CM01 – Concrete and Masonry Structures 1

HW9 – Stiffening walls

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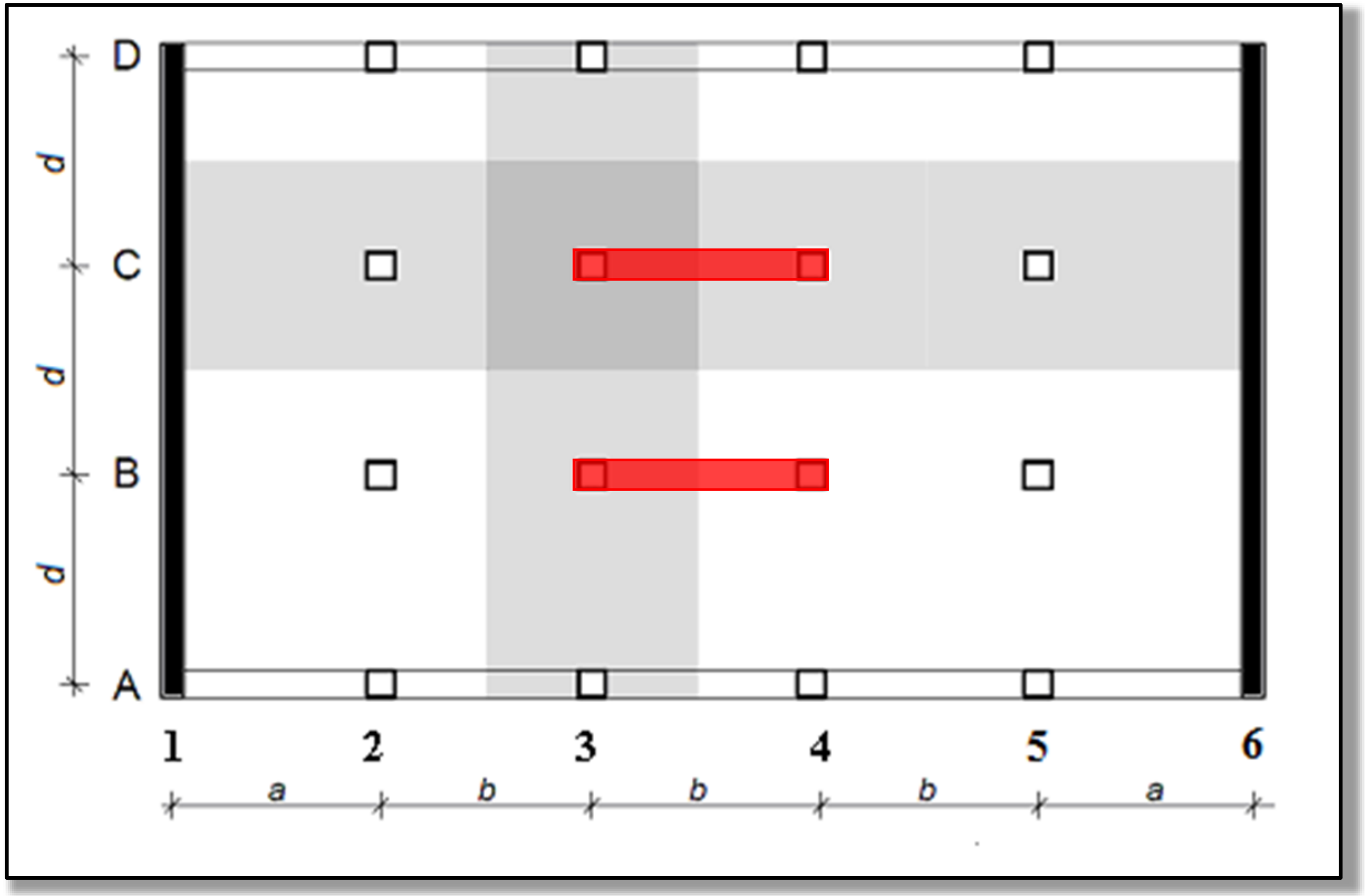
Task 4

Task 4 – Stiffening wall

In Task 4, stiffening walls in the structure from Task 3 will be designed.



Task 4 – Assignment

Task 4: Reinforced concrete stiffening walls

For the structure from Task 3, design sufficient number of reinforced concrete stiffening walls in the longitudinal direction (stiffening in transversal direction is already provided by the exterior walls in rows 1 and 6).
Design the stiffening walls so that there is no tension in the foot of the walls when characteristic wind load and minimum vertical load is applied.

Individual parameters (parameters in **bold** you can find on teacher's website):

T – Terrain category
W – Wind load area
h [m] – floor height (see 1st task)
n **–** number of floors (see 1st task)

Please work out:

1. **Design of geometry** (number and positioning of the walls)
2. **Sketch of reinforcement** for a selected wall

Task 4 – Assignment goals

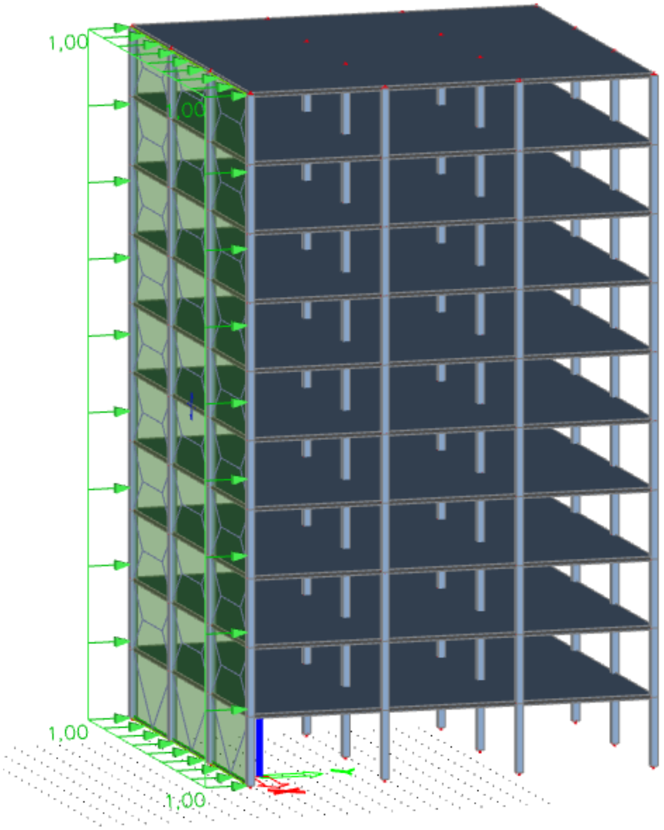
Our goal will be to:

1) Calculate **wind loads**.
2) Calculate **vertical loads**.
3) Design **geometry of walls** (number, lengths, positions).
4) Design **reinforcement** of stiffening walls.
5) Draw a **sketch** of reinforcement.

Theory

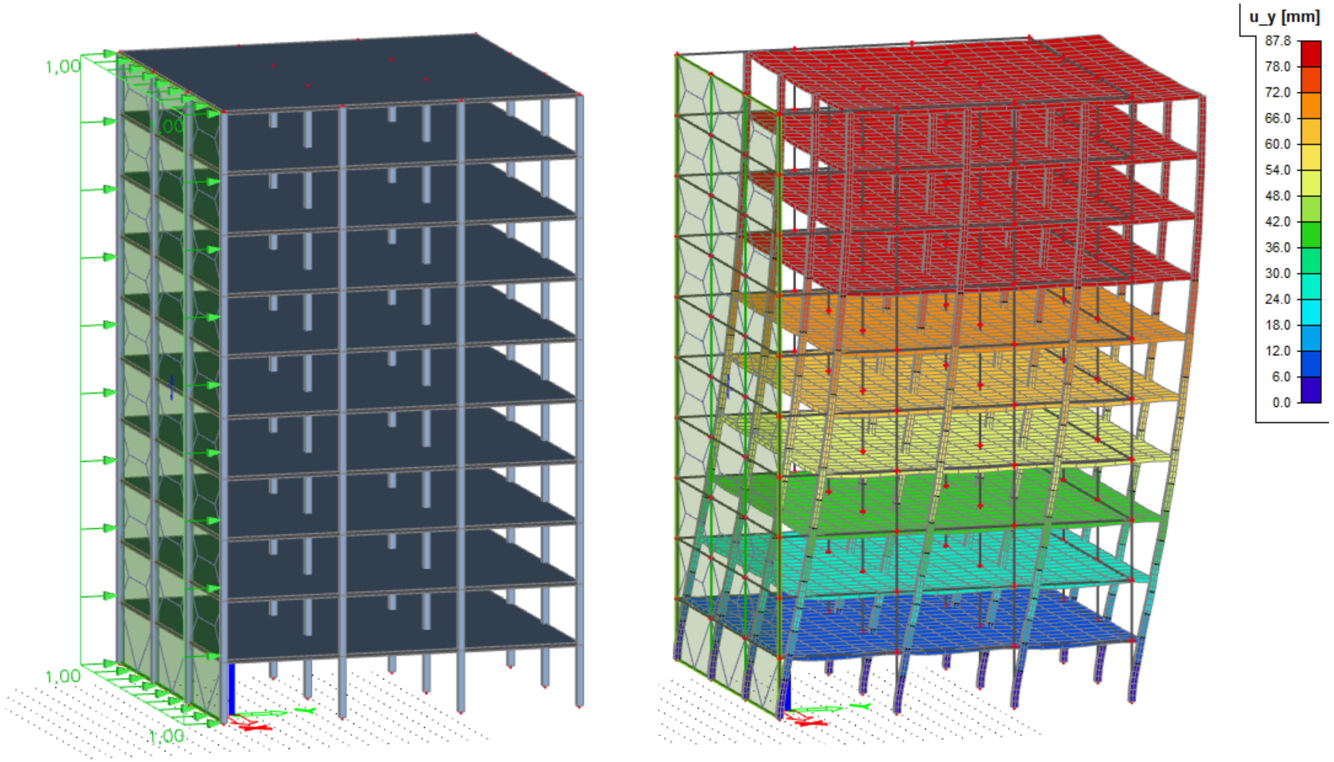
Horizontal loads

Horizontal loads (wind, earthquake, etc.) induce horizontal and vertical **internal forces** and **deflections** in a structure.



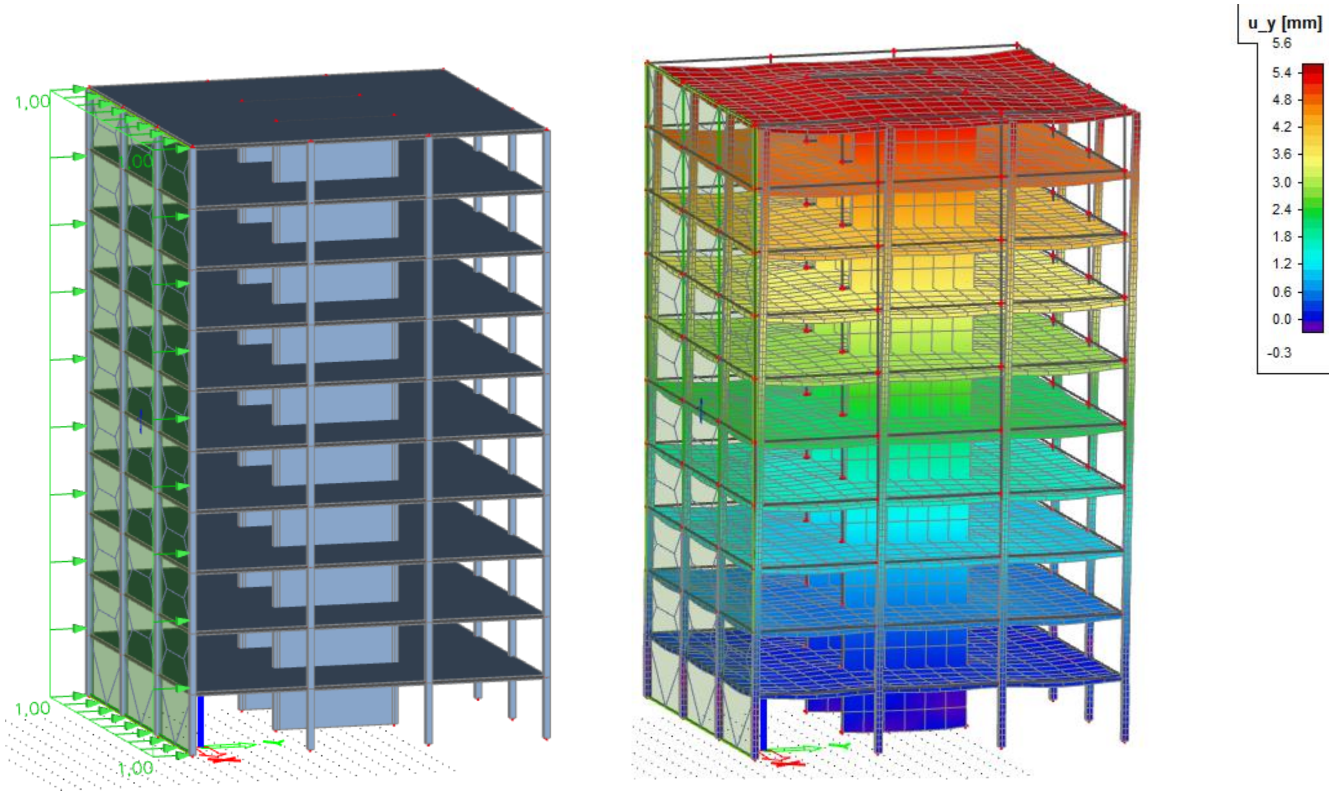
Deflections without walls

A structure **supported only by columns** is very flexible, and thus, the **deflections are extremely big**!



Deflections with walls

If a **perpendicular wall** is used in the structure, the **deflections are much smaller**.



Stiffness (deflection resistance)

The ability of a structural member to **resist deflections** strongly depends on the **moment of inertia** of its cross section:

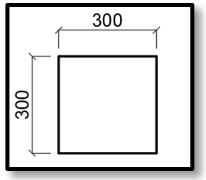
$$I = \frac{1}{12} b h^3.$$

As can be readily seen, the **height of the cross-section is most important**.

Stiffness (deflection resistance)

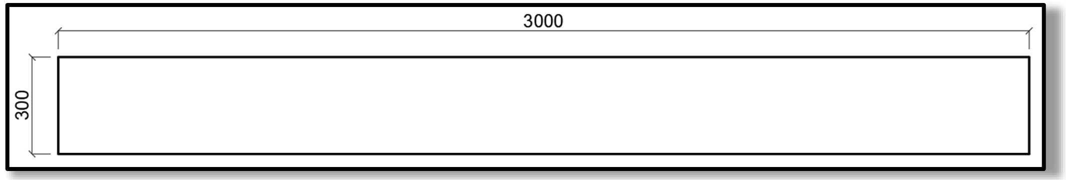
Column's moment of inertia:

$$I = \frac{1}{12}bh^3 = \frac{1}{12}0.3 \cdot 0.3^3 = 0.0081\ \mathrm{m}^4$$



Walls's moment of inertia:

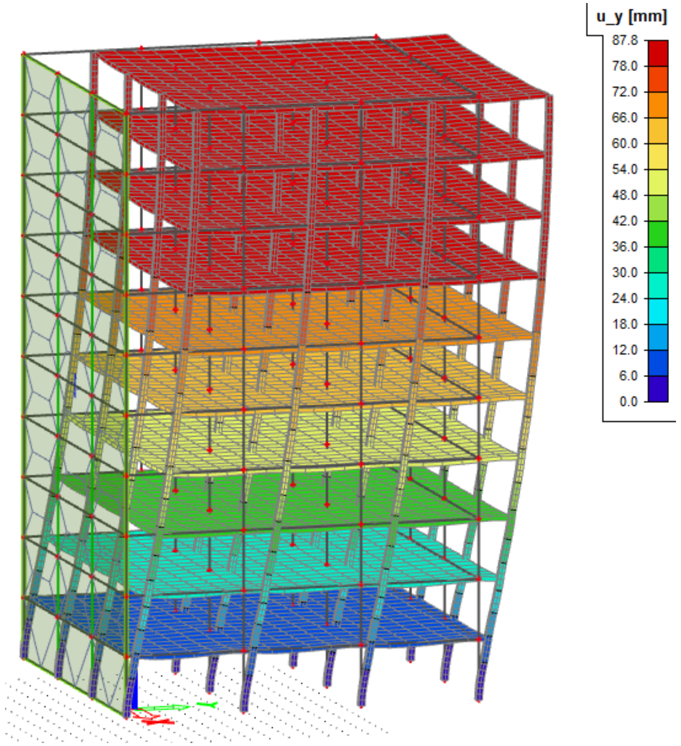
$$I = \frac{1}{12}bh^3 = \frac{1}{12}0.3 \cdot 3^3 = 8.1\ \mathrm{m}^4$$

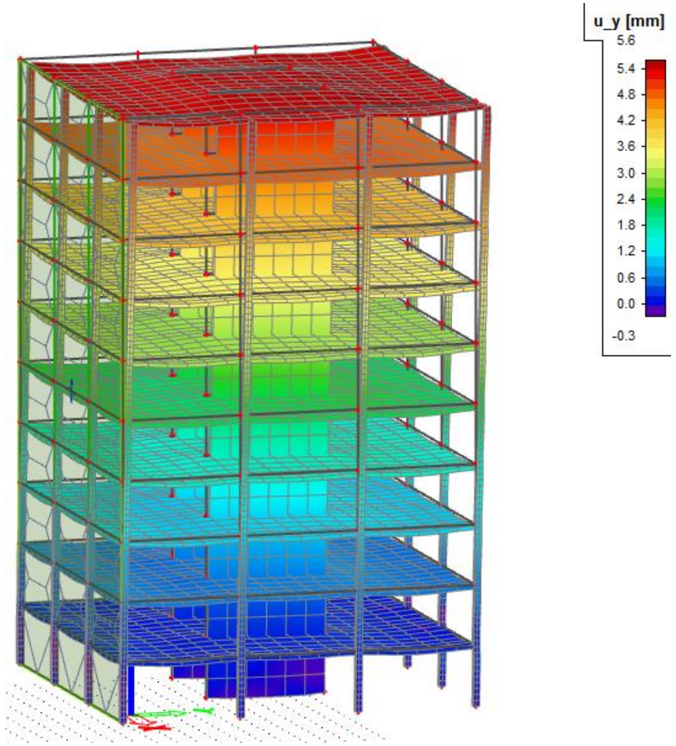


A 3-meter-long **wall is 1000 times stiffer** than a 300x300 mm column! Therefore, **<u>we use walls to increase horizontal stiffness</u> of structures**.

Comparison

With walls, the horizontal deflection are **5.6 mm instead of 87.8 mm**.

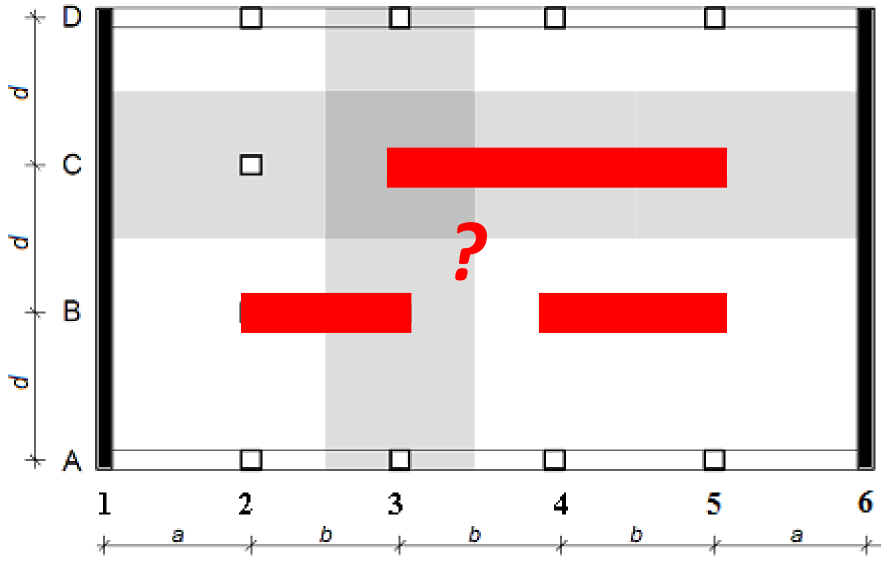




Vertical load

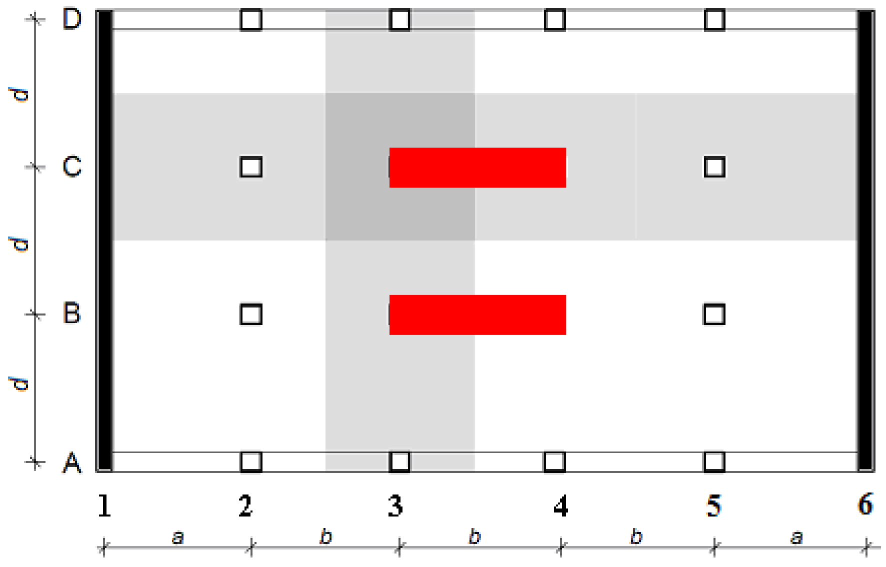
Number of walls

In order to calculate the vertical loads in the walls, we need to determine the tributary areas for the walls, and for this, **we need to know the number and geometry of the walls**.



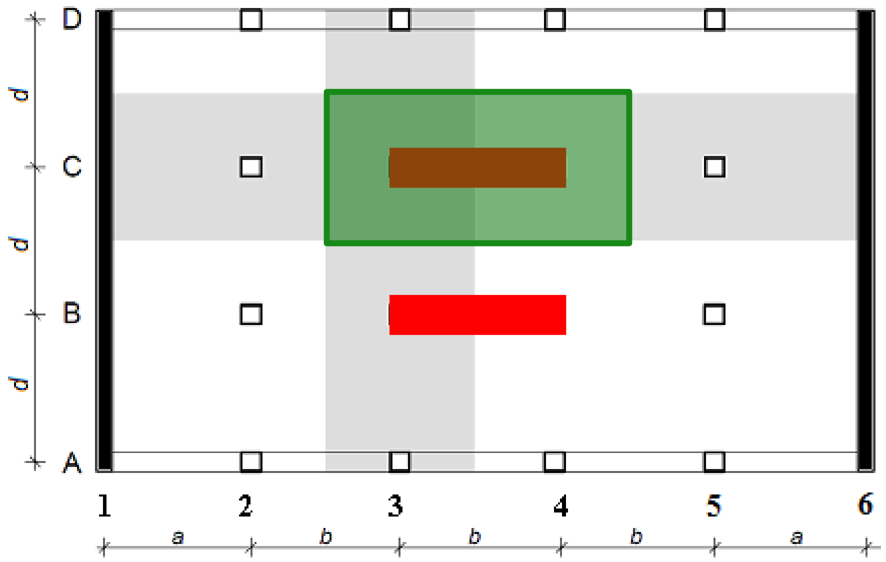
Number of walls

As a **first estimate**, we will design **two walls** each **one-span long** and **250 mm thick**.



Tributary area

The **tributary area for each wall** can be determined in the same way as for the columns in previous HW's – i.e., it is the part of the slab whose closest support is the wall.



Loads

For the design of the walls, we will **need to know the minimal and maximal loads** (normal forces) which can occur in the walls.

The **minimal load** (R_{min} [kN]) is the **characteristic** load from:

- self-weight of the slab* from the tributary area,
- self-weight of the wall.

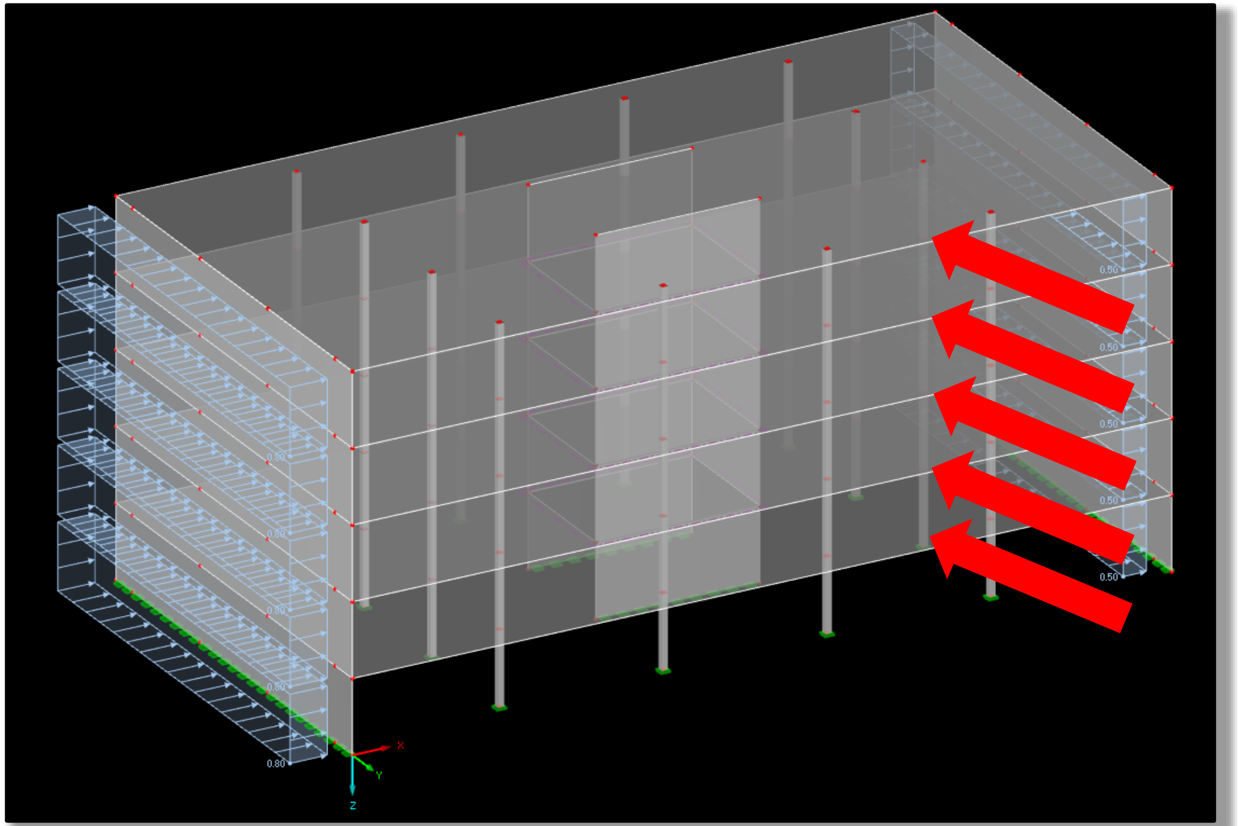
The **maximal load** (R_{max} [kN]) is the **design** load from:

- self-weight of the slab* from the tributary area,
- other permanent load of the slab* from the tributary area,
- live load of the slab* from the tributary area,
- self-weight of the wall.

* Use the slab loads from Task 3.

Loads

When calculation the loads, do not forget that the structure has multiple floors! Therefore, **you must sum the loads from all of the floors***.



* In the HW, you can assume all the floors to be the same (i.e., the roof is loaded in the same way as a typical floor).

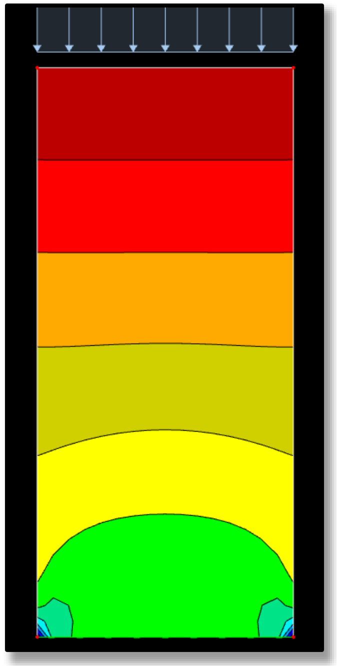
Load effects

The vertical loads will induce **uniform** compressive **normal stress** in the wall footing:

$$\sigma_N = \frac{N}{A} = \frac{R}{b_w L_w},$$

where R is the load in the foot of the wall,
where t_w is the wall thickness,
where L_w is the wall length.

We must calculate σ_N for both R_{min} and R_{max}!

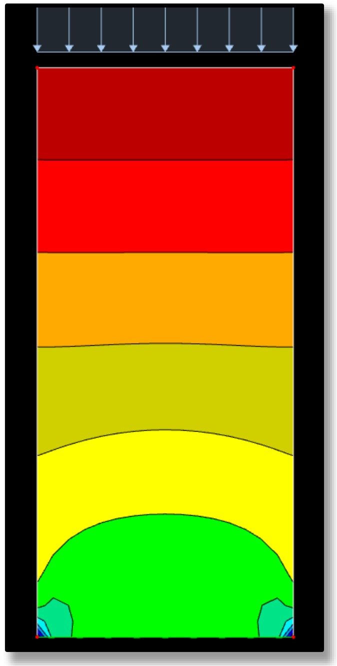


Load effects

We must calculate σ_N for both R_{min} and R_{max}! Therefore, we will get:

$$\sigma_{N,min} = \frac{R_{min}}{b_w L_w},$$

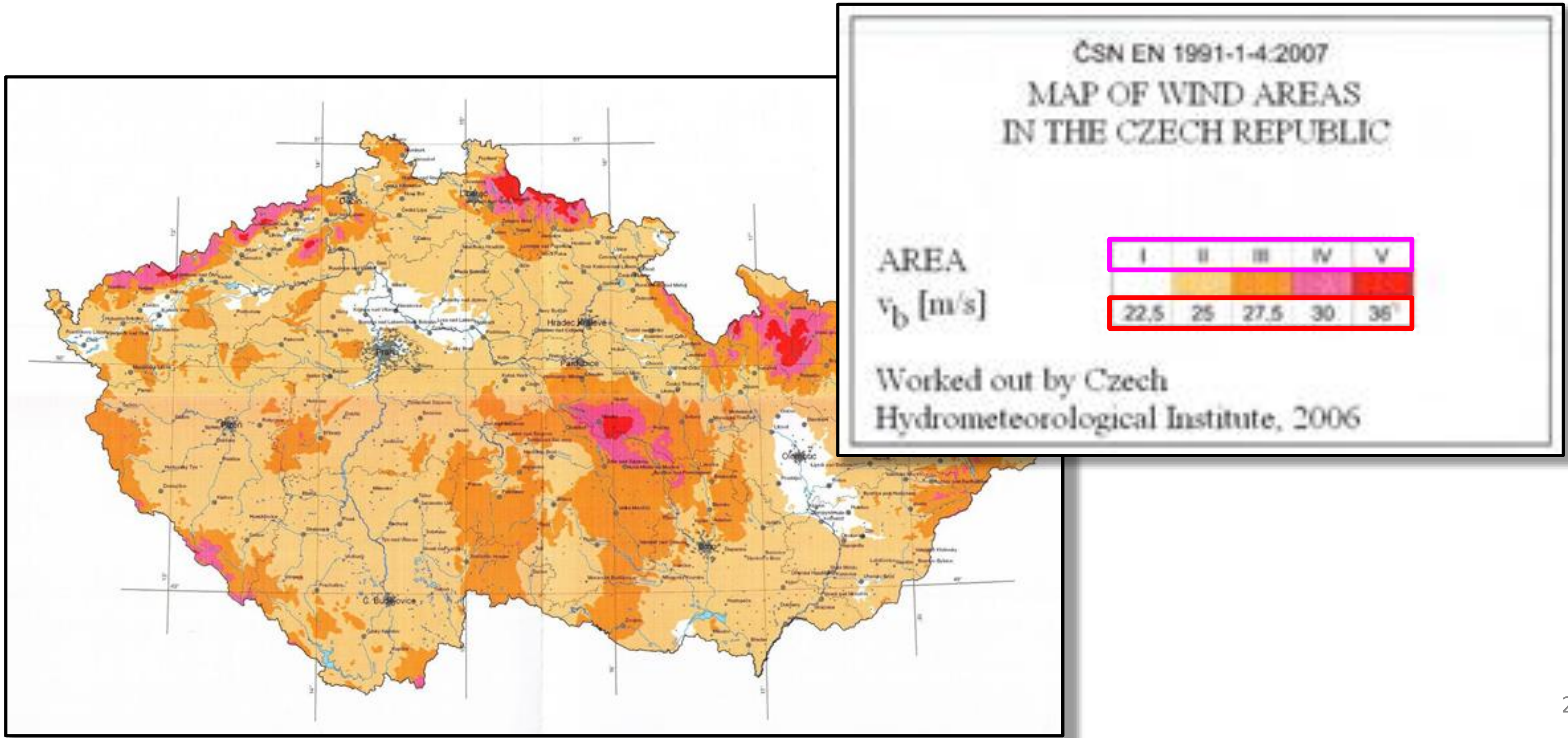
$$\sigma_{N,max} = \frac{R_{max}}{b_w L_w}.$$



Wind load

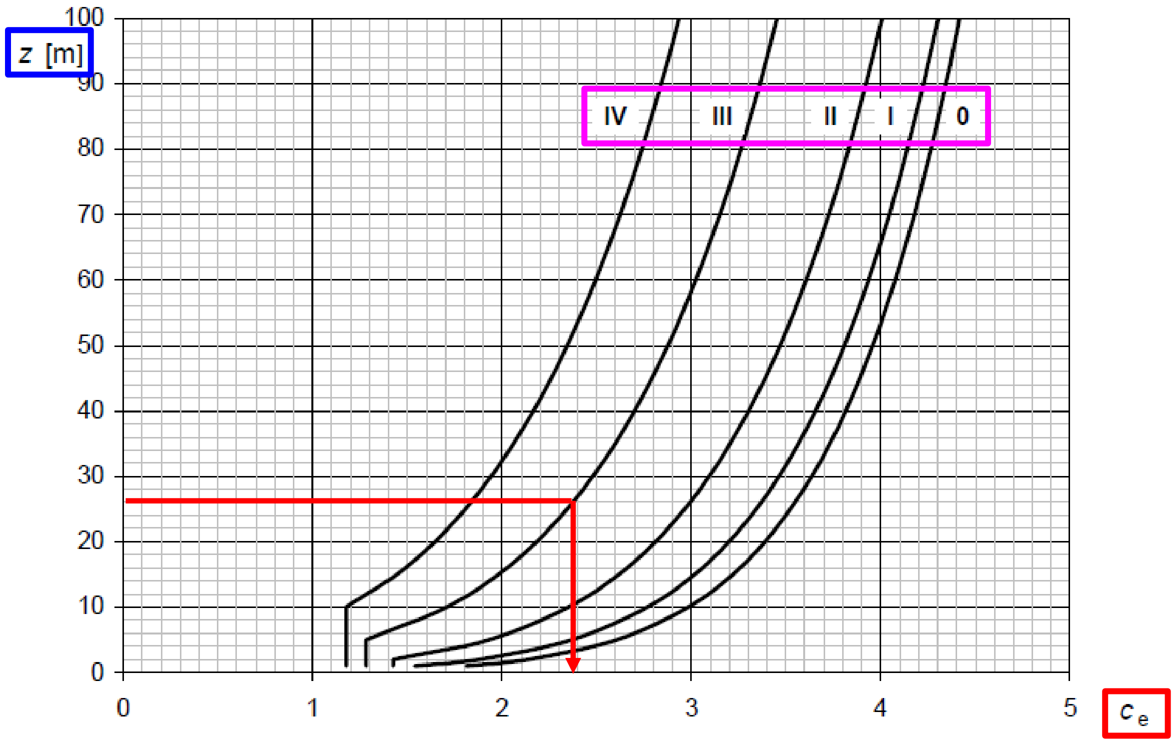
Wind load

The wind load is calculated based on the “*Basic wind velocity*”, which depends on the “*Wind load area*”.



Wind load

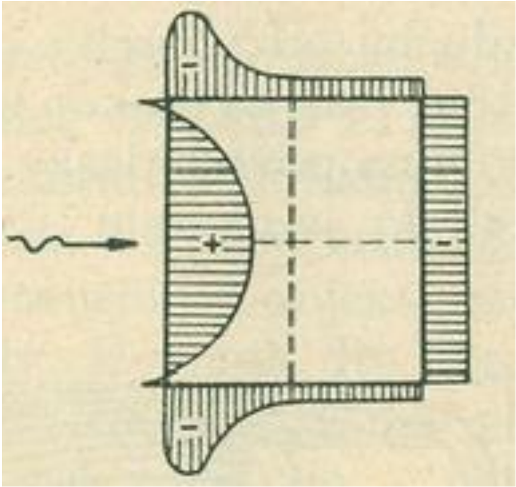
The wind load is also affected by the "*Exposure factor*", which depends on the "*Terrain category*" and the height of the building (z)*.



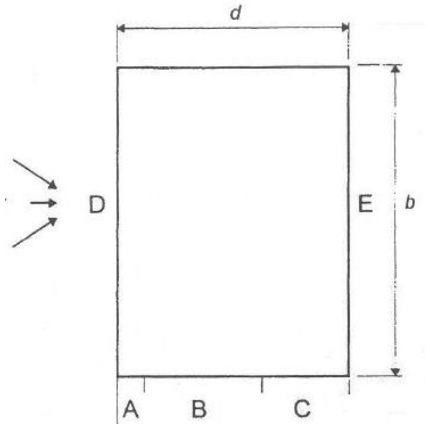
* You must calculate the height of your building from the number of floors and height of one floor from Task 3.

Wind load

The wind load is further affected by the *"External pressure coefficient"*, which depends on the wind direction and structure orientation.



Real distribution of wind pressure



In Eurocode: Coefficients for areas A – E

In our HW, we will assume the most extreme coefficient: $\boldsymbol{c_{pe} = 1.3}$ (sum of pressure 0.8 in windward area D and suction 0.5 in leeward area E).

Wind load

The **characteristic value of wind load** is calculated as:

$$w_k = \left(\frac{1}{2}\rho_v v_b^2\right) c_e(z) c_{pe}.$$

Density of the air
(1.25 kg/m^3)

Example: $w_k = \left(\frac{1}{2} 1.25 \cdot 27.5^2\right) 2.38 \cdot 1.3 = 1462\ \mathrm{N/m^2} = 1.462\ \mathrm{kN/m^2}.$

Wind load

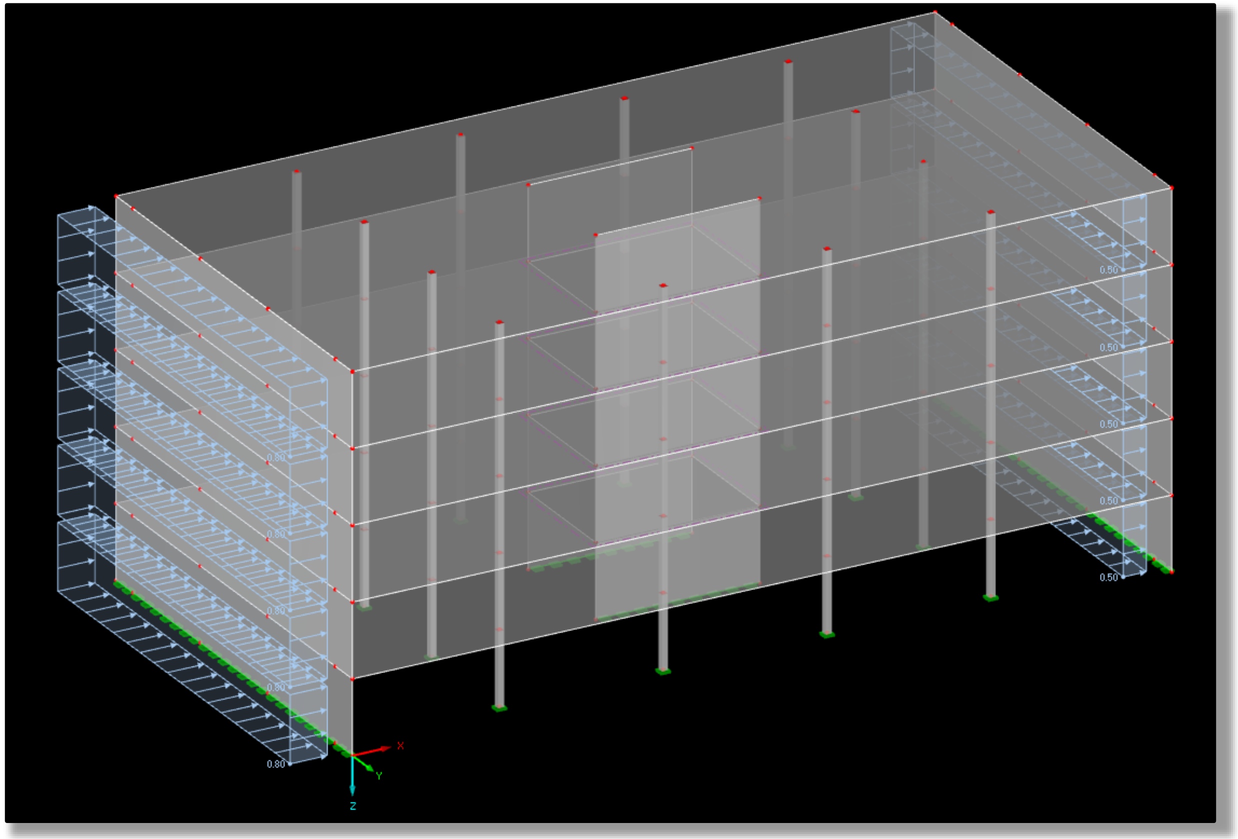
The **design value of wind load** is calculated as:

$$w_d = \gamma_Q w_k.$$

Safety factor (1.5)

Wind load

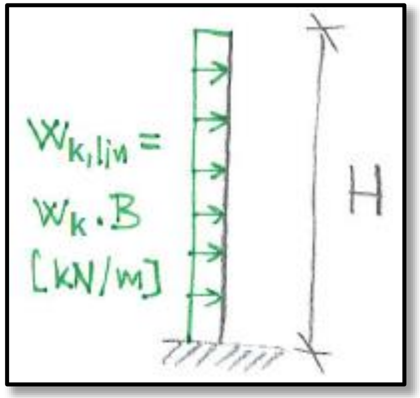
The obtained values are area loads on the face of the structure.

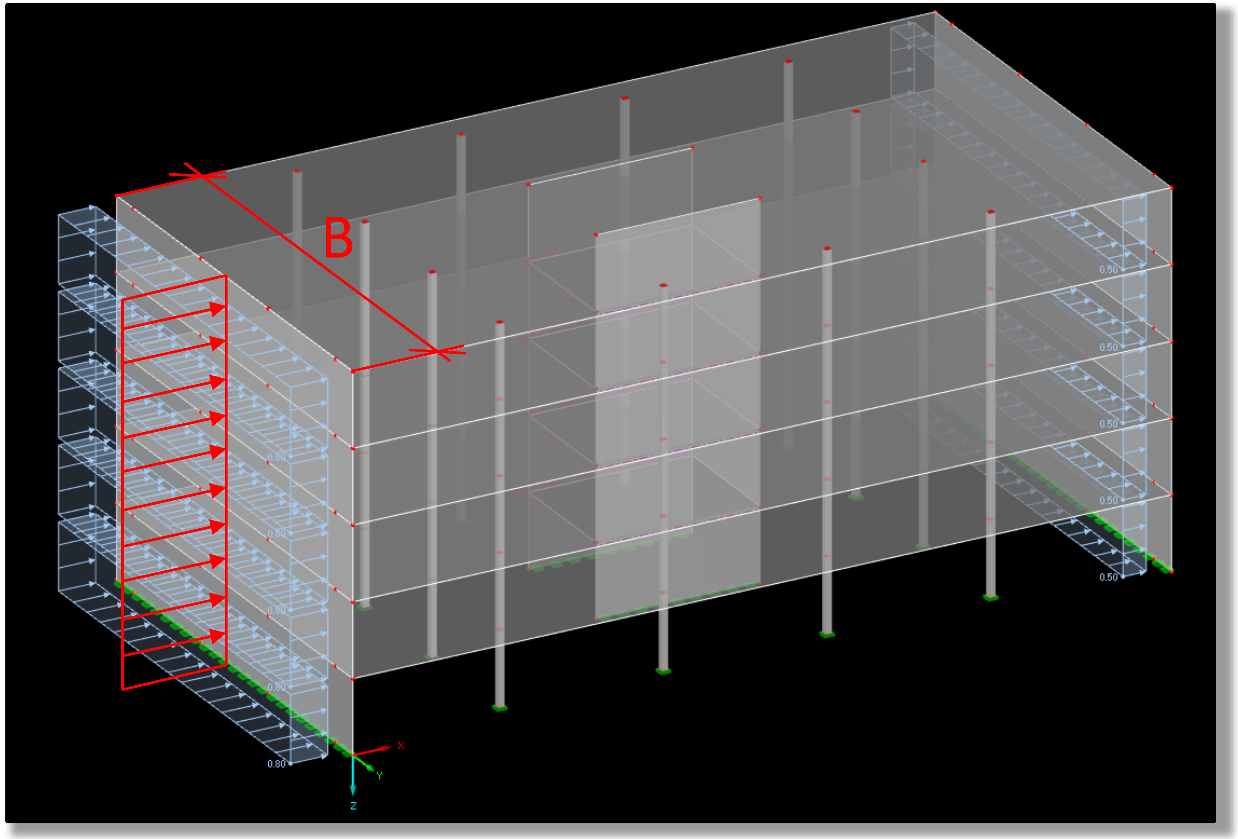


Linear wind load

However, for further calculations, we need the **linear wind loads** acting on the whole structure:

$$w_{k,lin} = w_k B,$$
$$w_{d,lin} = w_d B.$$





Load on individual walls

The calculated linear wind load w_{lin} acts on the whole structure. However, we need to find out the **linear load on each wall**:

$$w_{lin,1} = \frac{EI_1}{\sum EI_i} w_{lin} = \frac{1}{m} w_{lin}.$$

Only applicable if all of the walls have the same geometry.

Number of stiffening walls (n = 2 in our case)

Always applicable. The moment is divided according to moments of inertia. Remember it for the exam!

We must calculate $w_{lin,1}$ for both $w_{lin,k}$ and $w_{lin,d}$!

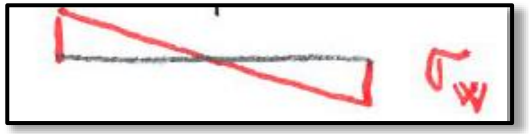
Load effects

The horizontal wind loads will induce bending moment in the wall footing (H is the height of the wall – assume the same as height of the structure "z"):

$$M_W = \frac{1}{2} w_{lin,1} H^2.$$

The bending moment will, in turn, induce **non-uniform normal stress** in the wall footing, and the highest stress on the ends of the wall will be:

$$\sigma_W = \pm \frac{M_w}{W} = \pm \frac{M_w}{\frac{1}{6} t_w L_w^2}.$$

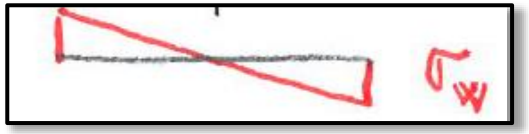


Load effects

We must calculate σ_W for both $w_{lin,1,k}$ and $w_{lin,1,d}$! Therefore, we will get:

$$\sigma_{W,k} = \pm \frac{\frac{1}{2} w_{lin,1,k} H^2}{\frac{1}{6} t_w L_w^2},$$

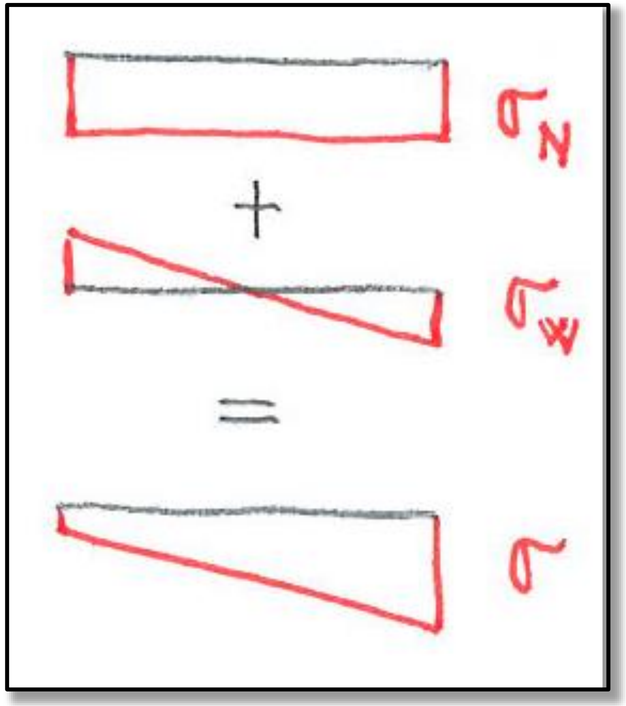
$$\sigma_{W,d} = \pm \frac{\frac{1}{2} w_{lin,1,d} H^2}{\frac{1}{6} t_w L_w^2}.$$



Load combinations

Load combinations

The **vertical and horizontal loads act together**. The **total stress** at the base of the wall is the **sum of the stresses** induced by these loads.



Load combinations

We have calculated both **minimal and maximal vertical loads** and both **characteristic and design wind loads**.

Now, we need to decide, **which load combinations to use for the design**. Generally, we design for 3 load combinations:

- **CO1 – Expected loads**:
  - minimum vertical load ($\sigma_{N,min}$) and characteristic wind load ($\sigma_{W,k}$),
- **CO2 – Compressive design loads**:
  - maximum vertical load ($\sigma_{N,max}$) and design wind load ($\sigma_{W,d}$),
- **CO3 – Tensile design loads**:
  - minimum vertical load ($\sigma_{N,min}$) and design wind load ($\sigma_{W,d}$).

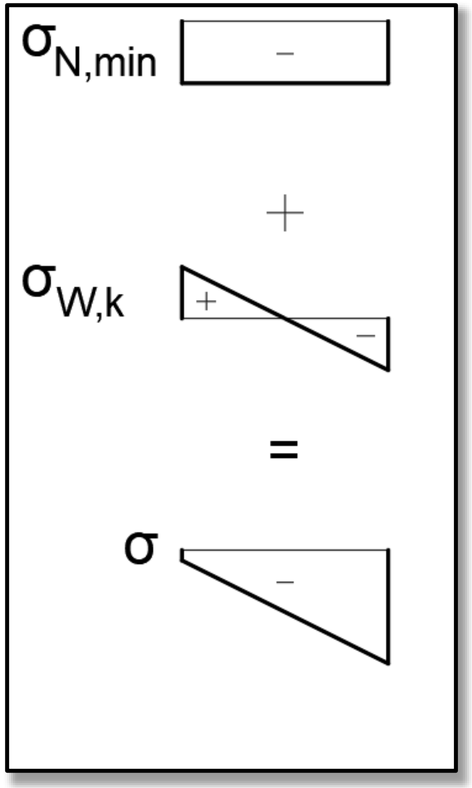
CO1 – Expected loads

CO1 is a combination of loads which **can occur** in the structure during its lifetime:

- minimum vertical load ($\sigma_{N,min}$),
- characteristic wind load ($\sigma_{W,k}$).

This load combination must induce **only compressive stress!**

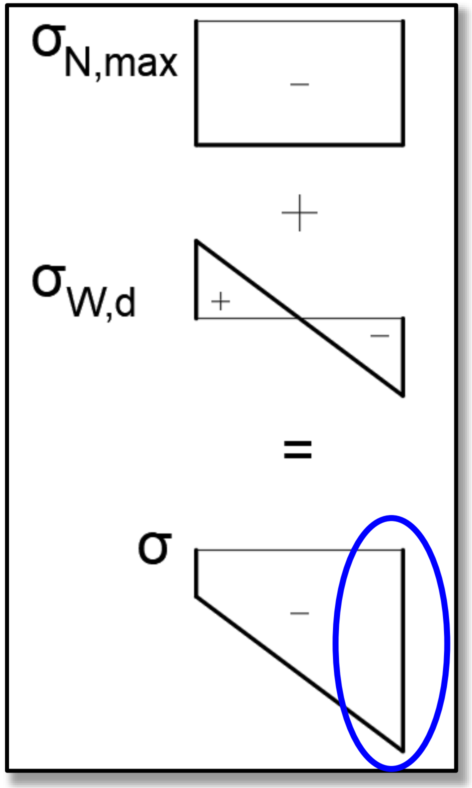
If the wind load is big, and **tensile stresses occur, the design must be adjusted** (increase the number of walls or lengths of the walls), and the **loads must be recalculated**!



CO2 – Compressive design loads

CO2 is a combination of loads which **probably won't occur** in the structure during its lifetime (but we still must assume them):

- maximum vertical load ($\sigma_{N,max}$),
- design wind load ($\sigma_{W,d}$).



This load combination will induce only compressive stress, and the **compressive stress will be high**.

We will use this combination to **design reinforcement in the most compressed part** of the wall.

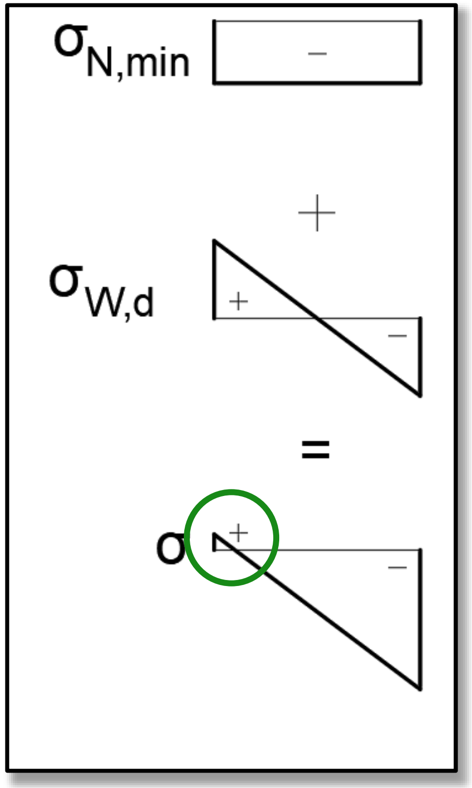
CO3 – Tensile design loads

CO3 is a combination of loads which **probably won't occur** in the structure during its lifetime (but we still must assume them):

- minimum vertical load ($\sigma_{N,min}$),
- design wind load ($\sigma_{W,d}$).

This load combination will induce compressive stress and **might also induce tensile stress**.

If tensile stress is induced, we will use this combination to **design reinforcement in the most tensioned part** of the wall.



Reinforcement design

Basic reinforcement design

When we design the wall reinforcement, we first design “Basic reinforcement” using only detailing rules – i.e., we **design only the minimal reinforcement** prescribed by Eurocode detailing rules.

Basic reinforcement design

Vertical reinforcement:

Sum of provided areas of vertical reinforcement per 1 m of the wall on both surfaces.

Area of reinforcement: $0.002a_c \le a_{s,v} \le 0.04a_c$

Cross-sectional area of 1 m of concrete wall (tw*1)

Spacing of rebars: $s_v \le \min(3t; 400 \text{ mm})$

Horizontal reinforcement:

$$a_{s,h} \ge \max(0.25a_{s,v}; 0.001a_c)$$

$$s_h \le 400 \text{ mm}$$

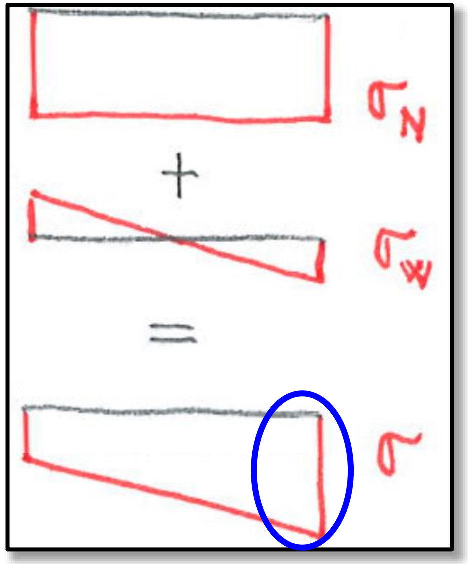
Example (state your design in the same way):

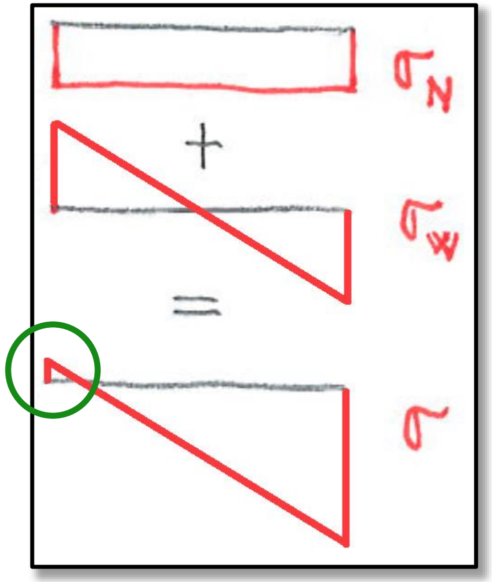
Vertical: Ø6 per 250 mm on both surfaces (as,v = 2*113 mm2/m)

Horizontal: Ø6 per 400 mm on both surfaces (as,h = 2*70 mm2/m)

Assessment of the wall

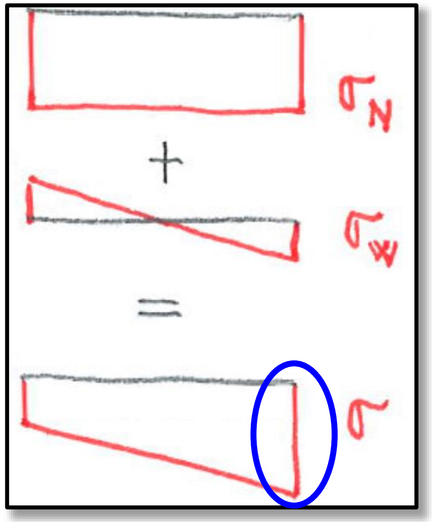
Next, we must assess, **whether the basic reinforcement is sufficient in the most loaded parts** of the wall – i.e. if the load-bearing capacity of the wall with the basic reinforcement is sufficient.



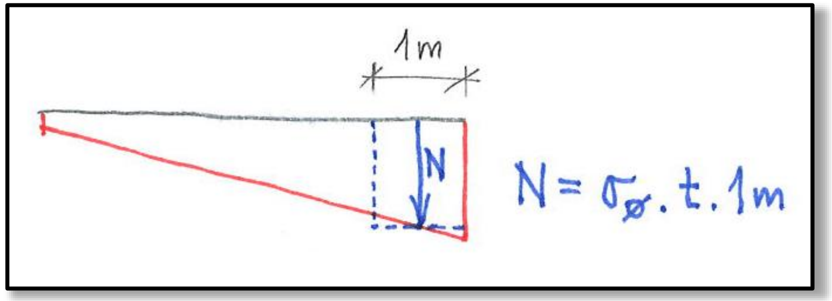


Compressed reinforcement

First, we will assess the most compressed part of the wall, and for this, we will **use the total stress from CO2**.

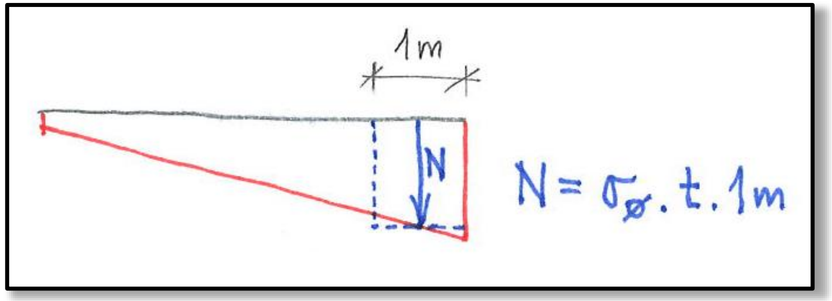


When we assess the wall, we **partition the wall into a 1-meter-wide strips** and assess them separately.



Compressed reinforcement

In the **most compressed strip**, we will **calculate the average stress** and **calculate the normal force** in this strip.



Using the normal force, we can calculate the required area of the vertical reinforcement in this strip:

$$a_{s,req,v} = \frac{N - 0{,}8 a_c f_{cd}}{\sigma_s}$$

400 MPa

Compressed reinforcement

If the **required area** is **more than the area according to detailing rules**, we must **design new vertical reinforcement in this strip** of the wall whose provided area will be larger than the required area.

If the **vertical reinforcement changes**, the **horizontal reinforcement might also need to be changed**.

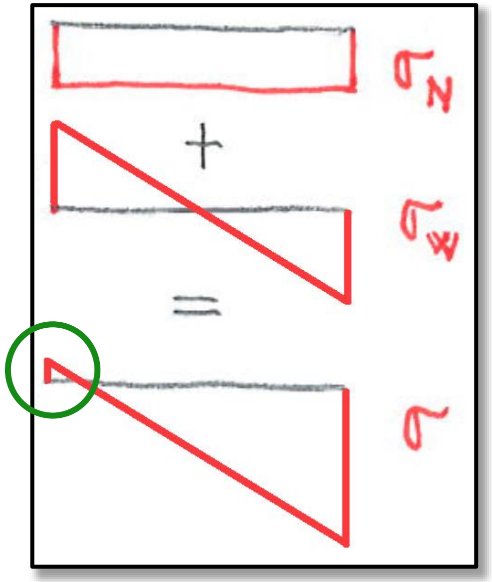
$$a_{\mathrm{s,h}} \geq \max\left(0.25 a_{\mathrm{s,v}} ; 0.001 a_{\mathrm{c}}\right)$$

$$s_{\mathrm{h}} \leq 400\ \mathrm{mm}$$

We will **use this reinforcement on BOTH EDGES of the wall**, because the wind can blow from both sides.

Tensile reinforcement

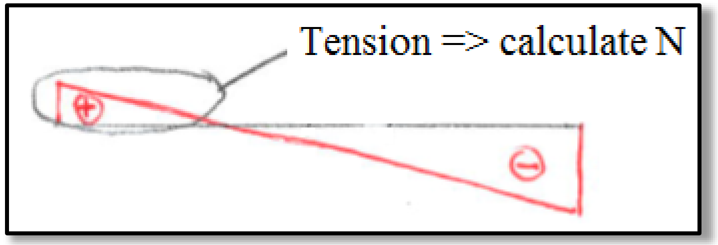
If tension has occurred in the CO3, we must also **assess the most tensile part of the wall**, using the total stress from CO3.



We will again **partition the wall into a 1-meter-wide strips** and assess them separately.

Tensile reinforcement

In the **most tensile strip**, we will **calculate the average stress** and **calculate the normal force** in this strip.



Using the normal force, we can calculate the required area of the vertical reinforcement in this strip:

$$a_{\text{s,req,v}} = \frac{N}{f_{\text{yd}}}$$

Tensile reinforcement

If the **required area** is **more than the area of currently designed reinforcement** (either reinforcement according to detailing rules or compressive reinforcement), we must **design new vertical reinforcement in this strip** of the wall whose provided area will be larger than the required area.

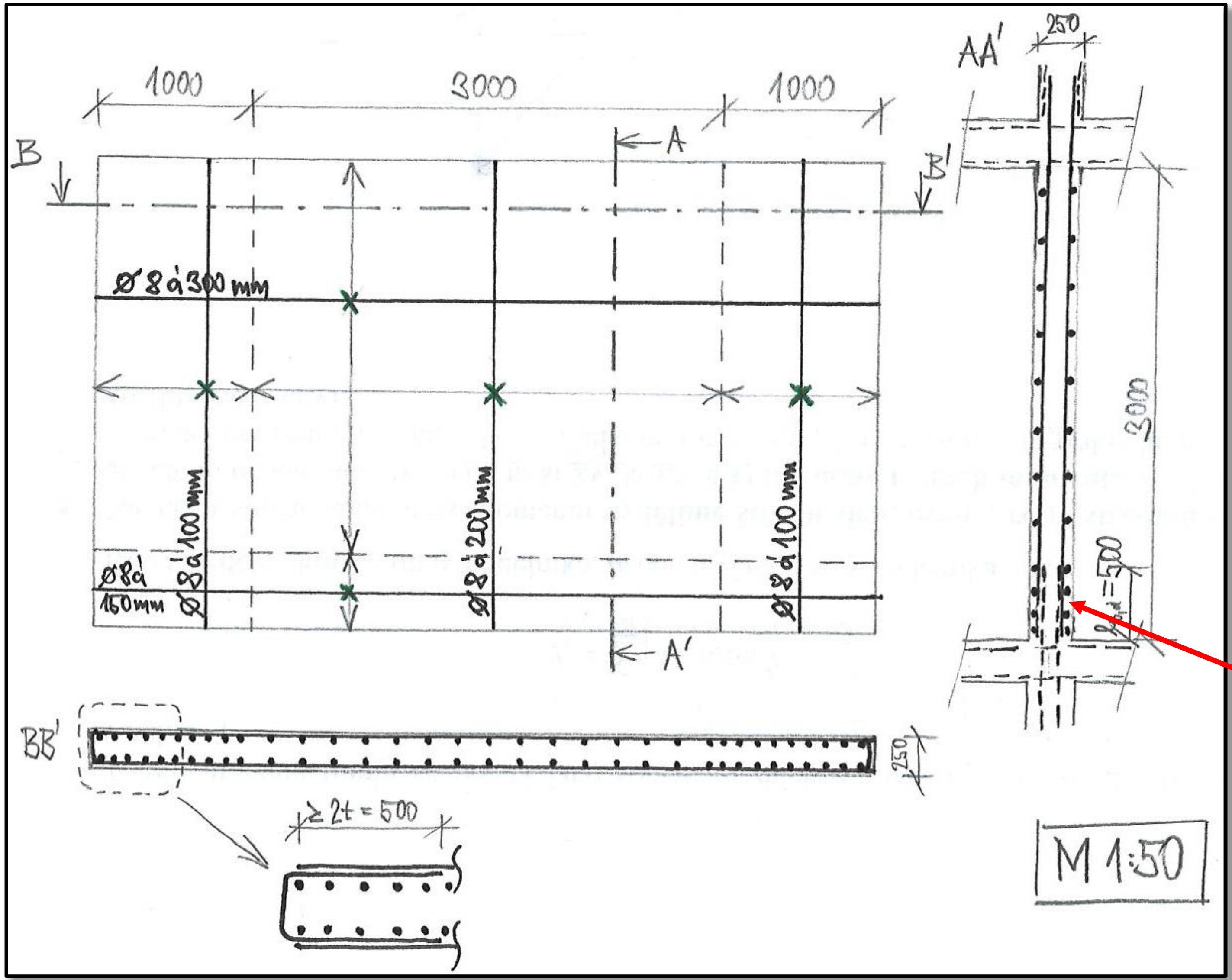
If the **vertical reinforcement changes**, the **horizontal reinforcement might also need to be changed**.

$$a_{\mathrm{s,h}} \geq \max\left(0.25 a_{\mathrm{s,v}}; 0.001 a_{\mathrm{c}}\right)$$

$$s_{\mathrm{h}} \leq 400\ \mathrm{mm}$$

Reinforcement design

Sketch of reinforcement



Be careful:

A) Reinforcement must be symmetric – „the wind can blow from both directions"

B) Use more reinforcement on the edges only if necessary

Double the horizontal reinforcement in lapping area

thank you for your attention

Recognitions

I thank **Assoc. Prof. Petr Bílý** for his original seminar presentation and other supporting materials from which this presentation was created.