HOW TO CHECK COLUMN BASE IN MULTI STOREY BUILDING?

… worked examples for CO001

Design and check column base in multi storey building. Column base behave as pinned in both directions. Column section is HEB 200 made of steel S235, concrete foundations are made from C25/30. Between base plate 20 mm thick and pad footing grout is realized with 50 mm thickness.

BUILDING DIMENSIONS

L = 6 m span a

B = 6 m span b

n_L = 8 number of spans in a direction

n_B = 6 number of spans in b direction

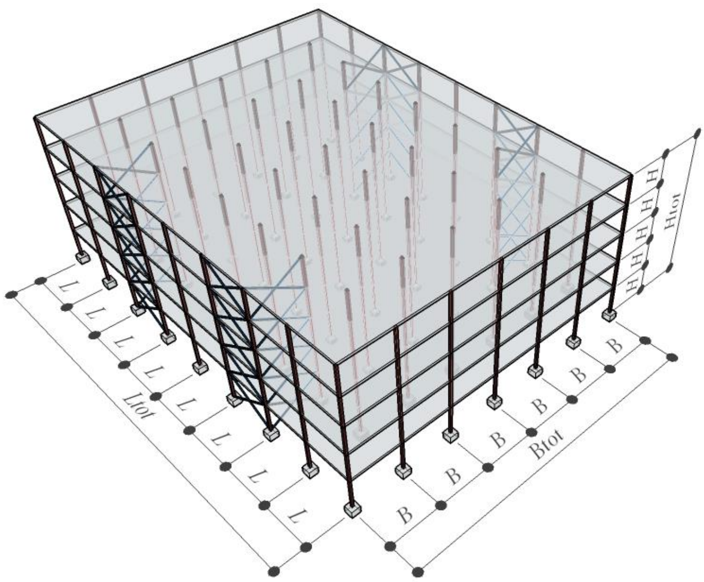
L_{tot} = 48 m building length

B_{tot} = 36 m building width

H = 3,6 m level high

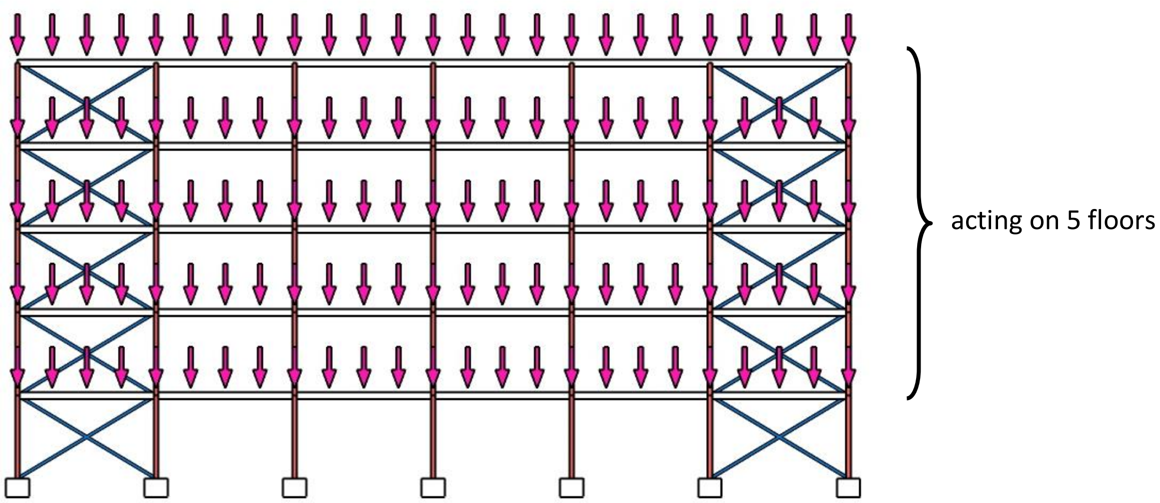
n_H = 5 number of floors

H_{tot} = 18 building high

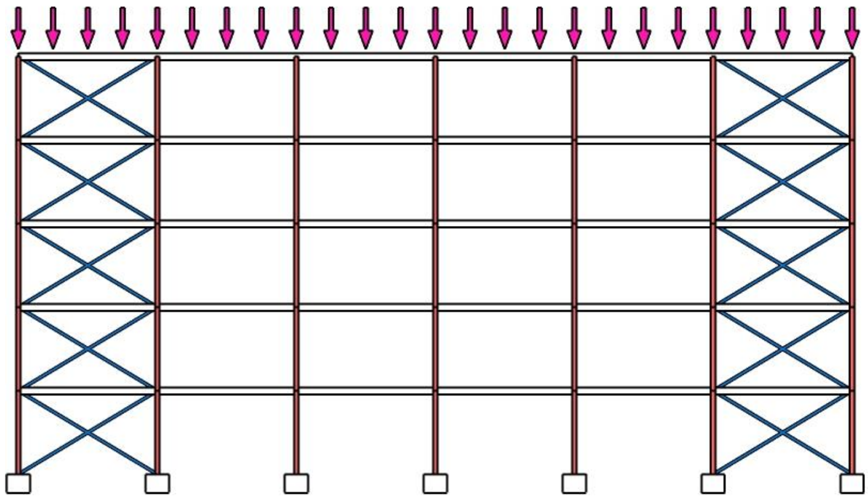


LOADS

g_k = 3,0 kN/m^2 dead load (ceiling + secondary beam + primary beam + floor)

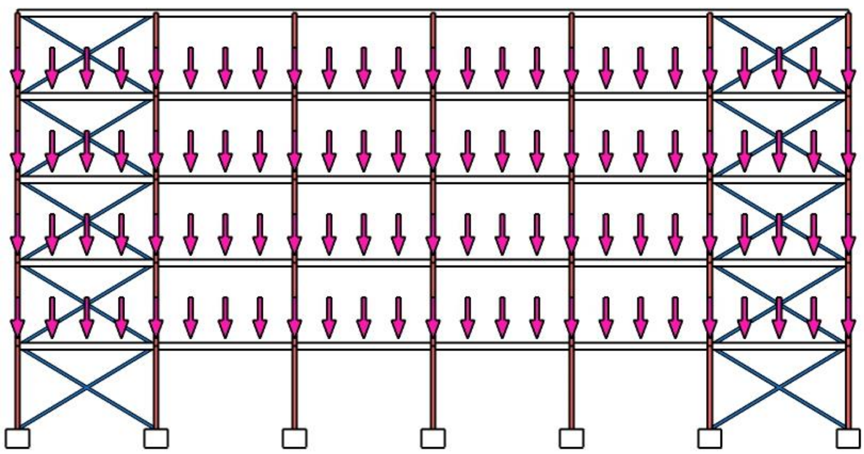


$q_{s,k}$ = 0,8 kN/m^2 snow load



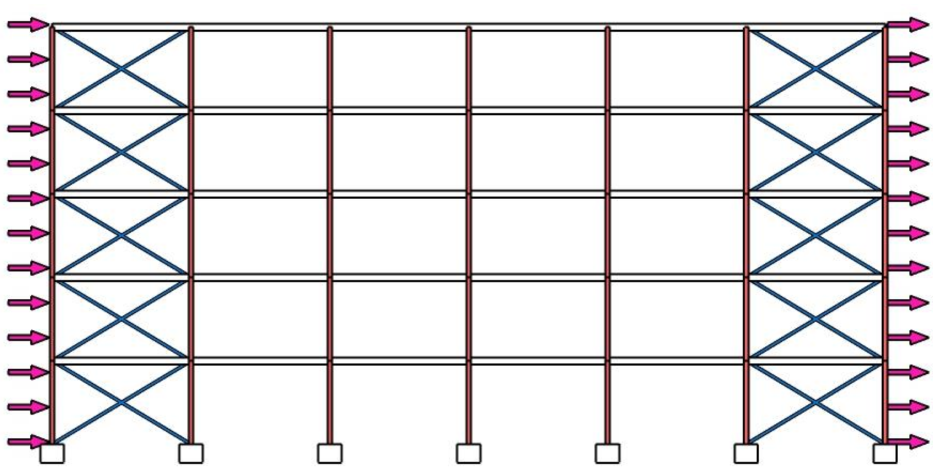
acting on 1 floor = roof

$q_{l,k}$ = 2,5 kN/m^2 live load (not closely specified)



acting on 4 floors

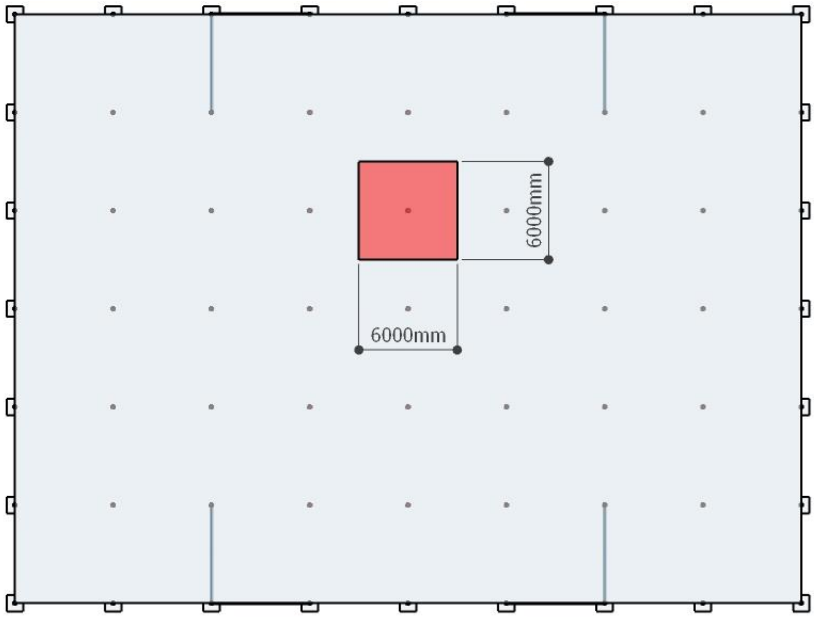
$q_{w,k}$ = 0,6 kN/m^2 wind load on walls



acting on 2 walls

EXAMPLE 1 – middle column out of bracing system

Calculate normal force at column base and check designed geometry and materials. Column is subjected to the self-weight, dead load, snow load and live load with loading area defined in figure. Calculated column is not part of bracing system – there are not additional forces due to bracing system. In column base there are compressive normal forces only, this forces are transmitted to foundations by contact between base plate and concrete. Anchor bolts are not loaded and they don't need to be checked.



Normal force in column base

Load area

$$A_{\text{load}} = B \cdot H = 6 \cdot 6 = 36 \ \text{m}^2$$

Column self-weight

$$N_{\text{self}} = A_{\text{column}} \cdot g_{\text{steel}} \cdot H = 7810 \ .10^{-6} \cdot 78{,}5 \cdot 18 = 11{,}0 \ \text{kN}$$

Dead load

$$N_{\text{dead}} = A_{\text{load}} \cdot g_{\text{k}} \cdot n_{\text{floor}} = 36 \cdot 3{,}0 \cdot 4 = 432{,}0 \ \text{kN}$$

Live load

$$N_{\text{live}} = A_{\text{load}} \cdot g_{\text{l,k}} \cdot n_{\text{floor}} = 36 \cdot 2{,}5 \cdot 4 = 360{,}0 \ \text{kN}$$

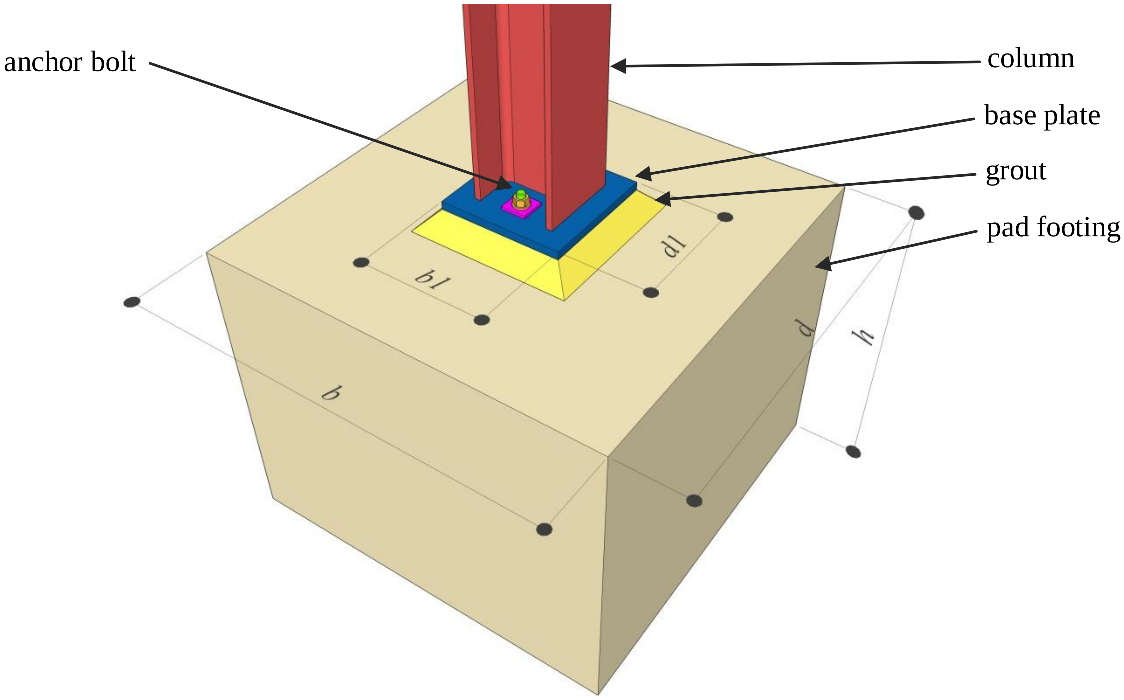
Snow load

$$N_{\text{snow}} = A_{\text{load}} \cdot g_{\text{s,k}} = 36 \cdot 0{,}8 = 28{,}8 \ \text{kN}$$

Total load using combination rule 6.10

$$N_{\text{Ed}} = \gamma_G \cdot (N_{\text{self}} + N_{\text{dead}}) + \gamma_Q \cdot (N_{\text{live}} + N_{\text{snow}} \cdot \psi_{0,\text{snow}}) = 1{,}35 \cdot (11 + 432) + 1{,}5 \cdot (360 + 28{,}8 \cdot 0{,}5) = 1160 \ \text{kN}$$

Column base geometry



t = 20 mm base plate thickness

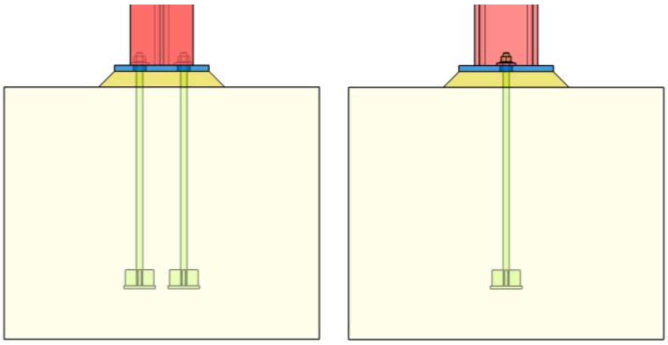
b_1 = 300 mm base plate width

d_1 = 300 mm base plate width

b = 1000 mm pad footing width

d = 1000 mm pad footing width

h = 800 mm pad footing depth



Column base material

Base plate material: structural steel S235

f_y = 235 MPa yield strength

E = 210 GPa Young's modulus

γ_{M0} = 1,0 partial safety factor for structural steel

Pad footing material: concrete C25/30

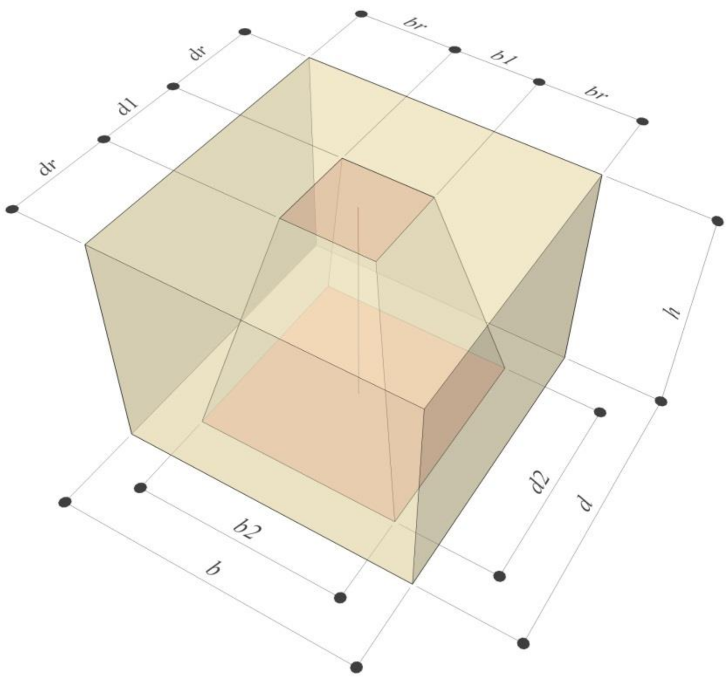
$f_{c,k}$ = 25 MPa compression strength

γ_c = 1,5 partial safety factor for concrete

Grout: not specified

Column base check

Strength in concentrated pressure is calculated using transmitting truncated cone according figure below. Load transmitting layer made of grout is neglected in calculations.



$$b_2 = \min \begin{Bmatrix} b_1 + 2b_r \\ 3b_1 \\ b_1 + h \end{Bmatrix} = \begin{Bmatrix} 300 + 2 \cdot 350 \\ 3 \cdot 300 \\ 300 + 800 \end{Bmatrix} = \begin{Bmatrix} 1000 \\ 900 \\ 1100 \end{Bmatrix} = 900 \text{ mm}$$

$$d_2 = \min \begin{Bmatrix} d_1 + 2d_r \\ 3d_1 \\ d_1 + h \end{Bmatrix} = \begin{Bmatrix} 300 + 2 \cdot 350 \\ 3 \cdot 300 \\ 300 + 800 \end{Bmatrix} = \begin{Bmatrix} 1000 \\ 900 \\ 1100 \end{Bmatrix} = 900 \text{ mm}$$

Stress concentration factor

$$k_j = \sqrt{\frac{b_2 \cdot d_2}{b_1 \cdot d_1}} = \sqrt{\frac{900 \cdot 900}{300 \cdot 300}} = 3{,}0$$

Joint coefficient (introducing grout quality and thickness)

$\beta_j = 2/3$ on the safe side (if $f_{md} \geq 0{,}2\, f_{cd}$ and if $t \leq 0{,}2 \cdot \min\{b_1; d_1\}$

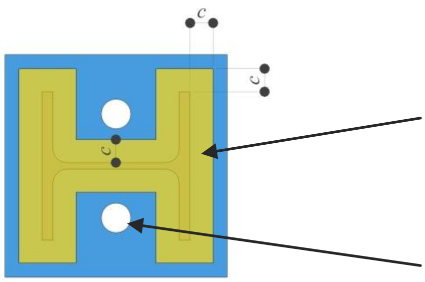
Design value of concrete concentrated pressure strength

$$f_{j,d} = \frac{\beta_j \cdot k_j \cdot f_{c,k}}{\gamma_c} = \frac{2/3 \cdot 3{,}0 \cdot 25}{1{,}5} = 33{,}3 \text{ MPa}$$

Effective length of cantilever

$$c = t \cdot \sqrt{\frac{f_y}{3 \cdot f_{j,d} \cdot \gamma_{M0}}} = 20 \cdot \sqrt{\frac{235}{3 \cdot 33{,}3 \cdot 1{,}0}} = 30{,}7 \text{ mm}$$

Effective area of the base plate under HEB section with uniformly distributed stress



$$A_{\text{eff}} = 47\ 529\ \text{mm}^2$$

Resistance of base plate

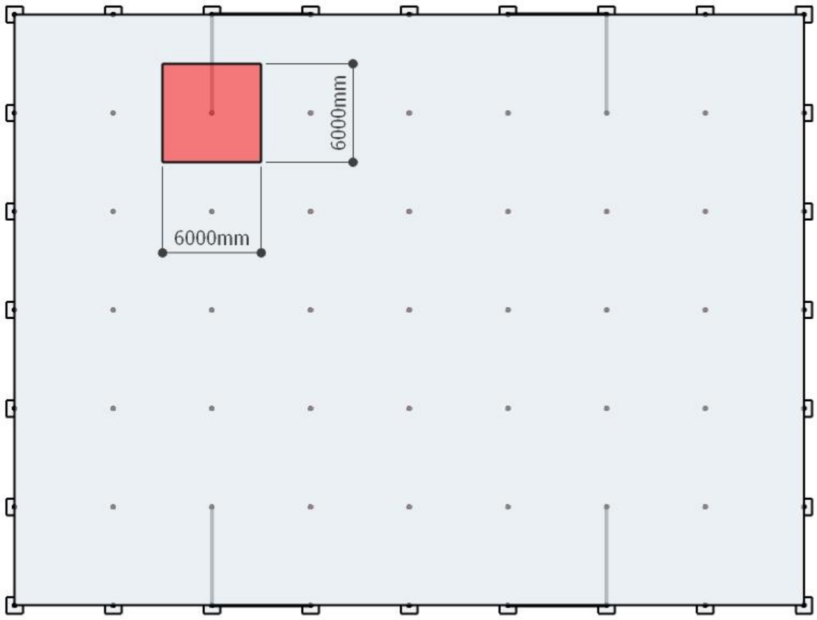
$$N_{\text{Rd}} = A_{\text{eff}} \cdot f_{\text{jd}} = 47\ 529 \cdot 33{,}3 = 1584\ .10^3\ \text{N} = 1584\ \text{kN}$$

Reliability condition

$$\frac{N_{\text{Ed}}}{N_{\text{Rd}}} = \frac{1160}{1584} = 0{,}73 \leq 1{,}0$$ => ***condition is satisfied***

EXAMPLE 2 – middle column is a member of bracing system

Calculate normal force at column base and check designed geometry and materials. Column is subjected to the self-weight, dead load, snow load and live load with loading area defined in figure. Calculated column is part of bracing system – there are additional compressive forces due to acting in bracing system. In column base there are compressive normal forces only, this forces are transmitted to foundations by contact between base plate and concrete. Anchor bolts are not loaded and they don't need to be checked.



a) Maximum normal force in column base

Load area

$$A_{load} = B \cdot H = 6 \cdot 6 = 36 \ \ m^2$$

Column self-weight

$$N_{self} = A_{column} \cdot g_{steel} \cdot H = 7810 \ .10^{-6} \cdot 78,5 \cdot 18 = 11,0 \ \ kN$$

Dead load

$$N_{dead} = A_{load} \cdot g_k \cdot n_{floor} = 36 \cdot 3,0 \cdot 4 = 432,0 \ \ kN$$

Live load

$$N_{live} = A_{load} \cdot g_{l,k} \cdot n_{floor} = 36 \cdot 2,5 \cdot 4 = 360,0 \ \ kN$$

Snow load

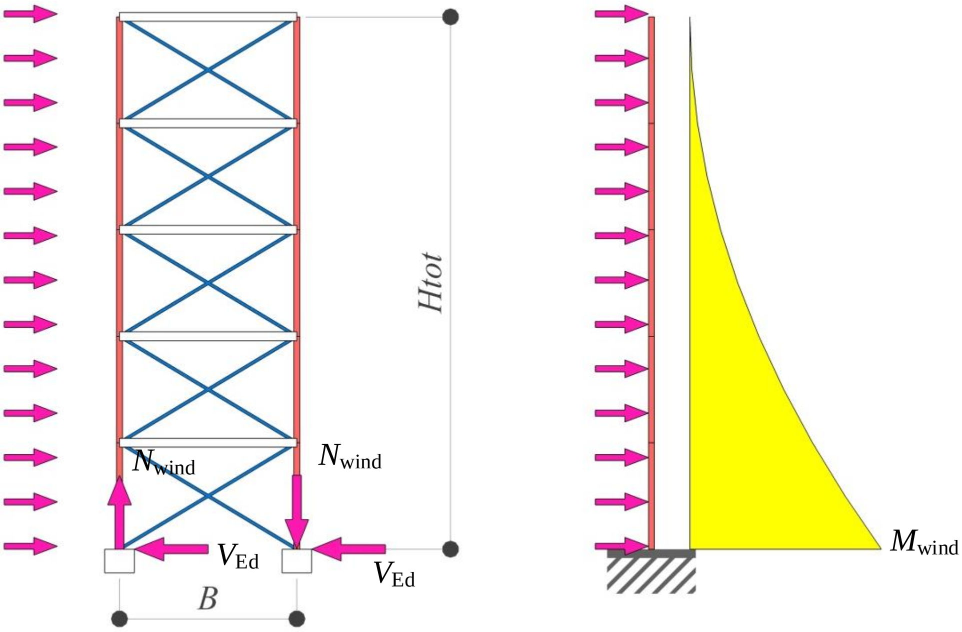
$$N_{snow} = A_{load} \cdot g_{s,k} = 36 \cdot 0,8 = 28,8 \ \ kN$$

Bending moment caused by wind load on cantilever substituting truss bracing:

$M_{wind} = q_{w,k} \cdot \frac{L_{tot}}{2} \cdot \frac{H_{tot}^2}{2} = 0,6 \cdot \frac{48}{2} \cdot \frac{18^2}{2} = 2333 \ \ kNm$ (simplified calculation is valid for two bracing at the both walls)

Additional force resulting from truss bracing

$$N_{wind} = \frac{M_{wind}}{B} = \frac{2333}{6} = 389 \text{ kN}$$ (compress)



Total load using combination rule 6.10

$$N_{Ed} = \gamma_G \cdot (N_{self} + N_{dead}) + \gamma_Q \cdot (N_{live} + N_{snow} \cdot \psi_{0,snow} + N_{wind} \cdot \psi_{0,wind}) =$$

$$= 1{,}35 \cdot (11 + 432) + 1{,}5 \cdot (360 + 28{,}8 \cdot 0{,}5 + 389 \cdot 0{,}6) = 1510 \text{ kN}$$

<u>Column base geometry</u>

Same as in example 1.

<u>Column base material</u>

Same as in example 1.

<u>Column base check</u>

Resistance is same as in example 1

Reliability condition

$$\frac{N_{Ed}}{N_{Rd}} = \frac{1510}{1584} = 0{,}95 \leq 1{,}0$$ => ***condition is satisfied***

<u>b) Horizontal force in column base</u>

$V_{Ed} = \gamma_Q \cdot q_{w,k} \cdot \frac{L_{tot}}{2} \cdot \frac{H_{tot}}{2} = 1{,}5 \cdot 0{,}6 \cdot \frac{48}{2} \cdot \frac{18}{2} = 194 \text{ kN}$ (simplified calculation is valid for two bracing at the both walls and both tensional and compressed bracing diagonals are active; in the case where only tensional diagonal is active – compressed diagonal is out of function – horizontal reaction is whole at one base plate)

Alternative 1: horizontal force transmitted by friction between base plate and concrete

The friction force $F_{\text{f,Rd}}$ dependent on the normal compression force in column base. This force should be calculated as minimum force $N_{\text{c,Ed,min}}$ from combination of dead load (with partial coefficient 1,0) and wind load.

$$N_{\text{c, Ed, min}} = \gamma_G \cdot (N_{\text{self}} + N_{\text{dead}}) + \gamma_Q \cdot N_{\text{wind}} = 1{,}0 \cdot (11 + 432) + 1{,}5 \cdot 389 = 1026 \text{ kN}$$

$$F_{\text{f, Rd}} = C_{\text{f, d}} \cdot N_{\text{c, Ed, min}} = 0{,}2 \cdot 1026 = 205 \text{ kN}$$

Reliability condition

$$\frac{V_{\text{Ed}}}{V_{\text{Rd}}} = \frac{194}{205} = 0{,}95 \leq 1{,}0$$ => *condition is satisfied*

Alternative 2: horizontal force transmitted by shear of anchor bolts

This calculation may be used only for standard diameters of bolt holes!

Shear resistance of one bolt made of rod with diameter 20 mm, steel S355:

$$F_{\text{vb, Rd}} = \min \begin{Bmatrix} F_{\text{1, vb, Rd}} \\ F_{\text{2, vb, Rd}} \end{Bmatrix} = \min \begin{Bmatrix} 40{,}82 \\ 32{,}03 \end{Bmatrix} = 32{,}03 \text{ kN}$$

where

$$F_{\text{1, vb, Rd}} = 0{,}85 \cdot \frac{\alpha_{\text{v}} \cdot f_{\text{ub}} \cdot A_{\text{s}}}{\gamma_{\text{M2}}} = 0{,}85 \cdot \frac{0{,}5 \cdot 490 \cdot 245}{1{,}25} = 40{,}82 \text{ kN}$$ (coefficient 0,85 should be used for bolts made of rods)

$$F_{\text{2, vb, Rd}} = \frac{\alpha_{\text{bc}} \cdot f_{\text{ub}} \cdot A_{\text{s}}}{\gamma_{\text{M2}}} = \frac{0{,}333 \cdot 490 \cdot 245}{1{,}25} = 32{,}03 \text{ kN}$$

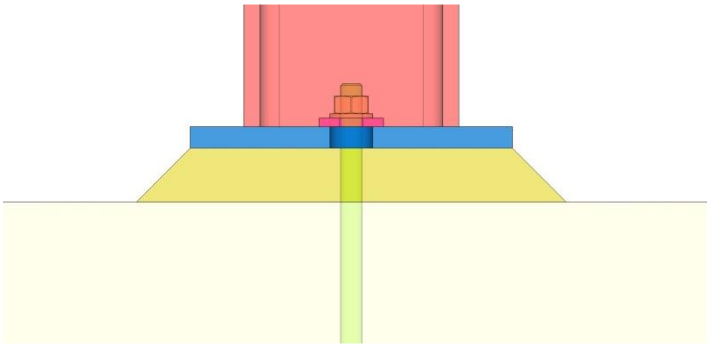
$$\alpha_{\text{bc}} = 0{,}44 - 0{,}0003 \cdot f_{\text{yb}} = 0{,}44 - 0{,}0003 \cdot 355 = 0{,}333$$

Resistance of two bolts in column base

$$V_{\text{Rd}} = n_{\text{b}} \cdot F_{\text{vb, Rd}} = 2 \cdot 32{,}03 = 64 \text{ kN}$$

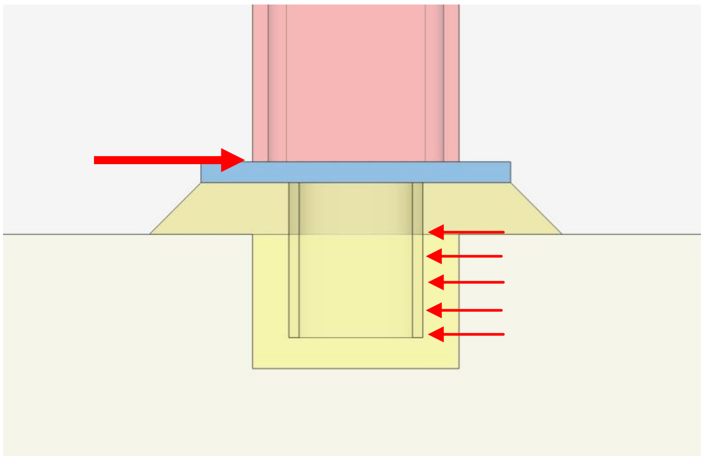
Reliability condition

$$\frac{V_{\text{Ed}}}{V_{\text{Rd}}} = \frac{194}{64} = 3{,}03 \leq 1{,}0$$ => *condition is not satisfied*



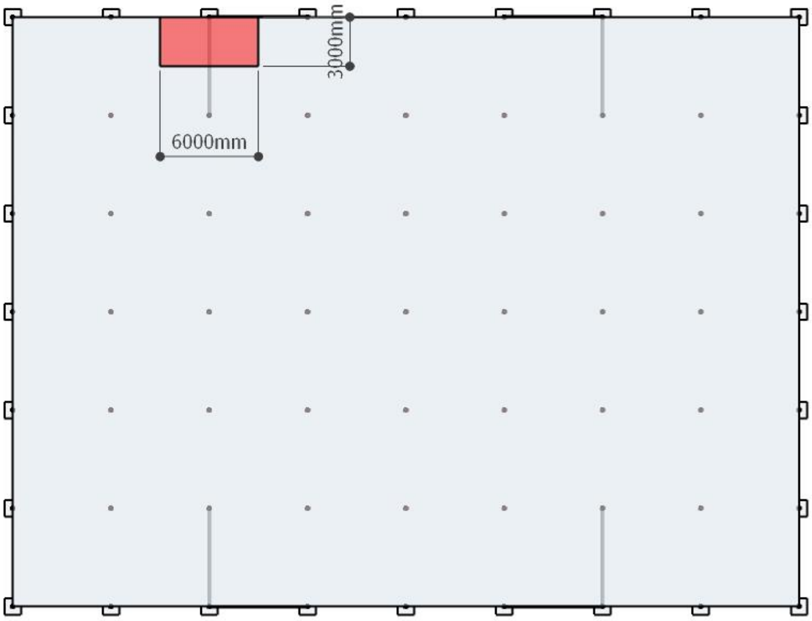
<u>Alternative 3: horizontal force transmitted by shear key (shear lug)</u>

Shear key made of IPE, HEB or channel (sometimes CHS or SHS may be used) is welded to bottom face of base plate. On the upper face of pad footing, empty space is omitted during concreting. After the column is erected and fixed in vertical position, the empty space is infill by grout. Shear key ant it's welds need to be checked on bending and shear. Horizontal stress should be compared with concrete strength.



EXAMPLE 3 – facade column as a member of bracing system

Calculate normal force at column base and check designed geometry and materials. Column is subjected to the self-weight, dead load, snow load and live load with loading area defined in figure bellow. Calculated column is part of bracing system – there are additional tensional forces due to acting in bracing system.



a) Maximum normal force in column base

Load area

$$A_{load} = B \cdot H = 3 \cdot 6 = 18 \ \text{m}^2$$

Column self-weight

$$N_{self} = A_{column} \cdot g_{steel} \cdot H = 7810 \ .10^{-6} \cdot 78,5 \cdot 18 = 11,0 \ \text{kN}$$

Dead load

$$N_{dead} = A_{load} \cdot g_k \cdot n_{floor} = 18 \cdot 3,0 \cdot 4 = 216,0 \ \text{kN}$$

Live load

$$N_{live} = A_{load} \cdot g_{l,k} \cdot n_{floor} = 18 \cdot 2,5 \cdot 4 = 180,0 \ \text{kN}$$

Snow load

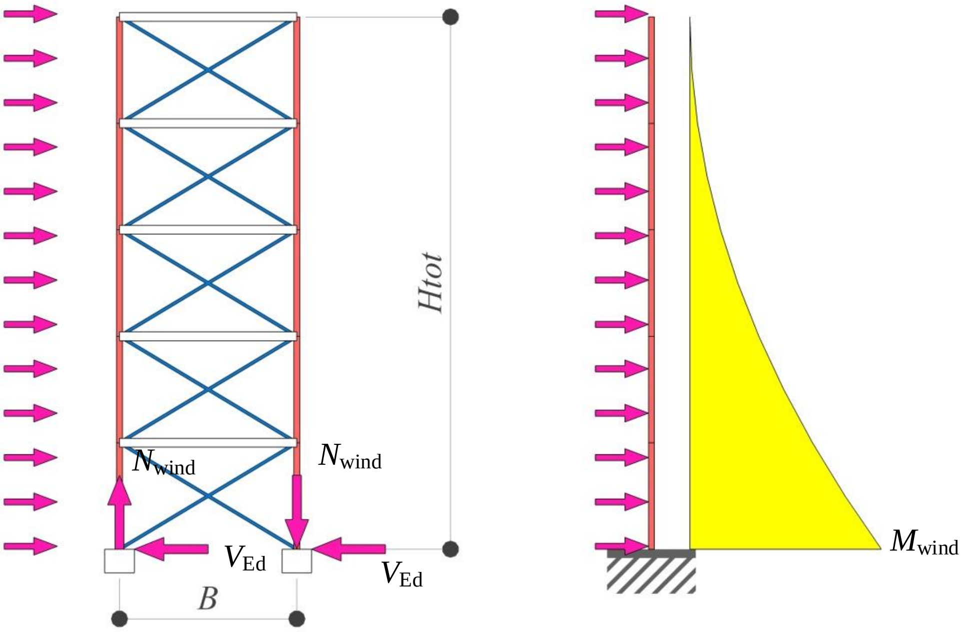
$$N_{snow} = A_{load} \cdot g_{s,k} = 18 \cdot 0,8 = 14,4 \ \text{kN}$$

Bending moment on cantilever substituting truss bracing caused by wind load:

$M_{wind} = q_{w,k} \cdot \frac{L_{tot}}{2} \cdot \frac{H_{tot}^2}{2} = 0,6 \cdot \frac{48}{2} \cdot \frac{18^2}{2} = 2333 \ \text{kNm}$ (simplified calculation is valid for two bracing at the both walls)

Additional force resulting from truss bracing

$$N_{\mathrm{wind}} = \frac{M_{\mathrm{wind}}}{B} = \frac{2333}{6} = 389 \ \mathrm{kN}$$ (tension force)



Total load using combination rule 6.10

$$N_{\mathrm{Ed}} = \gamma_G \cdot (N_{\mathrm{self}} + N_{\mathrm{dead}}) + \gamma_Q \cdot (N_{\mathrm{live}} + N_{\mathrm{snow}} \cdot \psi_{0,\mathrm{snow}} + N_{\mathrm{wind}} \cdot \psi_{0,\mathrm{wind}}) =$$
$$= 1{,}35 \cdot (11 + 216) + 1{,}5 \cdot (180 + 14{,}4 \cdot 0{,}5 + 389 \cdot 0{,}6) = 971 \ \mathrm{kN}$$

Column base geometry

Same as in example 1.

Column base material

Same as in example 1.

Column base check

Resistance is same as in example 1

Reliability condition

$$\frac{N_{\mathrm{Ed}}}{N_{\mathrm{Rd}}} = \frac{971}{1584} = 0{,}61 \quad \leq \quad 1{,}0$$ => ***condition is satisfied***

b) Minimum normal force in combination with horizontal force in column base

$$V_{\mathrm{Ed}} = \gamma_Q \cdot q_{\mathrm{w,k}} \cdot \frac{L_{\mathrm{tot}}}{2} \cdot \frac{H_{\mathrm{tot}}}{2} = 1{,}5 \cdot 0{,}6 \cdot \frac{48}{2} \cdot \frac{18}{2} = 194 \ \mathrm{kN}$$ (simplified calculation is valid for two bracing at the both walls and both tensional and compressed bracing diagonals are active; in the case where only tensional diagonal is active – compressed diagonal is out of function – horizontal reaction is whole at one base plate)

Total load using combination rule 6.10 (compressive forces are favourable, tensional force is unfavourable)

$$N_{Ed} = \gamma_{G,\ fovourable} \cdot (N_{self} + N_{dead}) + \gamma_{Q,\ unfovourable} \cdot N_{wind} + \gamma_{Q,\ fovourable} \left(N_{live} + N_{snow} \cdot \psi_{0,snow}\right) =$$

$$= 1{,}0 \cdot (11 + 216) + 1{,}5 \cdot -389 + 0{,}0 \cdot (180 + 14{,}4 \cdot 0{,}5) = -357 \text{ kN}$$ (tension force in column!)

In column base there is tensional normal force, this force is transmitted to foundations by anchor bolts. Base plate is not loaded and it don’t need to be checked.

Alternative 1: horizontal force transmitted by friction between base plate and concrete

Couldn't be used because of compressive normal force absence!!!

Alternative 2: horizontal force transmitted by shear of anchor bolts

Same as in example 2.

Alternative 3: horizontal force transmitted by shear key (shear lug)

Same as in example 2.

Anchor bolts check

There are more ways how to anchor bolts may fail. Next conditions should be checked:

- Tension of bolts (according to the EN 1993-1-8)
- Adhesion failure between bolt and concrete (according to the CEN/TS 1992-4-1; ETAG 001)
- Pull out of one bolt from concrete block (according to the CEN/TS 1992-4-1; ETAG 001)
- Pull out of group of bolts from concrete block (according to the CEN/TS 1992-4-1; ETAG 001)

Equilibrium limit state

Pull out of whole pad footing from ground (according to the EN 1990)