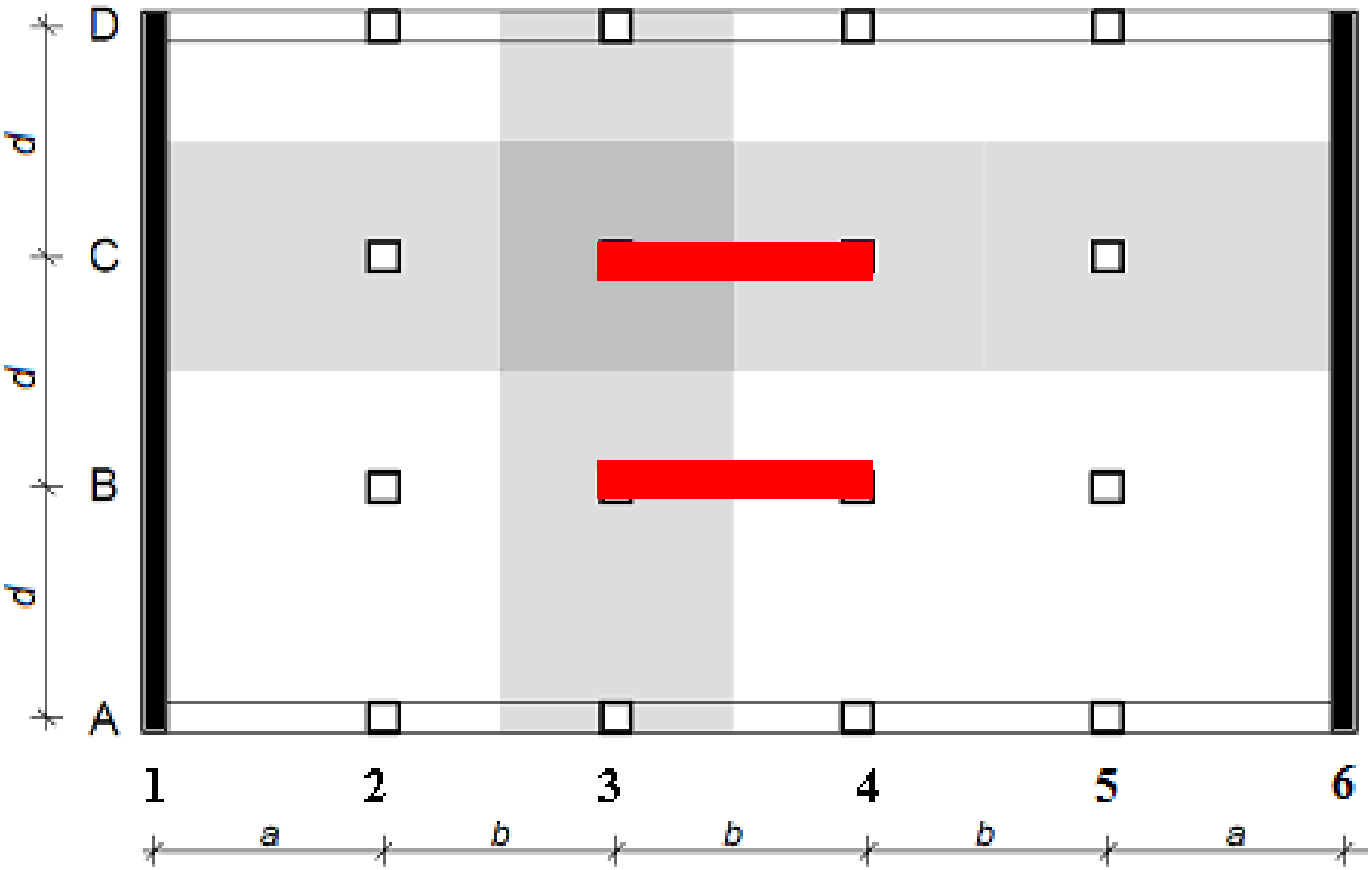
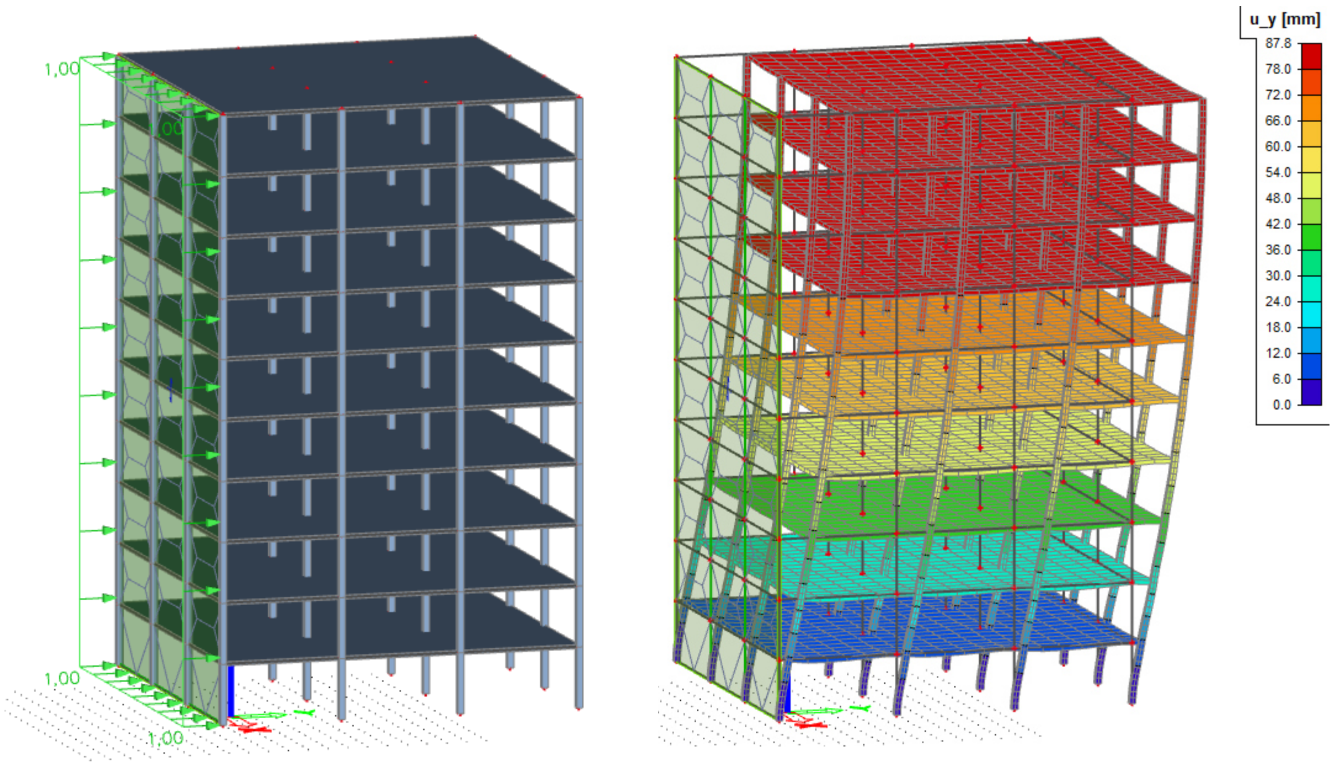
4th task: **RC stiffening walls in the structure from 3rd task in longitudinal direction**



Introduction

- Horizontal loads (wind, earthquake etc.) have to be transferred to the foundation
- Structure supported just by columns is flexible => high deflections => additional bracing needed in multi-storey buildings



Introduction

- Stiffness of an element strongly depends on moment of inertia of its cross section

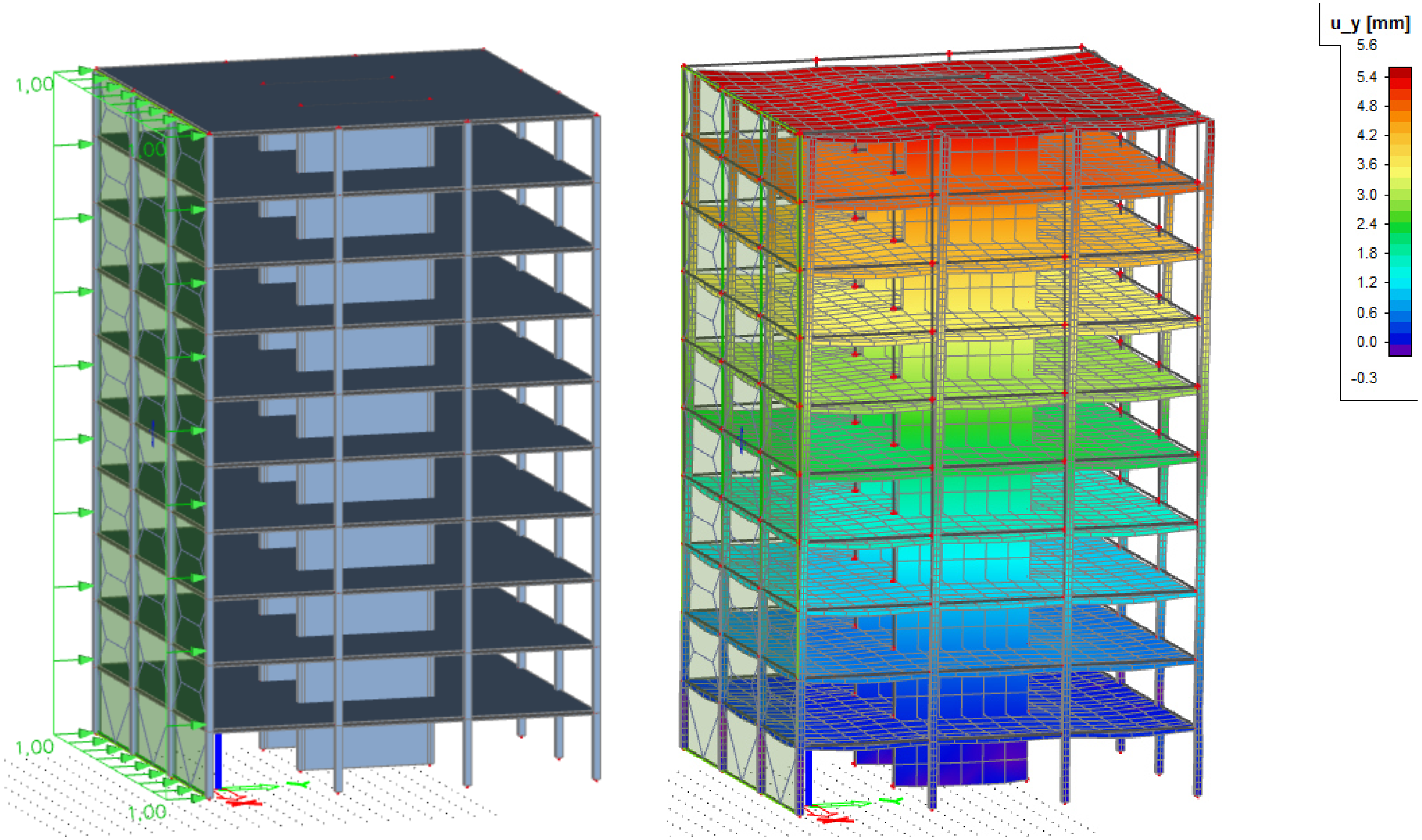
$$I = \frac{1}{12} b h^3$$

=> 300x2000 mm wall is **297times** stiffer than 300x300 mm column

=> We use **walls** or **cores** to increase horizontal stiffness of structures (to brace them)

Introduction

- The same structure with stiffening walls:



- Horizontal deflection 5.6 mm instead of 87.8 mm

Our goal will be to

- Calculate wind loads
- Calculate vertical loads
- Design geometry of stiffening walls (number, length, position)
- Design reinforcement of stiffening walls
- Draw a sketch of reinforcement

Load combinations

- We have to calculate stresses in the foot of a stiffening wall from three load combinations:
  - **C1**: Characteristic wind load + minimum vertical load
  - **C2**: Design wind load + maximum vertical load
  - **C3**: Design wind load + minimum vertical load
- We will use C1 for the design of geometry, C2 and C3 for the design of reinforcement
- In C1 and C2, we have to **avoid tension** in the foot of the wall
- In C3, tension is allowed

Wind loads

- **Characteristic** value of wind load w_k:

$$w_k = q_b \cdot c_e(z) \cdot c_{pe}$$

Basic dynamic pressure of the wind [N/m²]

Exposure factor, based on the type of terrain and height of the building, see later

External pressure coefficient, in our case 1.3 (pressure 0.8 in windward area D + suction 0.5 in leeward area E)

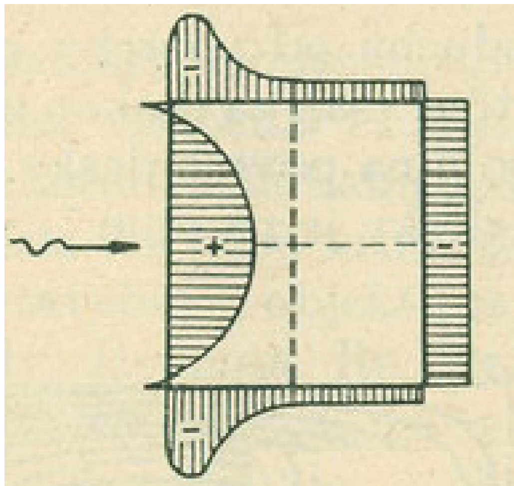
$$q_b = \frac{1}{2} \rho_v v_b^2$$

Density of the air, 1,25 kg/m³

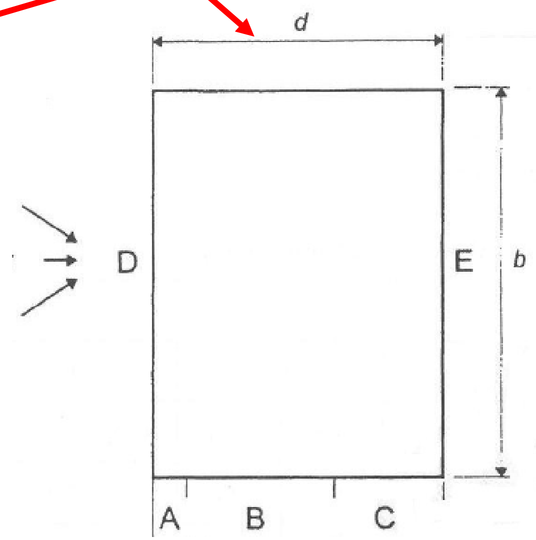
Basic wind velocity, see later

Example (be careful about the units):

$$q_b = \frac{1}{2} \cdot 1{,}25 \cdot 25^2 = 390\ \text{N/m}^2 = 0{,}39\ \text{kN/m}^2$$



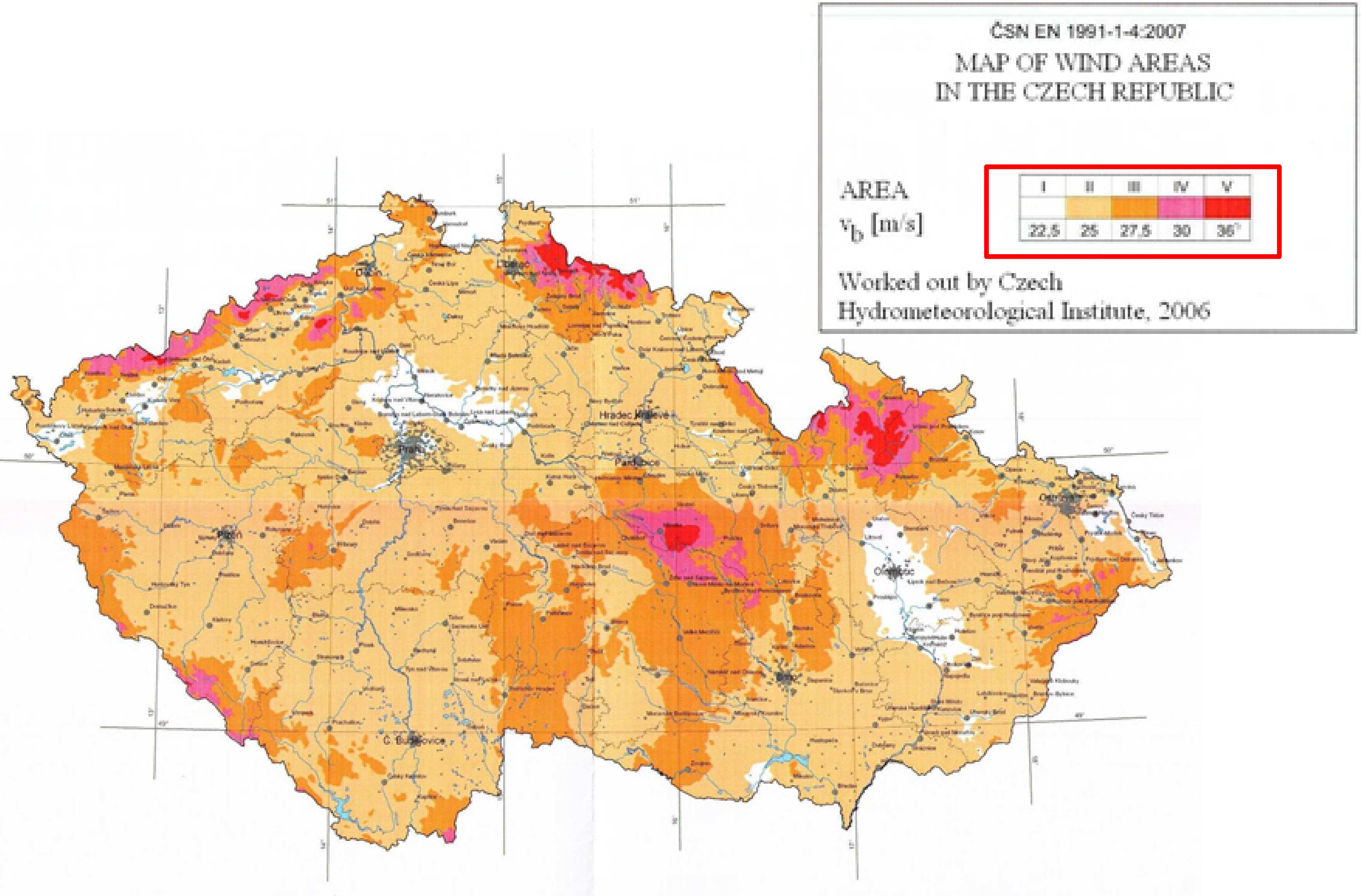
Real distribution of wind pressure



In Eurocode: Coefficients for areas A – E

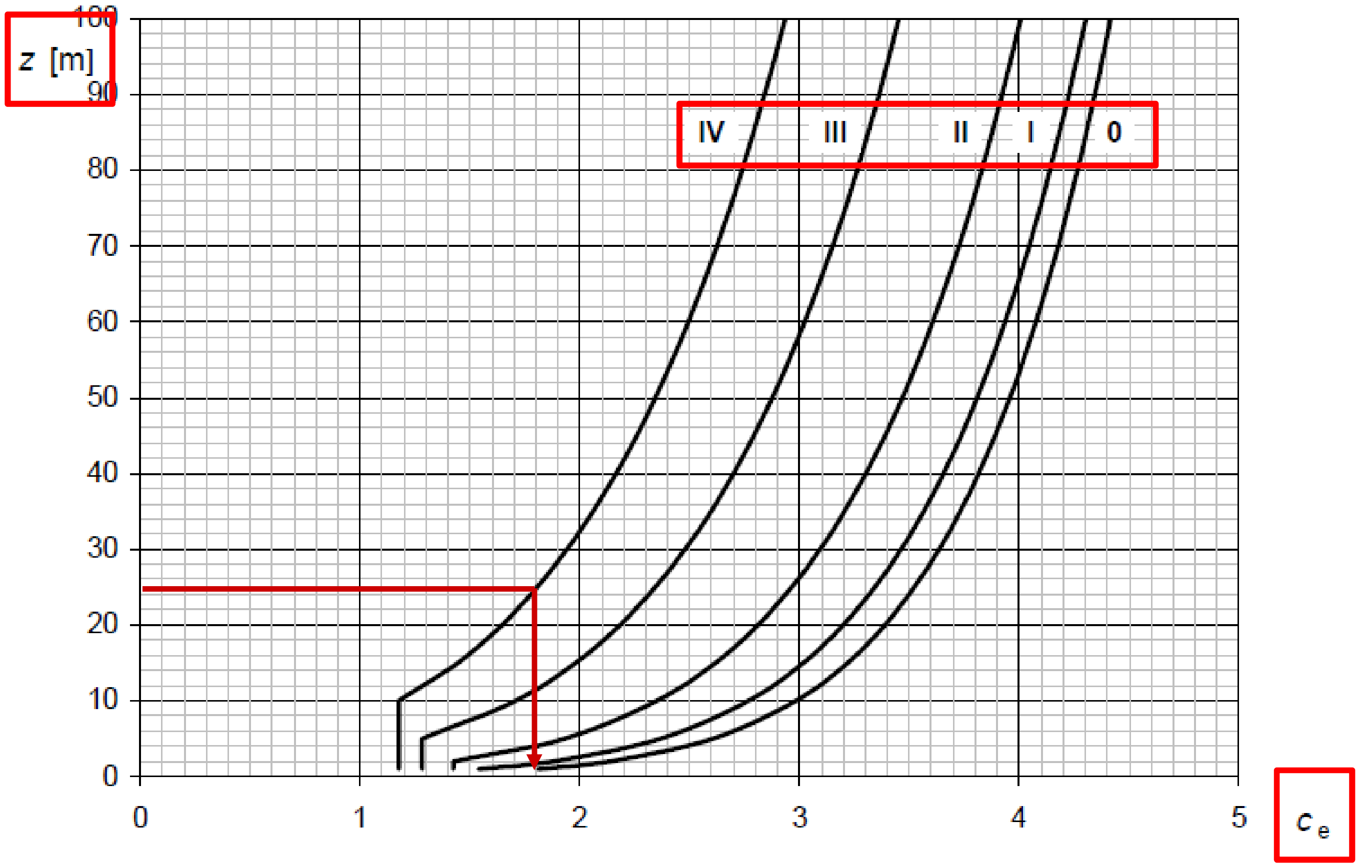
Wind loads

- Basic wind velocity – based on wind load area



Wind loads

- Exposure factor
  - Terrain category – III (suburb) or IV (dowtown)
  - z – in our case, the height of the building (use the number of floors and height of one floor from the 1st task)



Wind loads

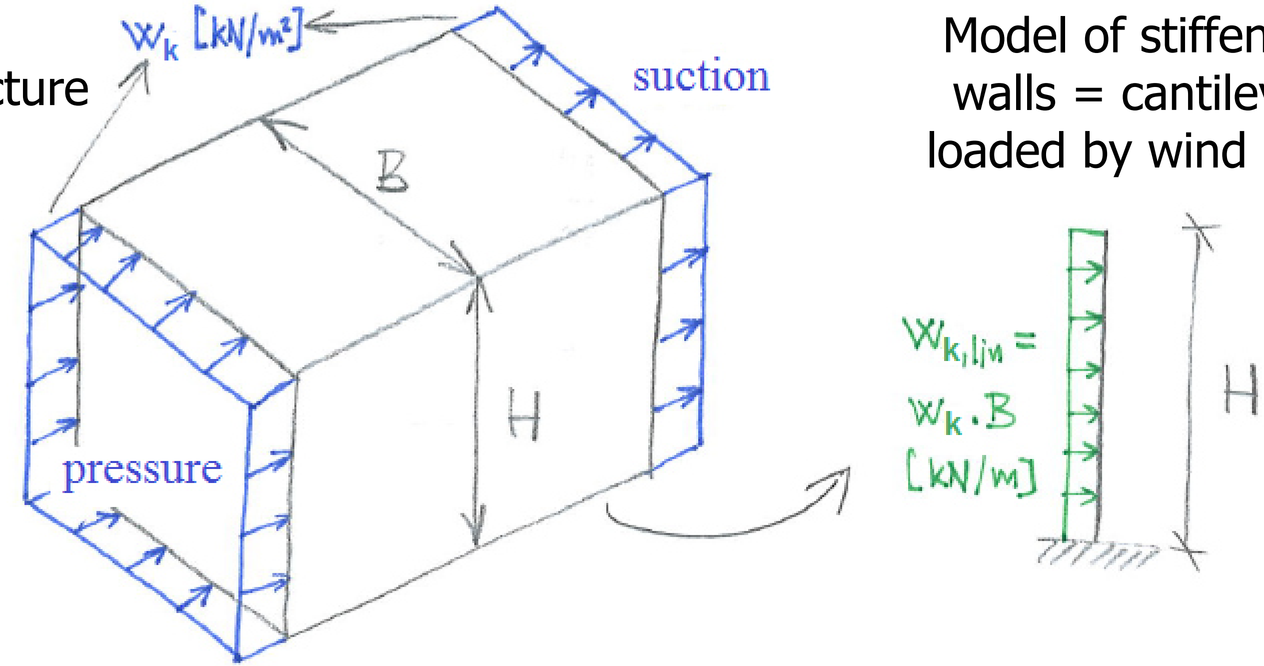
- Design value of wind load w_d in kN/m^2 (load per 1 m^2 of the facade):

Partial factor, 1.5

$$w_\mathrm{d} = \gamma_\mathrm{Q} \cdot w_\mathrm{k}$$

- For further calculations, we need **linear** load in kN/m – $w_{k,lin}$ and $w_{d,lin}$ (load per 1 m of stiffening walls)

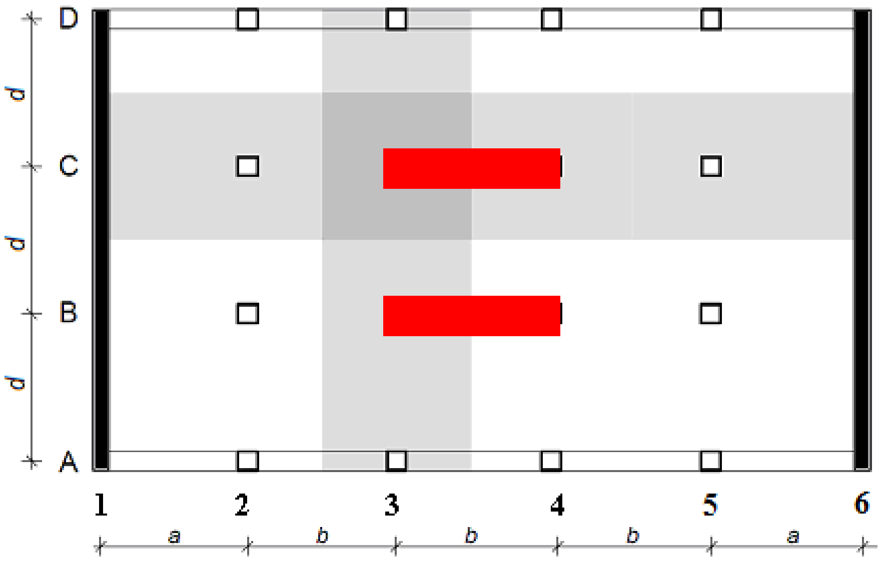
Our structure



Model of stiffening walls = cantilever loaded by wind load

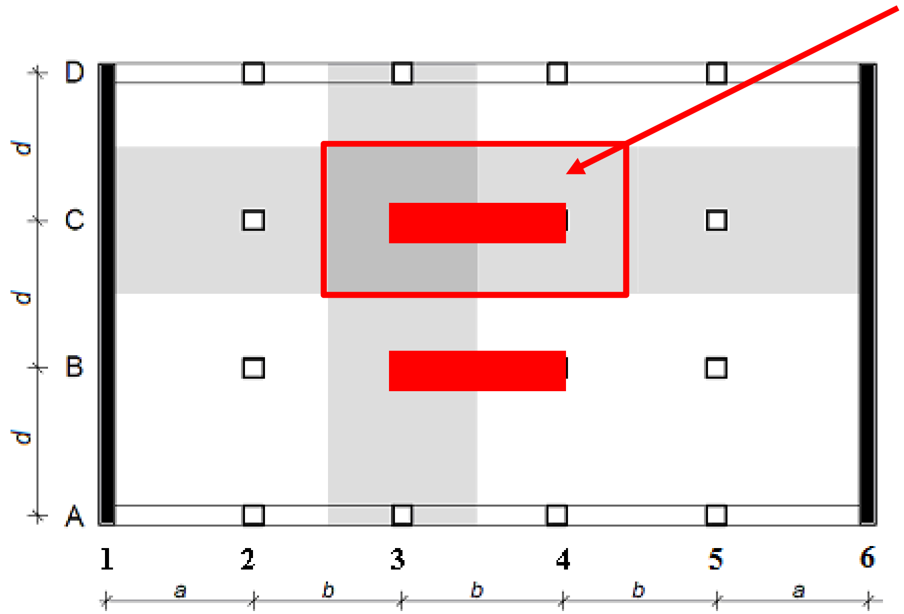
Vertical loads

- We have to estimate the geometry of the stiffening walls
- 1st estimate: 2 walls, length = 1 span, thickness = 200 to 250 mm



Vertical loads

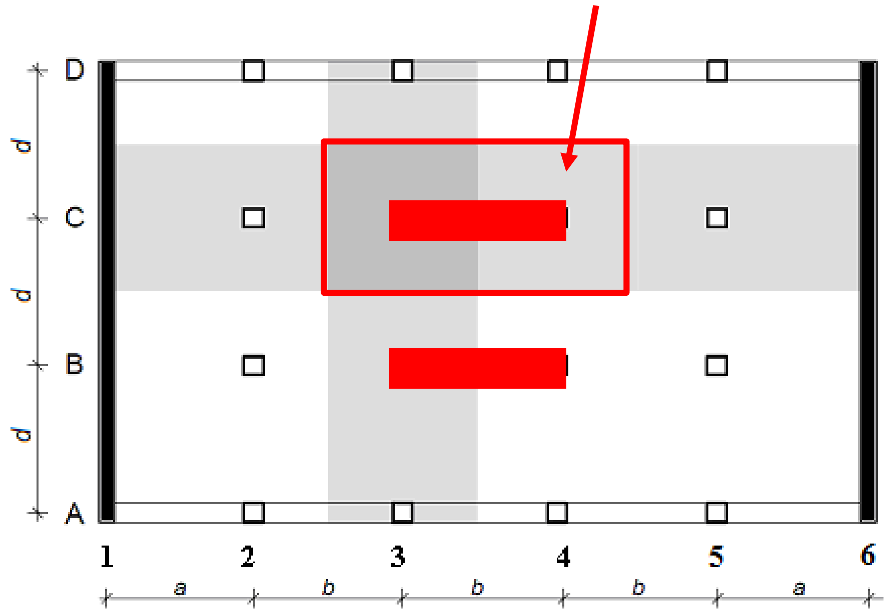
- **Minimum** vertical load: characteristic load from the self-weigth of RC structure in tributary area



- *n* floors => include the load from *n* slabs and *n* walls. Consider all the floors to be the same. Take slab loads from 3rd task.
- Calculate reaction R_{min} [kN]

Vertical loads

- **Maximum** vertical load: design load from the self-weigth of RC structure, other permanent load and live load in tributary area



- *n* floors => include the load from *n* slabs and *n* walls
- Calculate reaction R_{max} [kN]

Design of geometry of the walls

- We have estimated the geometry, now we will check it. We will use **comb. C1**.
- Total bending moment from the characteristic wind load in the foot of all stiffening walls is:

$$M_{\mathrm{w}} = \frac{1}{2} w_{\mathrm{k,lin}} H^2$$

- If all the walls are indentical, stress from the characteristic wind load in the foot one stiffening wall is:

$$\sigma_{\mathrm{w}} = \pm \frac{1}{m} \cdot \frac{M_{\mathrm{w}}}{W}$$

Number of stiffening walls, 2 in our case

Section modulus of one wall, $W = 1/6 * t * L^2$ (t – thickness of the wall, L – length of the wall)

Design of geometry of the walls

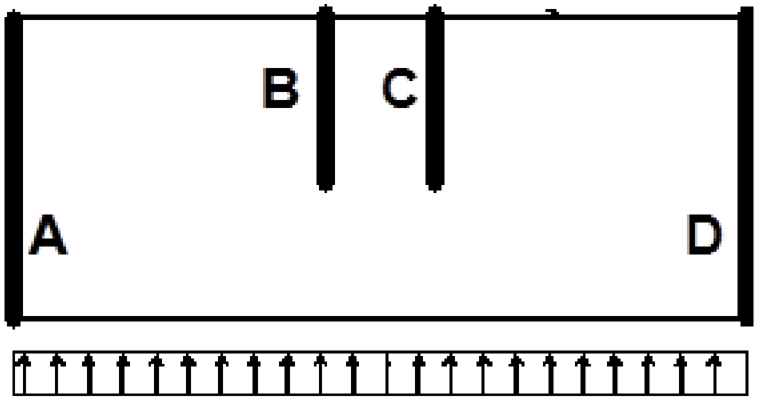
- If the walls are NOT identical, then the stress in wall A is:

Elastic modulus of concrete

Moment of inertia of wall A, $I_A = 1/12 * t * L^3$

$$\sigma_w = \pm \frac{EI_A}{\sum_i EI_i} \cdot \frac{M_w}{W_A}$$

Total bending stiffness of all the walls (E*I = bending stiffness)



- *Simply:* The moment is divided according to moments of inertia. Remember it for the exam!

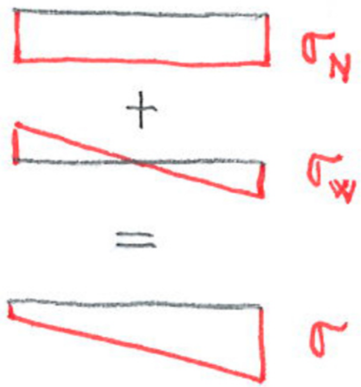
Design of geometry of the walls

- Stress from the minimum vertical load in the foot of one stiffening wall is:

$$\sigma_N = \frac{R_{min}}{A}$$

Cross-sectional area of one wall, A = t*L
(NOT the tributary area!!!)

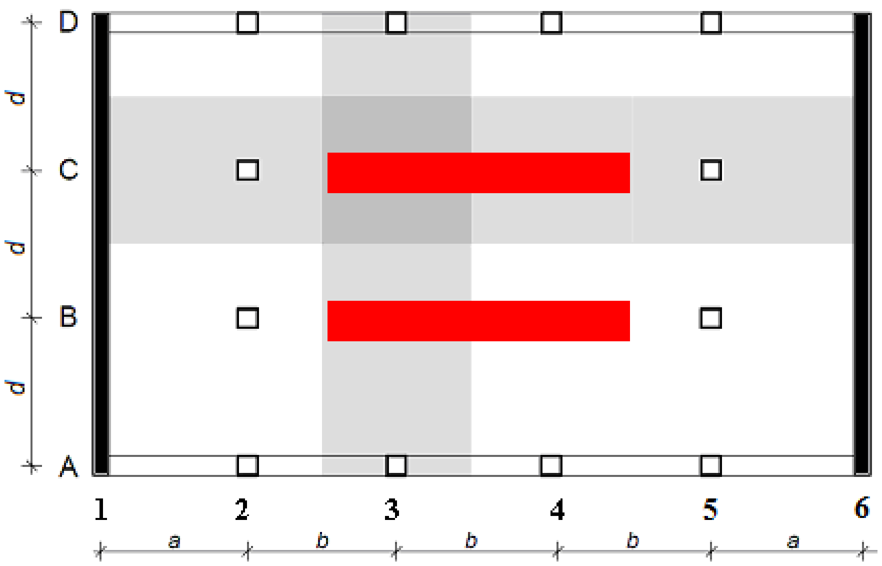
- Total stress in the foot of one stiffening wall:



- We have to **avoid tension** in C1. If you receive tension for your estimated geometry, you have to **change the design**.

Design of geometry of the walls

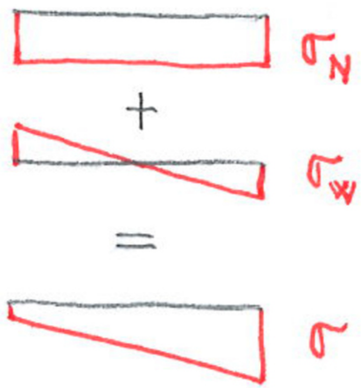
- You can:
  - Increase number of stiffening walls – not efficient (small vertical load in outer walls)
  - Increase thickness of stiffening walls – not efficient (stress from verical load decreased)
  - **Increase the length of stiffening walls**



Recalculate the stresses for new geometry

Design of reinforcement

- Calculate total stresses in the foot of stiffening walls in combinations **C2** and **C3**



- In C2, we have to avoid tension (should be OK if there was no tension in C1)
- In C3, tension is allowed if tensile reinforcement is provided

Basic reinforcement

- In 1st step, design the reinforcement in the whole wall just based on **detailing rules**
- **Vertical reinforcement:**

Required area of vertical reinforcement per 1 m of the wall (put one half to each surface)

$$0.002a_c \leq a_{s,v} \leq 0.04a_c$$

Cross-sectional area of 1 m of concrete wall

Spacing of rebars

$$s_v \leq \min(3t; 400\text{ mm})$$

- **Horizontal reinforcement:**

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

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

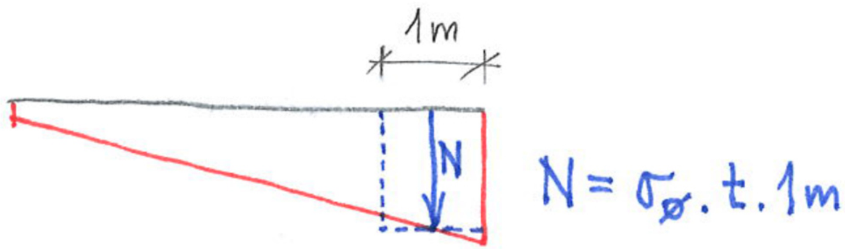
- Example (give **your** design in the same way):

Vertical: Ø6 per 250 mm on both surfaces ($a_{s,v}$ = 2*113 mm^2/m)

Horizontal: Ø6 per 400 mm on both surfaces ($a_{s,h}$ = 2*70 mm^2/m)

Compressed reinforcement

- Use the total stress from C2, take average stress in 1 m strip on the edge and calculate N:



- Required area of vertical reinforcement is:

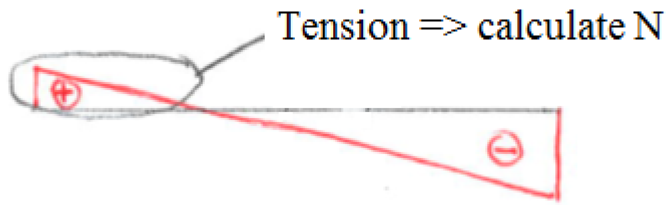
$$a_{s,req,v} = \frac{N - 0,8 a_c f_{cd}}{\sigma_s}$$

400 MPa

- If this area is more than the area according to detailing rules, use this vertical reinforcement on the edge of the wall and adjust the horizontal reinforcement

Tensile reinforcement

- If you received tension in C3, take average stress in 1 m on the edge and calculate N (as in the previous case)

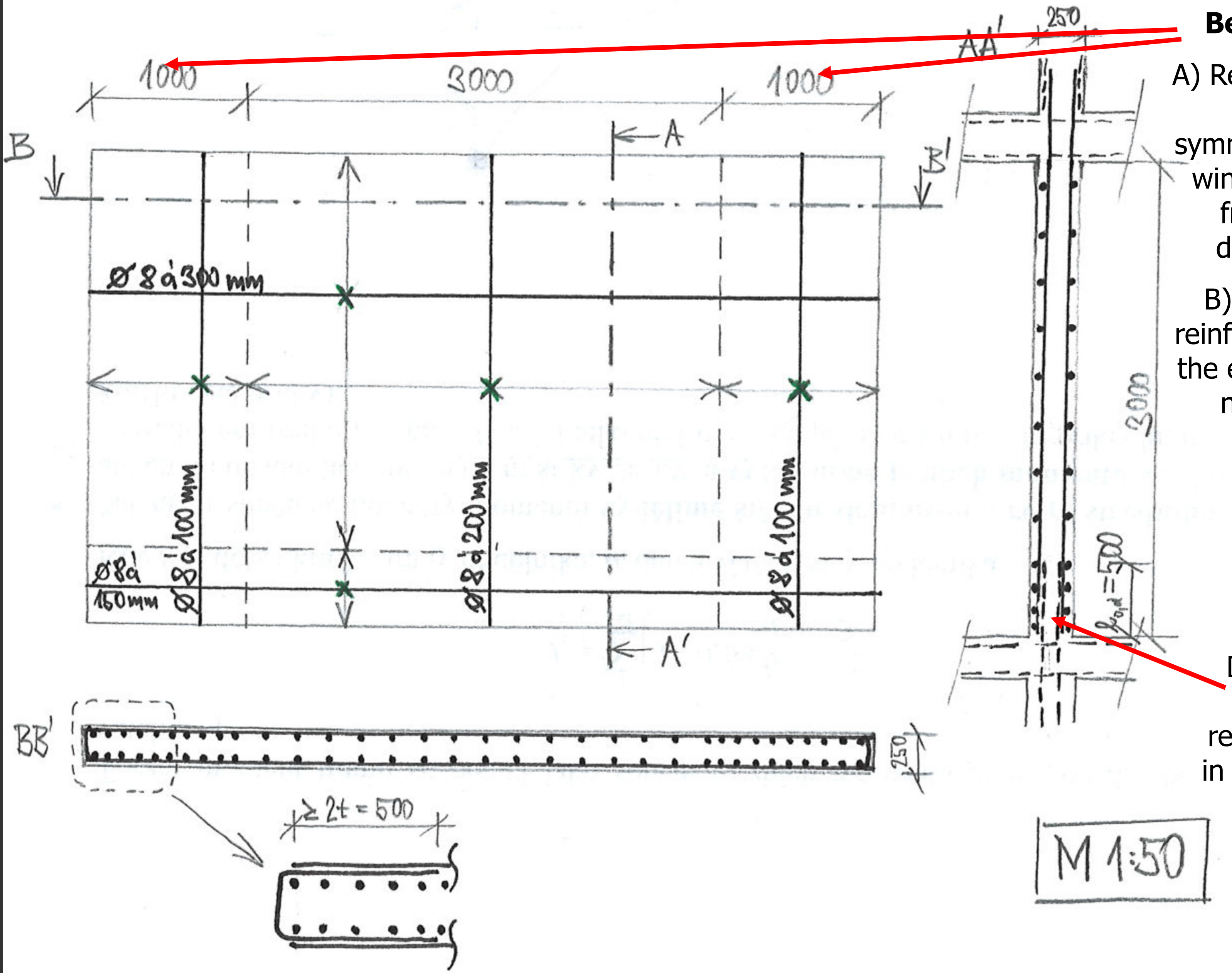


- Required area of vertical reinforcement is:

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

- If this area is more than the area according to detailing rules and more that the area of compressed reinforcement, use this vertical reinforcement on the edge of the wall and adjust the horizontal reinforcement

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