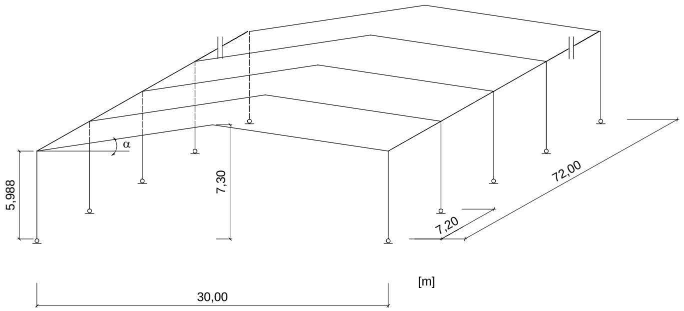
Example: Determination of loads on a building envelope

This worked example explains the procedure of determination of loads on a portal frame building. Two types of actions are considered: wind actions and snow actions.



Basic data

- Total length : b = 72,00 m
- Spacing: s = 7,20 m
- Bay width : d = 30,00 m
- Height (max): h = 7,30 m
- Roof slope: α = 5,0°

Height above ground:

h = 7,30 m

α = 5°

leads to:

h' = 7,30 – 15 tan 5° = 5,988 m

1 Wind loads

Basic values

Determination of basic wind velocity:

EN 1991-1-4 § 4.2

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

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

Fundamental value of the basic wind velocity (see European windmap):

$v_{b,0}$ = 26 m/s (for Aachen - Germany)

Terrain category II ⇒ z_0 = 0,05 m

$z > z_{min}$

EN 1991-1-4 § 4.3.2 Table 4.1

⇒ $v_b = c_{dir} \times c_{season} \times v_{b,0}$ = 26 m/s

For simplification the directional factor c_{dir} and the seasonal factor c_{season} are in general equal to 1,0.

Basic velocity pressure

EN 1991-1-4 § 4.5 eq. 4.10

$$q_b = \frac{1}{2} \times \rho_{air} \times v_b^2$$

where: ρ_{air} = 1,25 kg/m³ (air density)

⇒ $q_b = \frac{1}{2} \times 1{,}25 \times 26^2 = 422{,}5$ N/m²

Peak pressure

EN 1991-1-4 § 4.5, eq. 4.8

$$q_p(z) = [1 + 7 I_v(z)] \times \frac{1}{2} \times \rho \times v_m(z)^2$$

Calculation of $v_m(z)$

$v_m(z)$ mean wind velocity

$v_m(z) = c_r(z) \times c_o(z) \times v_b$

Where: $c_o(z)$ is the orography factor

$c_r(z)$ is the roughness factor

$$c_r(z) = k_T \times \ln\left(\frac{z}{z_0}\right) \quad \text{for } z_{min} \le z \le z_{max}$$

$$c_r(z) = c_r(z_{min}) \quad \text{for } z \le z_{min}$$

Where: z_0 is the roughness length

k_T is the terrain factor, depending on the roughness length z_0 calculated using

$$k_T = 0{,}19 \times \left(\frac{z_0}{z_{0,II}}\right)^{0,07}$$

Where: $z_{0,II}$ = 0,05 (terrain category II)

z_{min} is the minimum height — EN 1991-1-4 §4.3.2 Table 4.1

z_{max} is to be taken as 200 m

Calculation of $l_v(z)$

$l_v(z)$ turbulence intensity — EN 1991-1-4 §4.4 eq. 4.7

$$l_v = \frac{k_I}{c_o(z) \times \ln(z/z_0)} \quad \text{for } z_{min} \le z \le z_{max}$$

$$l_v = l_v(z_{min}) \quad \text{for } z < z_{min}$$

Where: k_I is the turbulence factor recommended value for k_I is 1,0

z = 7,30 m

so: $z_{min} < z < z_{max}$

$$q_p(z) = \underbrace{\left[1 + \frac{7k_I}{c_o(z) \times \ln(z/z_0)}\right]}_{\text{squared gust factor}} \times \underbrace{\frac{1}{2} \times \rho \times v_b^2}_{\text{basic pressure}} \times \underbrace{\left(k_T \times \ln(z/z_0)\right)}_{\text{wind profile}}$$

$$q_p(7{,}30) = \left[1 + \frac{7}{\ln(7{,}30/0{,}05)}\right] \times \frac{1}{2} \times 1{,}25 \times 26^2 \times \left(0{,}19 \times \left(\frac{0{,}05}{0{,}05}\right)^{0,07} \times \ln(7{,}30/0{,}05)\right)^2$$

$$= \left[1 + \frac{7}{\ln(7{,}30/0{,}05)}\right] \times 422{,}5 \times 0{,}947^2 \times 10^{-3} = 0{,}911 \text{ kN/m}^2$$

Wind pressure on surfaces — EN 1991-1-4 § 7.2

(pressure coefficients for internal frame)

A positive wind load stands for pressure whereas a negative wind load indicates suction on the surface. This definition applies for the external wind action as well as for the internal wind action.

External pressure coefficients

The wind pressure acting on the external surfaces, w_e should be obtained from the following expression: — EN 1991-1-4 §5.2 eq. 5.1

$$w_e = q_p(z_e) \times c_{pe}$$

where: z_e is the reference height for the external pressure

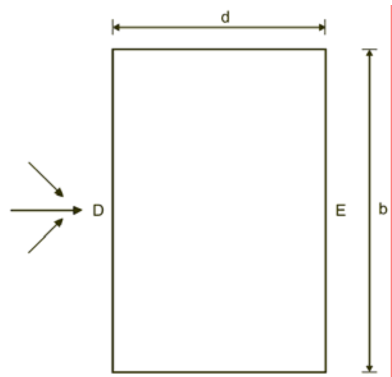
c_{pe} is the pressure coefficient for the external pressure depending on the size of the loaded area *A*.
= $c_{pe,10}$ because the loaded area *A* for the structure is larger than 10 m²

a) vertical walls — EN 1991-1-4 § 7.2 Table 7.1

for $\frac{h}{d} = \frac{7{,}30}{30{,}00} = 0{,}24 \le 0{,}25$

D: c_{pe} = 0,7

E: c_{pe} = - 0,3



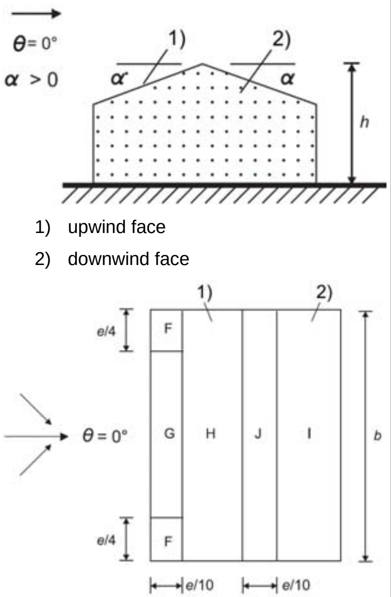
b) duopitch roofs

with $\alpha = 5{,}0°$,

$\theta = 0°$ (wind direction)

$e = \min(b;\ 2h)$
$= \min(72{,}00;\ 14{,}60)$
$= 14{,}60$ m

EN 1991-1-4 § 7.2 Table 7.4a



G: $c_{pe} = -1{,}2$

H: $c_{pe} = -0{,}6$

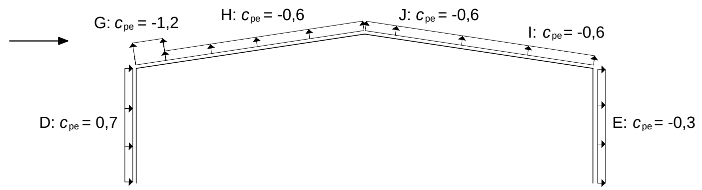
I: $c_{pe} = -0{,}6$

J: $c_{pe} = 0{,}2\ /\ -0{,}6$

$\Rightarrow c_{pe} = -0{,}6$

(see Table 7.4a , Note 1)

External pressure coefficients c_{pe} (for zone D, E, G, H, I and J):



Internal pressure coefficient

EN 1991-1-4 §5.2 eq.5.2

The wind pressure acting on the internal surfaces of a structure, w_i should be obtained from the following expression

$w_i = q_p(z_i) \times c_{pi}$

where: z_i is the reference height for the internal pressure

c_{pi} is the pressure coefficient for the internal pressure

The internal pressure coefficient depends on the size and distribution of the openings in the building envelope.

Within this example it is not possible to estimate the permeability and opening ratio of the building. So c_{pi} should be taken as the more onerous of + 0,2 and – 0,3. In this case c_{pi} is unfavorable when c_{pi} is taken to + 0,2.

EN 1991-1-4 § 7.2.9 (6) Note 2

Wind loads

The wind loadings per unit length w (in kN/m) for an internal frame are calculated using the influence width (spacing) $s = 7{,}20$ m:

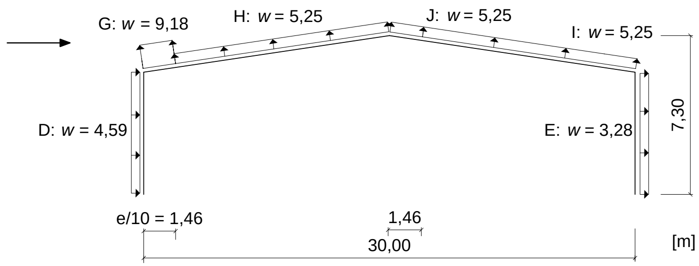
$w = (c_{pe} + c_{pi}) \times q_p \times s$

Internal and external pressures are considered to act at the same time. The worst combination of external and internal pressures are to be considered for every combination of possible openings and other leakage paths.

EN 1991-1-4 § 7.2.9

Characteristic values for wind loading in [kN/m] for an internal frame:

- zones D, E, G, H, I and J



2 Snow loads

General

Snow loads on the roof should be determined as follows:

EN 1991-1-3 §5.2.2 eq.5.1

$$s = \mu_i \times c_e \times c_z \times s_k$$

where: μ_i is the roof shape coefficient

c_e is the exposure coefficient, usually taken as 1,0

c_t is the thermal coefficient, set to 1,0 for normal situations

s_k is the characteristic value of ground snow load for the relevant altitude

Roof shape coefficient

Shape coefficients are needed for an adjustment of the ground snow load to a snow load on the roof taking into account effects caused by non-drifted and drifted snow load arrangements.

The roof shape coefficient depends on the roof angle.

EN 1991-1-3 §5.3 Table 5.1

$0° \leq \alpha \leq 30°$ ⇒ $\mu_1 = 0,8$

Snow load on the ground

The characteristic value depends on the climatic region.

For a site in Aachen (Germany) the following expression is relevant:

EN 1991-1-3 Annex C Table C1

$$s_k = (0,264 \times 2 - 0,002) \times \left[1 + \left(\frac{A}{256}\right)^2\right] \text{ kN/m}^2$$

Where: z is the zone number (depending on the snow load on sea level), here $z = 2$

A is the altitude above sea level, here $A = 175$ m

$$s_k = (0,264 \times 2 - 0,002) \times \left[1 + \left(\frac{175}{256}\right)^2\right] = 0,772 \text{ kN/m}^2$$

Snow load on the roof

$s = 0,8 \times 1,0 \times 1,0 \times 0,772 = 0,618$ kN/m²

spacing = 7,20 m

⇒ for an internal frame:

$s = 0,618 \times 7,20 = 4,45$ kN/m