Eurocodes – Background and Applications

Eurocode example:
Actions on a six storey building

18-20 February 2008

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1. Introduction

The present example illustrates the Eurocode actions on a six storey building.

The characteristic actions and design actions on a six storey building are determined. The support reactions are calculated for the actions considered. These cover permanent actions, imposed loads, wind actions and snow loads.

The building is indefinitely long and supported per 10 m along the building in the points A and B. The points A and B shown in figure 1.1 illustrate two points, for which the support reactions are calculated.

The building includes residential and office areas as shown in figure 1.1. This indicates that medium Consequence Class CC2 may be assumed, see B3.1 in EN 1990:2002.

The following recommended partial safety factors for permanent actions are applied, see table A1.2(A) and A.1.2(B) in EN 1990:2002.

- EQU: $\gamma_{Gj,\sup}$ =1,10 and $\gamma_{Gj,\inf}$ =0,90.
- STR 6.10a: $\gamma_{Gj,\sup}$ =1,35 and $\gamma_{Gj,\inf}$ =1,00. Permanent actions only in 6.10a.
- STR 6.10b: $\xi\gamma_{Gj,\sup}$ =1,15 and $\gamma_{Gj,\inf}$ =1,00.

The recommended partial safety factor of 1.5 is applied for all variable actions, see table A1.2(A) and A.1.2(B) in EN 1990:2002.

The reliability class RC3 with K_{FI} =1,1 is assumed, see B3.3 in EN 1990:2002. The K_{FI} factor of 1,1 is applied to the partial safety factors of the unfavourable actions.

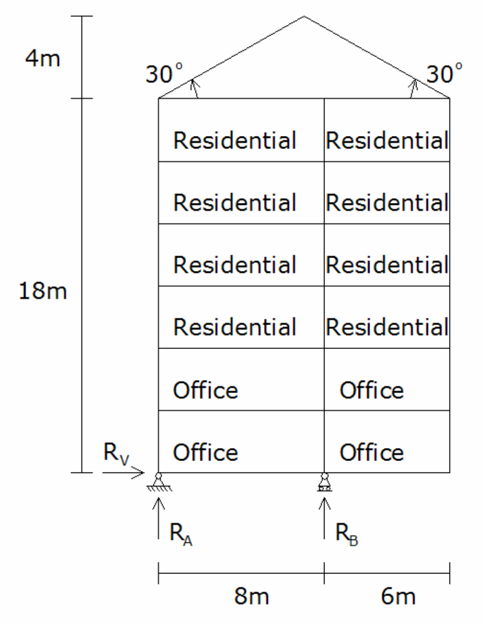


Figure 1.1 - Six storey building

2. Characteristic permanent actions (G)

The characteristic permanent actions are assumed as follows:

Distributed loads: $g_{roof} = 1{,}6$ kN/m^2

$g_{floor} = 2{,}4$ kN/m^2

Line loads: $G_{facade} = 2{,}4$ kN/m and 8,0 kN/m

$G_{wall} = 2{,}4$ kN/m

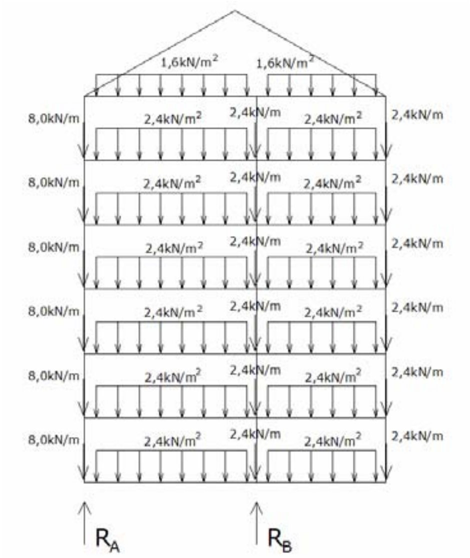


Figure 2.1 - Characteristic permanent action

The above-mentioned permanent actions give the characteristic permanent support reactions specified in table 2.1.

Table 2.1 - Support reactions from characteristic permanent actions

Vertical support reactions	[kN]
R_A [kN]	652
R_B [kN]	2356

3. Characteristic imposed loads (I)

The characteristic imposed uniformly distributed loads q and the load combination factors ψ_0 for residential areas and office areas are as follows:

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

$$\psi_{0,res} = 0{,}7$$

$$q_{off} = 3{,}0 \text{ kN/m}^2$$

$$\psi_{0,off} = 0{,}7$$

The recommended floor reduction factor α_A is calculated by:

$$\alpha_A = \frac{5}{7}\psi_0 + \frac{A_0}{A} \leq 1{,}0$$

in which ψ_0 is the above-mentioned load combination factor, the area A_0 =10,0 m², and A is the loaded area. For the three cases shown below, the reduced imposed loads are given in table 3.1 below.

Table 3.1 – Reduced imposed loads

Case no.	α_A	$\alpha_A\, q_{res}$	$\alpha_A\, q_{off}$
1	0,571	1,14	1,71
2	0,625	1,25	1,88
3	0,667	1,33	2,00

The recommended multi storey reduction factor α_n is calculated by:

$$\alpha_n = \frac{2 + (n-2) \cdot \psi_0}{n}$$

in which n is the number of storeys. Inserting the number of storeys gives:

$$\alpha_{4,res} = \frac{2 + (4-2) \cdot 0{,}7}{4} = 0{,}85$$

$$\alpha_{2,off} = \frac{2 + (2-2) \cdot 0{,}7}{2} = 1{,}0$$

The imposed loads shall be classified as variable free actions, see 2.2 (1)P in EN 1991-1-1:2002. This gives the relevant load cases shown in figure 3.1, and the support reactions are given in tables 3.2 and 3.3.

6.2.2 (1) in EN 1991-1-1:2002 specifies: "For the design of columns or walls, loaded from several storeys, the total imposed loads on the floor of each storey should be assumed to be distributed uniformly". This specification has not been applied in the present example.

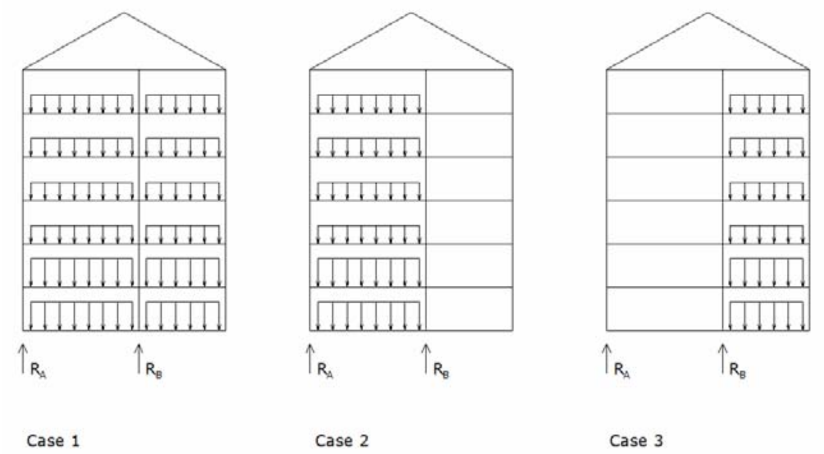


Figure 3.1 – Distribution of imposed loads

Table 3.2 - Support reactions from reduced imposed loads for residential areas, see table 3.1

Support reactions	Case 1	Case 2	Case 3
R_A [kN]	80	200	-120
R_B [kN]	560	200	440

Table 3.3 - Support reactions from reduced imposed loads for office areas, see table 3.1

Support reactions	Case 1	Case 2	Case 3
R_A [kN]	60	150	-90
R_B [kN]	420	150	330

Figure 3.2 illustrates the reduction for multi storey in case 1. The load on the two middle storeys are reduced by $\psi_{0,res}$. The loads on the rest of the storey are unchanged. The average reduction of the loads are expressed by α_n .

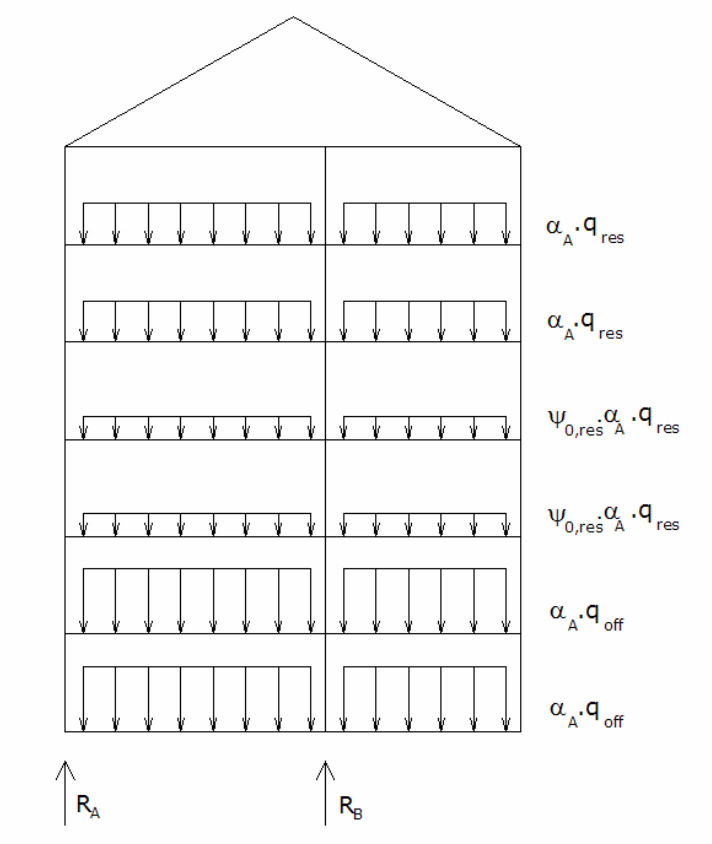


Figure 3.2 – Distribution of imposed loads with reduction for multi storey, case 1

4. Characteristic wind actions (W)

The indefinitely long facades of the building are assumed to be orientated north-south.

Basic values, see 4.2 in EN 1991-1-4:2005

The fundamental value of the basic wind velocity is assumed to be $v_{b,0}$ =24 m/s. For westerly and easterly winds perpendicular to the long facades, the directional factor squared has been assumed to be c_{dir}^2 =1,0 and c_{dir}^2 =0,8, respectively,

Terrain roughness, see 4.3.2 in EN 1991-1-4:2005

For westerly and easterly winds the upstream terrains are assumed to be a suburban terrain with a roughness length of z_0 =0,30 m and a lake with a roughness length of z_0 =0,01 m, respectively.

Wind turbulence and peak velocity pressure, see 4.4-4.5 in EN 1991-1-4:2005

The characteristic peak velocity pressures at building height 22,0 m above terrain are given in table 4.1 assuming flat terrain. The recommended turbulence factor of k_I =1,0 has been applied.

Table 4.1 – The characteristic peak velocity pressure q_p.

Wind direction	Directional factor squared c_{dir}^2	Terrain category	z_0 [m]	k_r	q_p [kN/m^2]
Wind from west	1,0	III	0,30	0,2154	0,810
Wind from east	0,8	I	0,01	0,1698	0,939

Pressure coefficients, see 7.2.2 and 7.2.5 in EN 1991-1-4:2005

The pressure coefficients for the wind action are given in figure 4.1.The lack of correlation of wind pressures between the windward and leeward side has been taken into account by the recommended procedure, see the note of 7.2.2 (3), giving a reduction factor of 0,87. Thus, the pressure coefficients for wind loads on the facades become $0{,}87 \cdot 0{,}80 = 0{,}70$ and $0{,}87 \cdot (-0{,}53) = -0{,}46$, respectively.

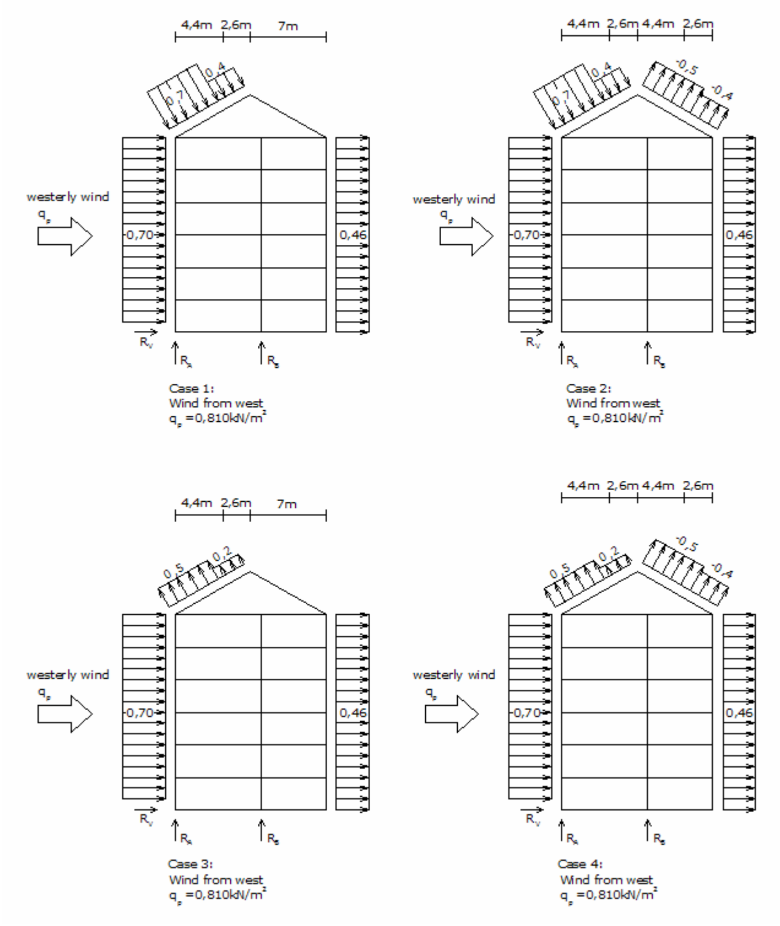


Figure 4.1 – Pressure coefficients for wind actions. Westerly winds.

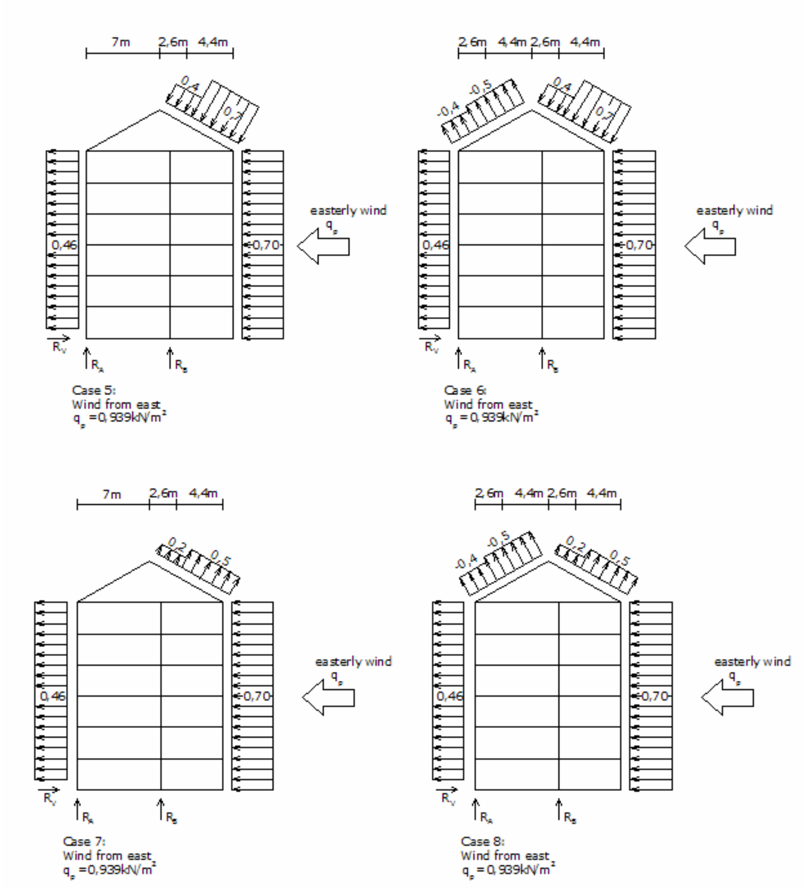


Figure 4.2 – Pressure coefficients for wind actions. Easterly winds.

The reactions from characteristic wind actions in table 4.2 are determined for a structural factor of 1. Thus, it is assumed that the load reducing effect of lack of correlation, in extension of the above-mentioned correction factor of 0,87, is balanced out by the load increasing effect from inertial forces originating from structural vibrations.

Table 4.2 – Support reactions from characteristic wind loads

	Westerly winds				Easterly winds			
Reactions	1	2	3	4	5	6	7	8
Vertical R_A [kN]	-217	-244	-174	-201	261	285	195	219
Vertical R_B [kN]	250	252	152	154	-222	-275	-220	-273
Horizontal R_V [kN]	-188	-202	-157	-171	218	235	182	198

The recommended reduction factor of $\psi_{0,w}$ =0,6 is applied, see table A1.1 in EN 1990:2002.

5. Characteristic snow loads (S)

The characteristic value of snow load on the ground is assumed to be $s_k = 0.9$ kN/m².

The shape coefficient for the snow load are given in figure 5 and the reactions for the characteristic snow load are given in table 5.1.

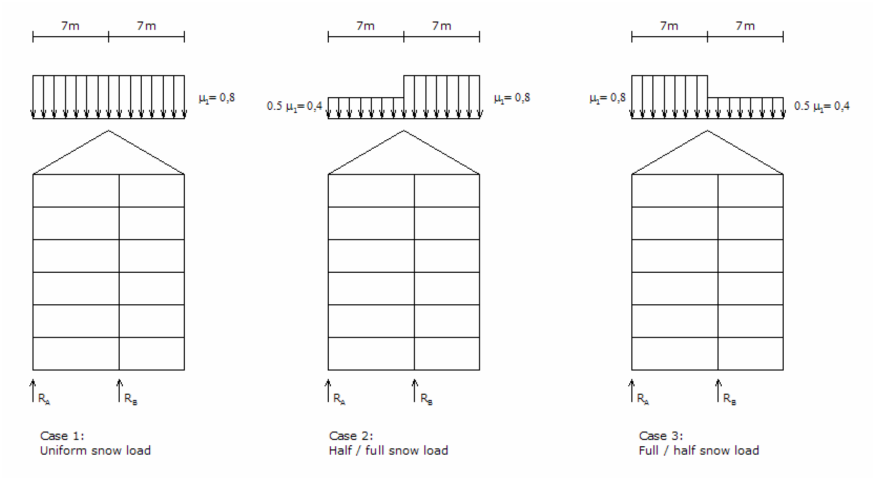


Figure 5.1 - Snow load shape coefficients

The recommended load combination factor for ”remainder of CEN Member States, for sites located at altitude H $\leq$ 1000 m a.s.l.” is assumed, i.e. $\psi_{0,S}$ =0,50.

Table 5.1 - Support reactions from characteristic snow loads

Support reactions	Case 1	Case 2	Case 3
R_A [kN]	13	-2	20
R_B [kN]	88	77	55

6. Combination of actions

Examples of possible load combinations are listed in table 6.1. The following comments may clarify some of the load combinations:

- When the imposed load is an accompanying action, the load combination factor ψ_0 is applied and not the multi storey reduction factor α_n, see 3.3.2 (2)P in EN 1991-1-1:2002.
- When the imposed loads act simultaneously with the other variable actions due to wind and / or snow, the total imposed loads considered in the load case shall be considered as a single action, see 3.3.1 (2)P in EN 1991-1-1: 2002.
- When the imposed loads are the only variable action present, one of the imposed load categories is dominating and the other is accompanying, see the load combinations STR (6.10b)-4 and STR (6.10b)-5.

STR load combinations for largest R_A and largest R_B

STR 6.10b-1: $1{,}1 \cdot 1{,}15 \cdot G + 1{,}1 \cdot 1{,}5 \cdot \alpha_{res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \alpha_{off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,w} W + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,s} S$

STR 6.10b-2: $1{,}1 \cdot 1{,}15 \cdot G + 1{,}1 \cdot 1{,}5 \cdot W + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,S} S$

STR 6.10b-3: $1{,}1 \cdot 1{,}15 \cdot G + 1{,}1 \cdot 1{,}5 \cdot S + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,W} W$

STR 6.10b-4: $1{,}1 \cdot 1{,}15 \cdot G + 1{,}1 \cdot 1{,}5 \cdot \alpha_{res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,off} I_{off}$

STR 6.10b-5: $1{,}1 \cdot 1{,}15 \cdot G + 1{,}1 \cdot 1{,}5 \cdot \alpha_{off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,res} I_{res}$

STR 6.10a: $1{,}1 \cdot 1{,}35 \cdot G$

STR load combinations for smallest R_A (permanent action favourable)

STR 6.10b-6: $1{,}0 \cdot G + 1{,}1 \cdot 1{,}5 \cdot \alpha_{res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \alpha_{off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,W} W + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,S} S$

STR 6.10b-7: $1{,}0 \cdot G + 1{,}1 \cdot 1{,}5 \cdot W + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,S} S$

STR 6.10b-8: $1{,}0 \cdot G + 1{,}1 \cdot 1{,}5 \cdot S + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,res} I_{res} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,off} I_{off} + 1{,}1 \cdot 1{,}5 \cdot \psi_{0,W} W$

STR 6.10b-9: $1{,}0 \cdot G + 1{,}1 \cdot 1{,}5 \cdot W$

STR load combinations for smallest R_B (permanent action favourable)

STR 6.10b-10: $1{,}0 \cdot G + 1{,}1 \cdot 1{,}5 \cdot W$

Table 6.1 – Design combination factors

	G	I_{res}	I_{off}	W	S	Dominating variable action
STR (6.10b)-1	$1{,}1\cdot 1{,}15$	$1{,}1\cdot 1{,}5\cdot 0{,}85$	$1{,}1\cdot 1{,}5\cdot 1{,}0$	$1{,}1\cdot 1{,}5\cdot 0{,}6$	$1{,}1\cdot 1{,}5\cdot 0{,}5$	I
STR (6.10b)-2	$1{,}1\cdot 1{,}15$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5$	$1{,}1\cdot 1{,}5\cdot 0{,}5$	W
STR (6.10b)-3	$1{,}1\cdot 1{,}15$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}6$	$1{,}1\cdot 1{,}5$	S
STR (6.10b)-4	$1{,}1\cdot 1{,}15$	$1{,}1\cdot 1{,}5\cdot 0{,}85$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	0	0	I_{res}
STR (6.10b)-5	$1{,}1\cdot 1{,}15$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 1{,}0$	0	0	I_{off}
STR (6.10b)-6	1,0	$1{,}1\cdot 1{,}5\cdot 0{,}85$	$1{,}1\cdot 1{,}5\cdot 1{,}0$	$1{,}1\cdot 1{,}5\cdot 0{,}6$	$1{,}1\cdot 1{,}5\cdot 0{,}5$	I
STR (6.10b)-7	1,0	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5$	$1{,}1\cdot 1{,}5\cdot 0{,}5$	W
STR (6.10b)-8	1,0	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}7$	$1{,}1\cdot 1{,}5\cdot 0{,}6$	$1{,}1\cdot 1{,}5$	S
STR (6.10b)-9	1,0	0	0	$1{,}1\cdot 1{,}5$	0	W
STR (6.10a)	$1{,}1\cdot 1{,}35$	0	0	0	0	-

The design support reactions are given in table 6.2. The largest upward pointing reactions in points A and B occur for STR (6.10b) - 2 and STR (6.10b) – 1, respectively. STR (6.10b) - 7 gives the smallest reaction in point A of 6 kN. Thus, an anchor in point A is not needed according to STR.

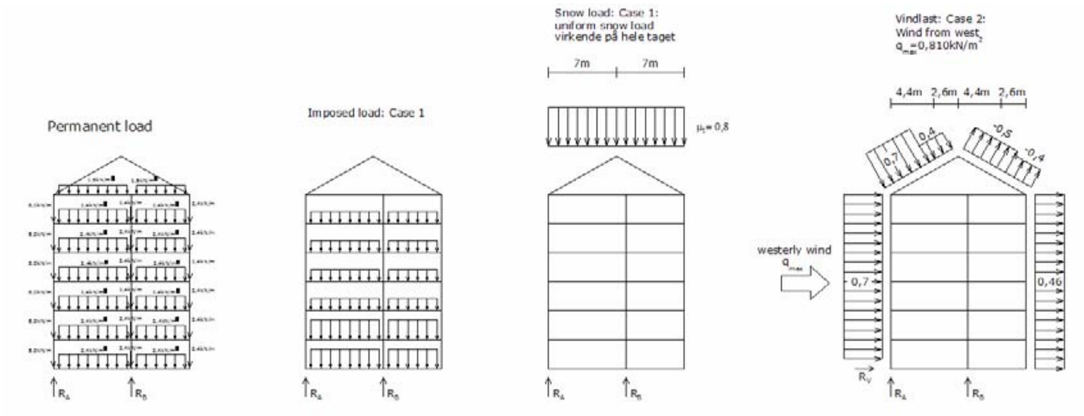
The dimensioning support reactions are shown bold in table 6.2.

Table 6.2 – Design support reactions - STR

	R_A [kN]	R_B [kN]
STR (6.10b)-1	1652	**4780**
STR (6.10b)-2	**1716**	4600
STR (6.10b)-3	1545	4507
STR (6.10b)-4	1279	4250
STR (6.10b)-5	1303	4319
STR (6.10b)-6	92	-
STR (6.10b)-7	**6**	-
STR (6.10b)-8	165	-
STR (6.10b)-9	250	1902
STR (6.10a)	968	3499

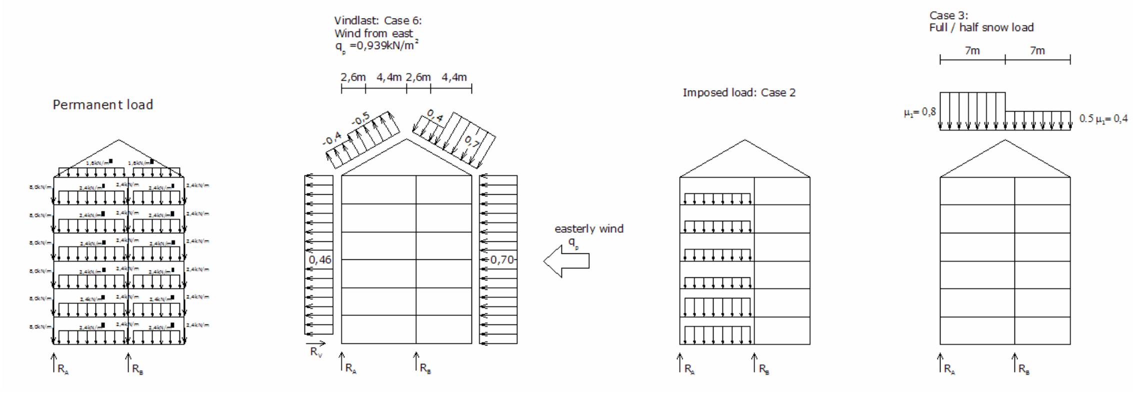
7. Dimensioning combination of actions - STR

Largest R_B: (STR (6.10b)-1)



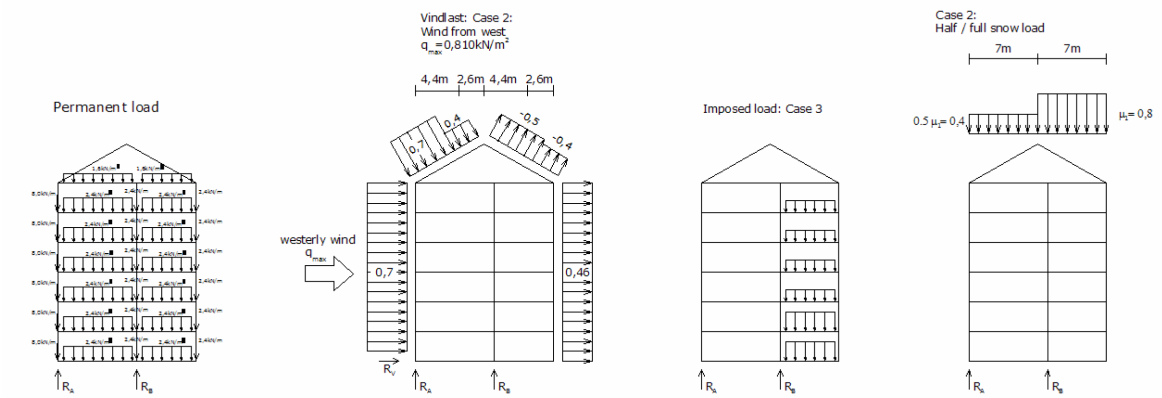
$1{,}1 \cdot 1{,}15 \cdot G$ "+" $1{,}1 \cdot 1{,}5 \cdot \alpha_n \cdot I$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,s} \cdot S$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,w} \cdot W$

Largest R_A: (STR (6.10b)-2)



$1{,}1 \cdot 1{,}15 \cdot G$ "+" $1{,}1 \cdot 1{,}5 \cdot W$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,I} \cdot I$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,s} \cdot S$

Smallest R_A: (STR (6.10b)-7)



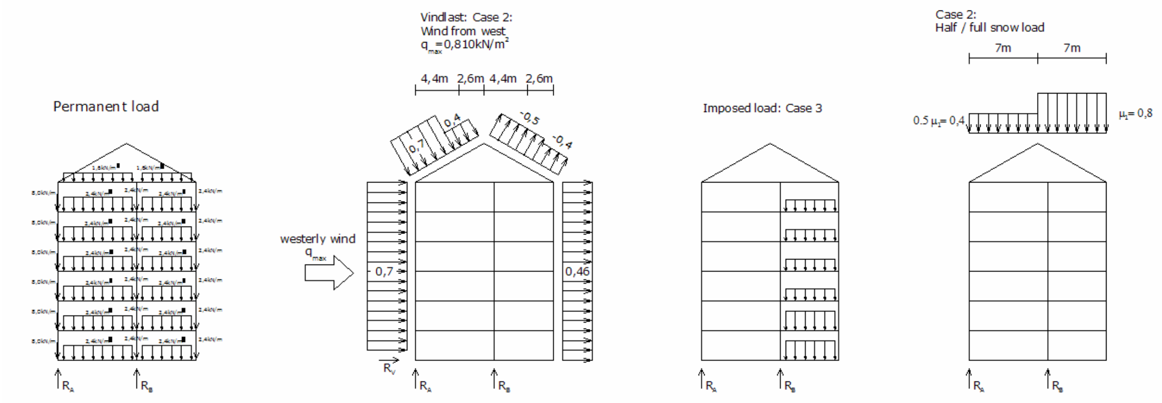
$1{,}0 \cdot G$ "+" $1{,}1 \cdot 1{,}5 \cdot W$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,I} \cdot I$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,s} \cdot S$

8. Loss of static equilibrium - EQU

The design support reaction in EQU is given in table 8.1.

Table 8.1 – Design support reaction - EQU

	R_A [kN]	R_B [kN]
EQU	**-153**	-



$1{,}10 \cdot G_{\text{sup}} + 0{,}9 \cdot G_{\text{inf}}$ "+" $1{,}1 \cdot 1{,}5 \cdot W$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,i} \cdot I$ "+" $1{,}1 \cdot 1{,}5 \cdot \psi_{0,s} \cdot S$

6.4.1 (1)P in EN 1990:2002 specifies:

"EQU : Loss of static equilibrium of the structure or any part of it considered as a rigid body, where:

- minor variations in the value or the spatial distribution of actions from a single source are significant, and
- the strengths of construction materials or ground are generally not governing"

Is EQU relevant in the present example?

If yes, how should the anchor be designed?

Give STR alone sufficient safety if an anchor is chosen in the first place?