocity $v_{b,0}$ is equal to 26 m/s. For this building the external wind pressure on the walls for the wind direction as given in figure 15 are considered in detail.

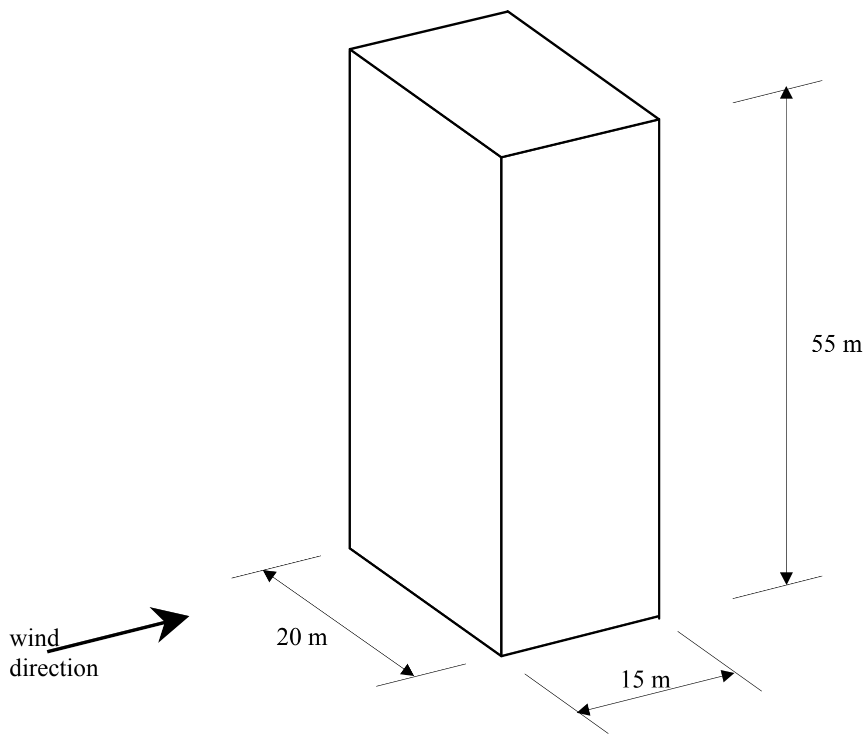


Figure 15. Simple rectangular high-rise building with flat roof

The wind forces on the main structure of a building in case of a quasi-static response need to be calculated according to section 5 of Part 1.4 of EN 1991 [1]. This results in the following equations for the wind forces (see example simple rectangular building with flat roof):

For external pressures: $$F_{w,e} = c_s\, c_d\, \Sigma\, q_p(z_e)\, c_{pe}\, A_{ref}(z) \tag{17}$$

For internal pressures: $$F_{w,i} = \Sigma\, q_p(z_i)\, c_{pi}\, A_{ref}(z) \tag{18}$$

c_sc_d is the structural factor. According to section 6.2 the structural factor should be derived from section 6.3 and Annex B. For a multi-storey steel building (see figure B.4.1 in Annex B.4) the factor c_sc_d is equal to 1,0 and gives a conservative approximation for the factor c_sc_d.

The external pressure coefficients and accompanying reference height can now be determined. The results are given in Figure 16 for the wind direction given in Figure 15. The resulting wind pressures are given in Figure 17.

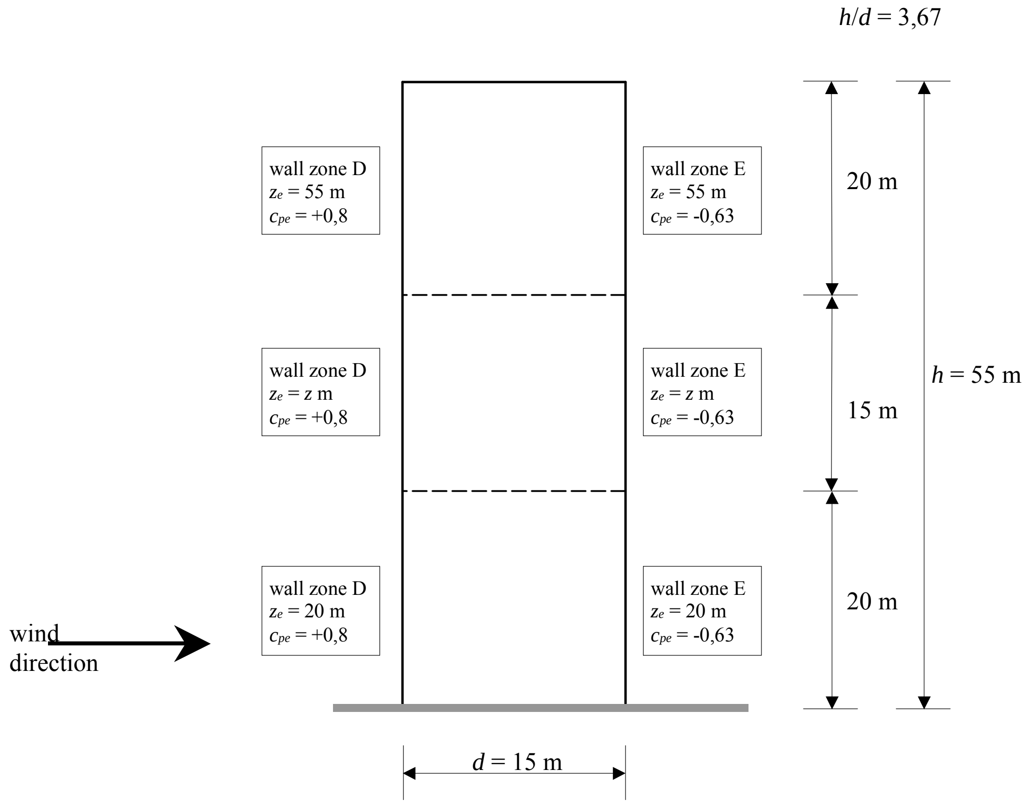


Figure 16. Pressure coefficients and accompanying reference heights

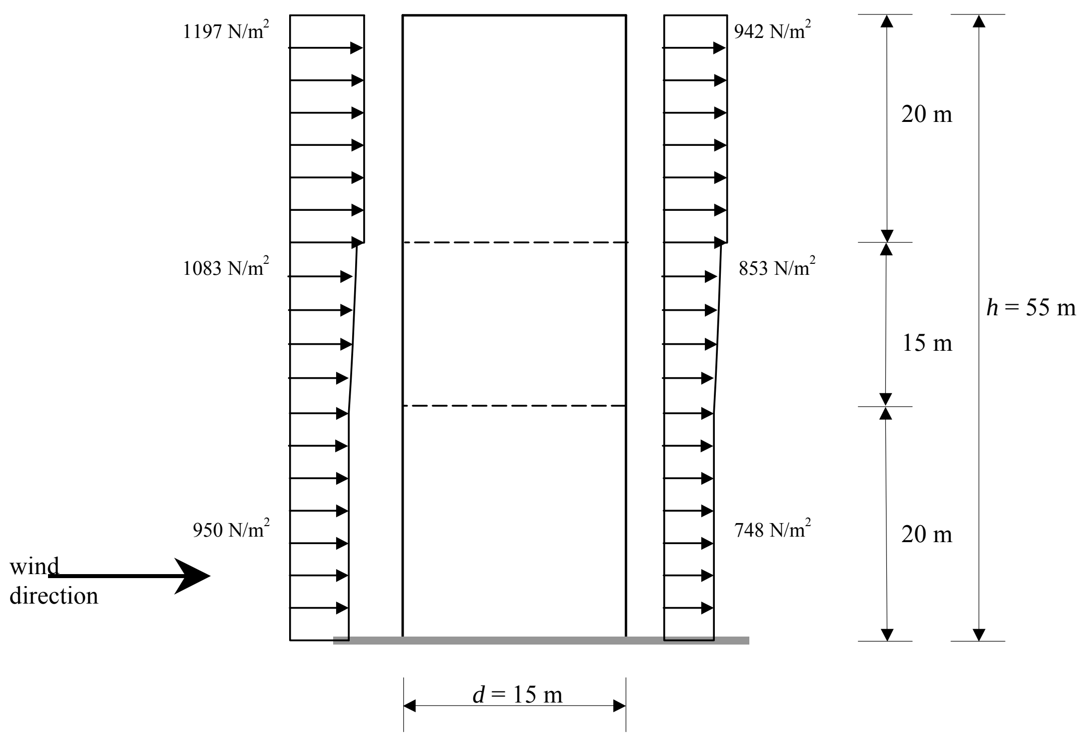


Figure 17. Distribution of the wind pressure on walls

6.6 Glazing panel

A glazing panel of a high-rise building is shown in Figure 17. The dimensions of the glazing panel are: Height 1,5 m and width 2 m. The glazing panel is part of the high building of the previous example.

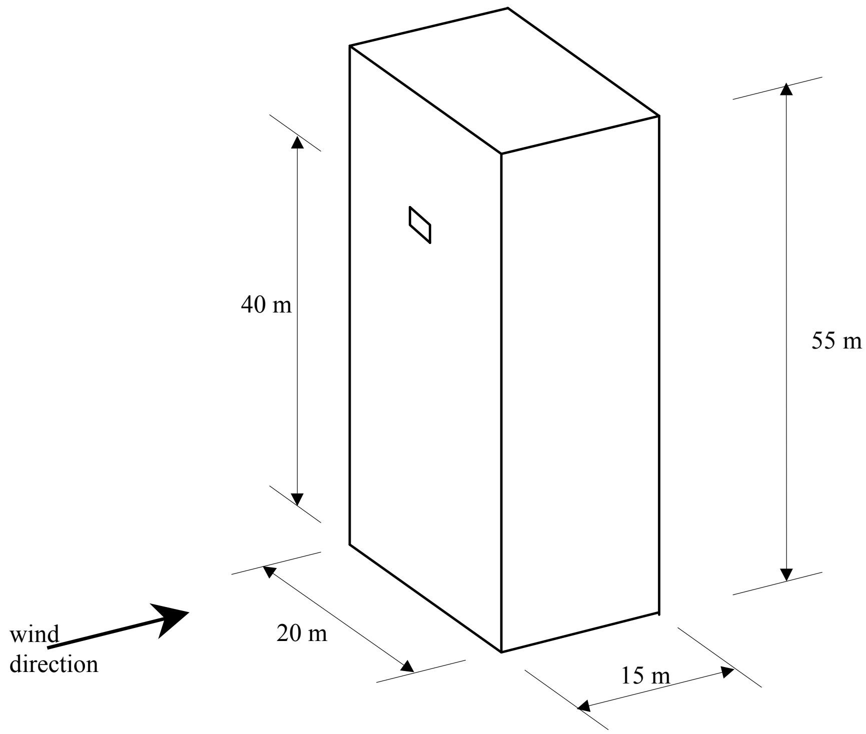


Figure 18. Glazing panel in a high building

According to Part 1.4 of EN 1991 [1] the wind actions on the glazing panel should be calculated as wind pressures according to section 5.1 of the wind code. Therefore the resulting wind actions on the glazing panel should be determined with the following equations:

For external pressures: $$w_e = q_p(z_e)\, c_{pe} \tag{19}$$

For internal pressures: $$w_i = q_p(z_i)\, c_{pi} \tag{20}$$

The pressure coefficients and accompanying reference height can now be determined according to section 7 from Part 1.4 of EN 1991 [1]. It follows that $c_{pe,10}$ = +0,8 and $c_{pe,1}$ = +1,0. This means the external pressure coefficient should be taken as: $c_{pe} = c_{pe,1} - (c_{pe,1} - c_{pe,10})\ {}^{10}\log A = 1{,}0 - 0{,}2\ {}^{10}\log 3 = +0{,}90$ with $z_e = h = 55$ m. The internal pressure coefficient should be taken as -0,4 or +0,3. The accompanying reference height should be taken equal to the mean height of the level considered. In this example this will be taken equal to: z_i = 40 m. The representative wind pressure on the glazing panel is equal to:

$$w = q_p(z_e)\, c_{pe} - q_p(z_i)\, c_{pi} = 1496 \cdot 0{,}90 + 1395 \cdot 0{,}40 = 1904 \text{ N/m}^2 \tag{21}$$

REFERENCES

[1] prEN 1991-1-4 Actions on Structures - Part 1-4: General Actions – Wind. European Committee for Standardisation, December 2003.

[2] EN 1990 Basis of structural design. European Committee for Standardization, CEN/TC 250, 2002.

[3] H. Gulvanessian, J.-A. Calgaro, M. Holický: Designer's Guide to EN 1990, Eurocode: Basis of Structural Design. Thomas Telford, London, 2002, ISBN: 07277 3011 8, 192 pp.