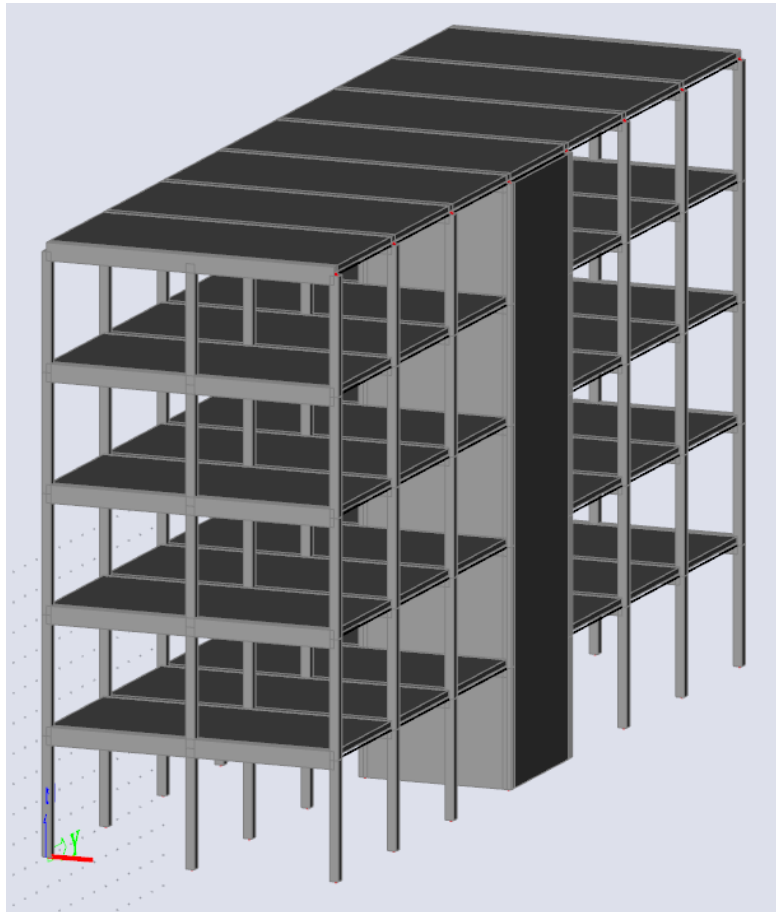*CM01 – Concrete and Masonry Structures 1*

# HW1 – Preliminary design of frame structure

# Task 1

# Task 1 – Frame structure

In Task 1, a frame structure will be designed.

# Task 1 – Assignment

Geometry: $R, a$ [m] – horizontal dimensions, $h$ [m] – floor height, $n$ – number of floors

Materials: Concrete – **concrete class**
Steel B 500 B ($f_{yk}$ = 500 MPa)

Loads:
Other permanent load of typical floor $\quad (g-g_0)_{floor.k}$ [kN/m²]
Other permanent load of the roof $\quad (g-g_0)_{roof.k}$ [kN/m²]
Live load of typical floor $\quad q_{floor.k}$ [kN/m²]
Live load of the roof $\quad q_{roof.k}$ = 0,75 kN/m²
Self-weight of the slab $\quad g_{0,k}$ (calculate from the slab depth)
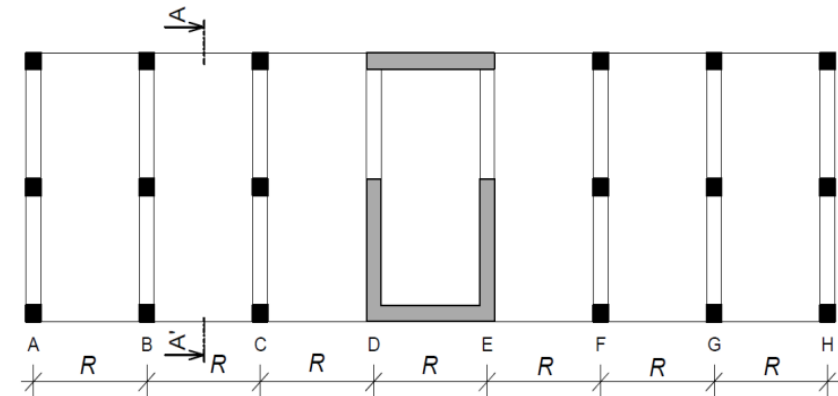
Another parameters:
$S$ – Exposure class related to environmental conditions
$Z$ – Working life of the structure

**Parameters in bold** are individual parameters, which you can find on the course website.
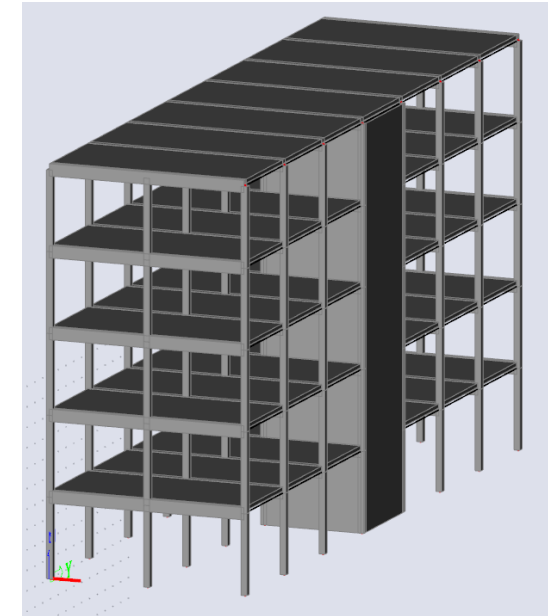


**Your individual parameters:**
https://docs.google.com/spreadsheets/d/1uQIuyyKEcG5jaZVLrsmm1ZRRNib_ow3MI
wgZSEDgnW8/

# Task 1 – Assignment goals

**Our goal** will be to:
- **Design the dimensions** of all elements.
- Do detailed **calculation of 2D frame** – calculation of bending moments, shear and normal forces using FEM software.
- **Design steel reinforcement** in the members.
- **Draw layout** of the reinforcement.

# Task 1 – part 1

# Task 1 – part 1

In this seminar, we will **design dimensions of all structural members** – i.e.:
- depth of the **slab**,
- cross-sectional dimensions of the **beam**,
- cross-sectional dimensions of the **column**.
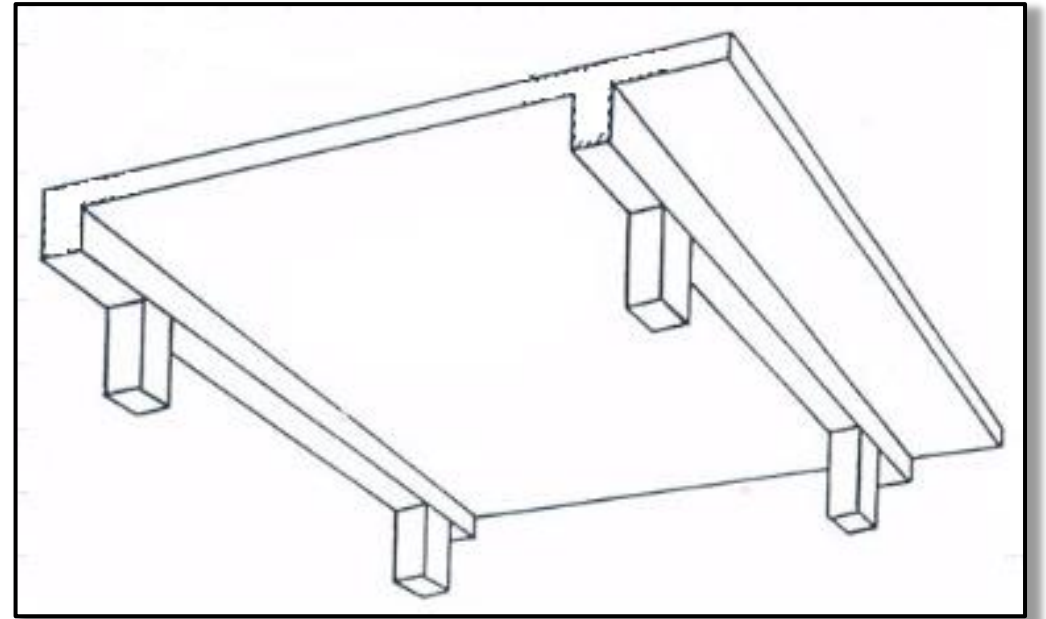


We will also do a **sketch of the structure**.

# Task 1 – part 1
## *Slab*
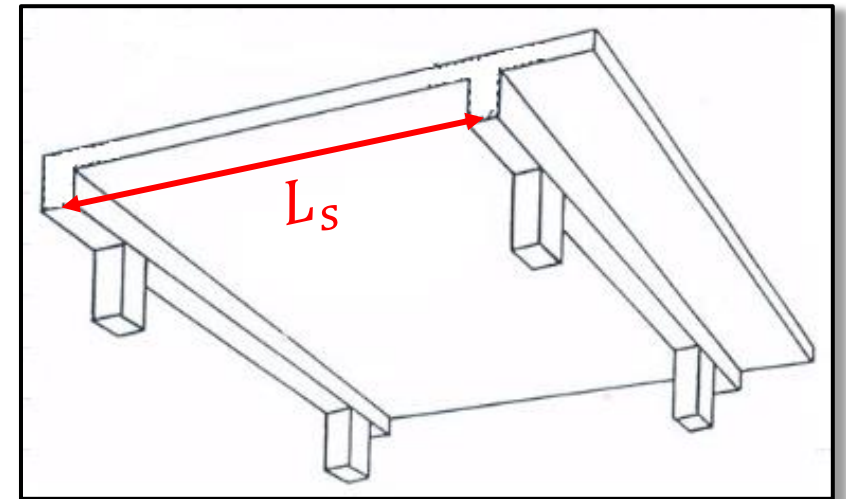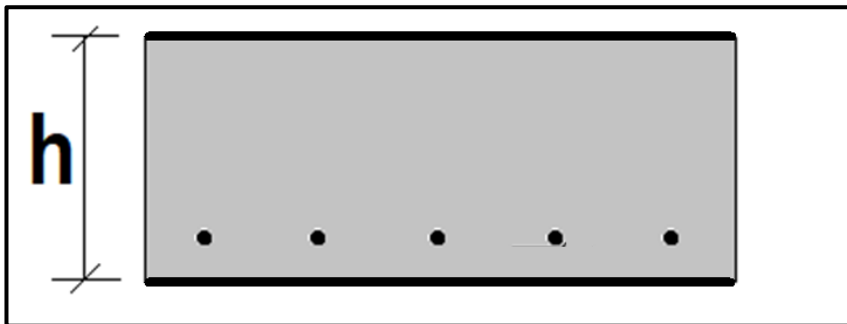
# Depth of a one-way slab

We will design the slab depth using an *empirical-estimation* equation:

$$h_s = \frac{L_s}{30} \text{ to } \frac{L_s}{25}.$$

The slab depth must be a multiple of 10 mm.

# Cover depth $c$

Next, we **need to calculate the *concrete cover*** for the slab reinforcement – the process of calculating the concrete cover is presented in [this presentation](#).
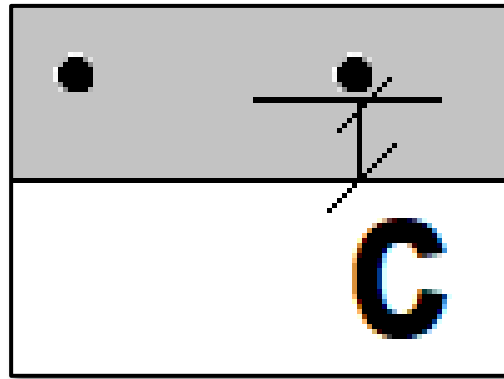
# Effective depth of slab

Next, we need to calculate the **_effective depth_** of the slab:

$$d_s = h_s - c - \frac{\varnothing}{2}.$$

Diameter of steel bars (assume 12 mm)

Cover depth



For more information about the effective depth, see this presentation.

# Assessment of the slab depth

Span-to-depth ratio should satisfy this condition (for deflection control):

$$\lambda = \frac{L_s}{d_s} \leq \kappa_{c1} \kappa_{c2} \kappa_{c3} \lambda_{d,tab}.$$
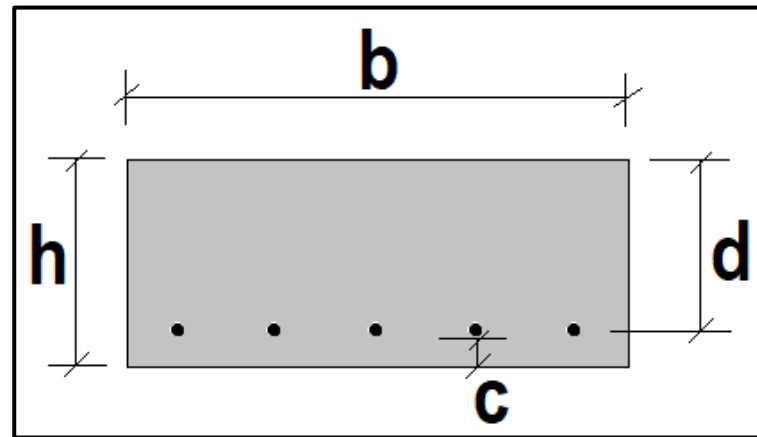
Value from the table. (For slabs assume the value for 0,5 % reinforcement ratio.)

Effect of shape
1.0

Effect of span
1.0

Effect of reinforcement
1.2

$\lambda_{d,tab}$ for outer span of the continuous beam/slab

| | Concrete class | | | | | | |
|---|---|---|---|---|---|---|---|
| $\rho$ | 12/15 | 16/20 | 20/25 | 25/30 | 30/37 | 40/50 | 50/60 |
| 0,5 % | 19,0 | 20,5 | 22,1 | 24,1 | 26 | 33,5 | 41,5 |
| 1,5 % | 15,9 | 16,4 | 16,9 | 17,6 | 18 | 19,5 | 20,8 |

For more information about the span-to-depth assessment, see this presentation.

# Assessment of slab depth

When assessing the span-to-depth ratio, if the condition is not satisfied for your designed slab depth, **do not try to fully satisfy this condition**\*! Only adjust the slab depth designed using the empirical equation with respect to the results of the condition – i.e.:

- If the condition is **not satisfied by a little** (up to 20%), it is **not necessary to change the slab depth**.
- If the condition is **not satisfied by a large amount (over 20%)**, it is advisable to **increase the slab depth by 10 to 50 mm** (depending on how much the conditions was not satisfied).

\* Fully satisfying the condition would lead to an uneconomical (too thick) slab.

# Task 1 – part 1
## *Beam*

# Cross-sectional dimension of the beam

Empirical estimation of beam height and width:

$$h_B = \frac{L_B}{15} \text{ to } \frac{L_B}{12},$$

$$b_B = \frac{h_B}{3} \text{ to } \frac{2h_B}{3},$$
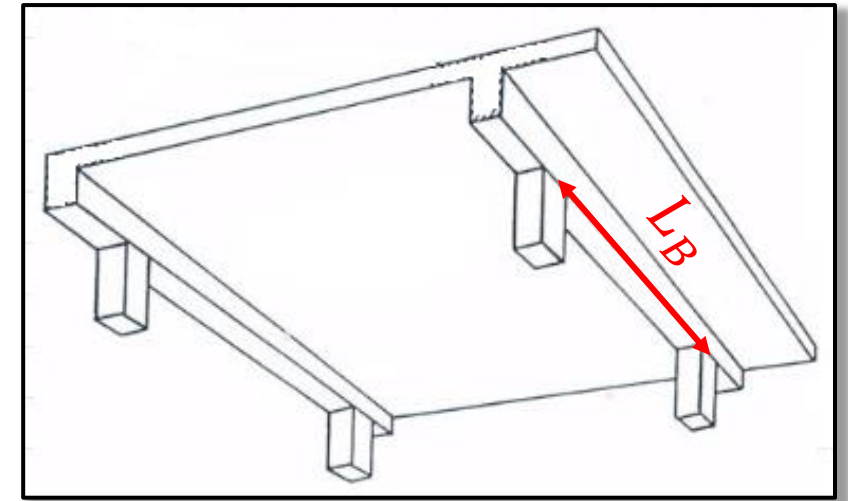


Also, the beam height must be at least 2.5x higher than the slab depth* (i.e., $h_B \geq 2.5\, h_s$).

The beam height and width must be **multiple of 50 mm**.

* To reach sufficient stiffness of the beam.

# Load

After designing the beam dimensions, calculate the **design value of the linear load acting on the beam**. The beam is loaded by:
- **self-weight** of the **beam**,
- **dead load** from the **slab**,
- **live load** from the **slab**.

# Preliminary check of the beam

To avoid troubles during detailed assessment later (e.g., the beam is too thin and cannot be reinforced enough), a preliminary check must be done.

First, we **estimate theoretical maximum values of internal forces** in the beam.

$$M_{\mathrm{Ed,max}} = \frac{1}{8} f_B l_B^2 \qquad V_{\mathrm{Ed,max}} = \frac{5}{8} f_B l_B$$

Load per 1 m of the beam in [kN/m]
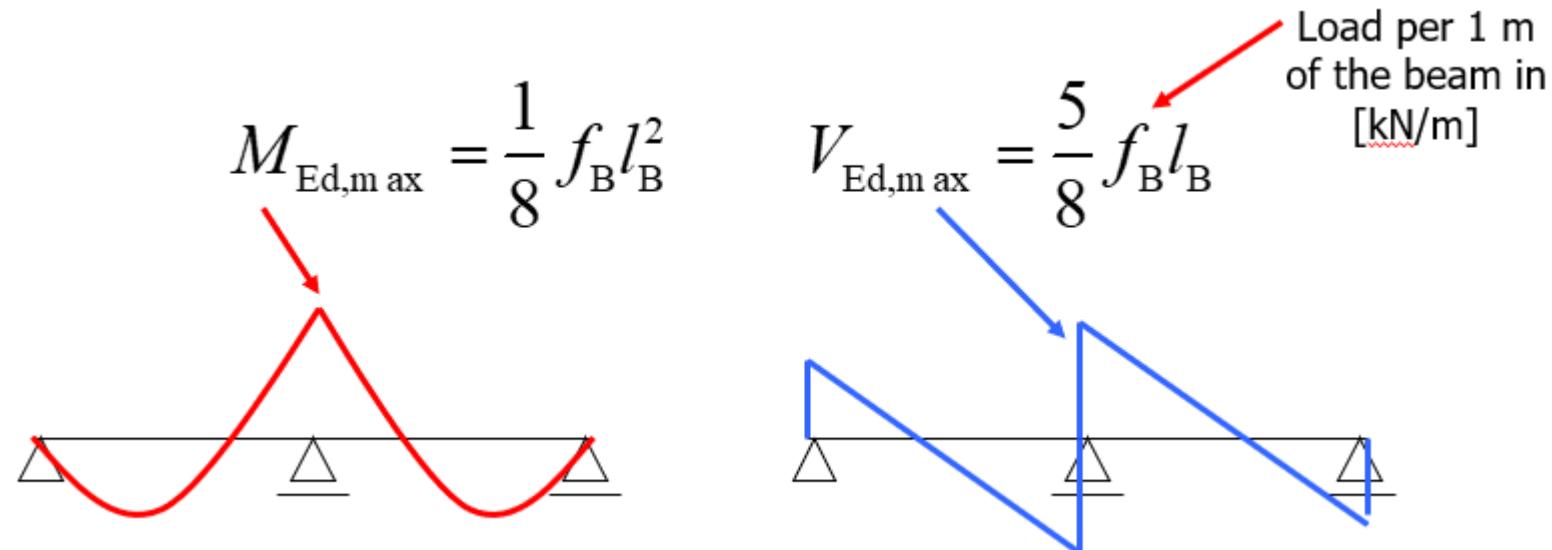
# Preliminary check of bending

For the check of bending, we calculate *relative bending moment* and find corresponding *relative height of compressed part of the beam* in a table.

$$\mu = \frac{M_{Ed,max}}{b_B d_B^2 f_{cd}} \xrightarrow{\text{table (see web)}} \xi$$

Relative height of compressed part of the beam (x/d)

Effective depth of the beam (assume 16 to 22 mm diameter of rebars)

Relative bending moment (a factor expressing to what extent the beam is utilized by the applied bending moment)

If $\xi \in \langle 0.15; 0.4 \rangle$, the design is ok.
If $\xi < 0.15$, you should decrease $h_B$ and/or $b_B$.
**If $\xi > 0.4$, you must increase $h_B$ and/or $b_B$.**

| μ | ω | ξ | ζ |
|---|---|---|---|
| 0,010 | 0,0101 | 0,013 | 0,995 |
| 0,020 | 0,0202 | 0,025 | 0,990 |
| 0,030 | 0,0305 | 0,038 | 0,985 |
| 0,040 | 0,0408 | 0,051 | 0,980 |
| 0,050 | 0,051 | 0,064 | 0,974 |
| 0,060 | 0,0619 | 0,077 | 0,969 |
| 0,070 | 0,0726 | 0,091 | 0,964 |
| 0,080 | 0,0835 | 0,104 | 0,958 |
| 0,090 | 0,0945 | 0,118 | 0,953 |
| 0,100 | 0,1056 | 0,132 | 0,947 |

# Preliminary check of reinforcement ratio

Reinforcement ratio must satisfy the condition:

$$\rho_{s,rqd} = \frac{A_{s,rqd}}{A_c} = \frac{\dfrac{M_{Ed,max}}{\zeta d_B f_{yd}}}{b_B d_B}$$

Relative value of lever arm of internal forces (z/d) – see table.

Required reinforcement ratio

**If $\rho_{s,rqd} > 0.04$, you must increase $h_B$ and/or $b_B$.**

# Preliminary check of load-bearing capacity in shear

Maximal shear force must satisfy the condition of load-bearing capacity of "compression diagonals":

$$V_{\mathrm{Rd,max}} = \nu \cdot f_{\mathrm{cd}} \cdot b_{\mathrm{B}} \cdot \zeta \cdot d_{\mathrm{B}} \cdot \frac{\cot \theta}{1 + \cot^2 \theta} \geq V_{\mathrm{Ed,max}}$$



Load-bearing capacity of compression diagonals in shear

Coefficient expressing effect of shear cracks and transversal deformations

Cotangent of angle of shear cracks (assume cot θ = 1,5)

$$\nu = 0,6 \left( 1 - \frac{f_{\mathrm{ck}}}{250} \right)$$
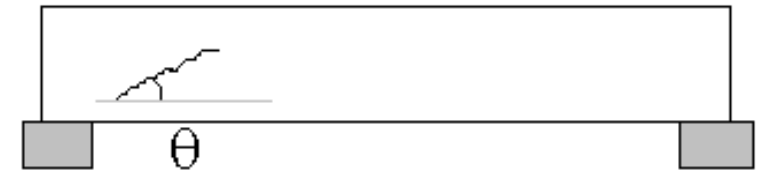
**If the condition is not satisfied, you must increase $h_B$ and/or $b_B$.**

# Preliminary check of deflection (span/depth ratio)

For the check of span/depth ratio, use the **same calculation procedure as for slab with the following differences**.

- Select a **row in the table for** $\lambda_{d,tab}$ (outer span) **according to value of** $\rho_{s,rqd}$ calculated above.
- If the **condition is not satisfied, you must increase** $h_B$ to satisfy it.



## Assessment of the slab depth

Span/depth ratio must satisfy this condition (for deflection control):

$$\lambda = \frac{L_s}{d_s} \leq \kappa_{c1}\kappa_{c2}\kappa_{c3}\lambda_{d,tab}.$$

Value from the table. (For slabs assume the value for 0,5 % reinforcement ratio.)

Effect of shape 1.0   Effect of span 1.0   Effect of reinforcement 1.2

$\lambda_{d,tab}$ for outer span of the continuous beam/slab

| $\rho$ | Concrete class | | | | | | |
|---|---|---|---|---|---|---|---|
| | 12/15 | 16/20 | 20/25 | 25/30 | 30/37 | 40/50 | 50/60 |
| 0,5 % | 19,0 | 20,5 | 22,1 | 24,1 | 26 | 33,5 | 41,5 |
| 1,5 % | 15,9 | 16,4 | 16,9 | 17,6 | 18 | 19,5 | 20,8 |

If the condition is satisfied, detailed calculation of deflections may be omitted in later detailed assessment.

# Task 1 – part 1
*Column*

# Cross-sectional dimension of the column

When designing column, the design load in its foot $N_{Ed}$ must first be calculated.

The design load must satisfy the centric-load condition

$$N_{Rd} = 0.8A_c f_{cd} + A_s \sigma_s \geq N_{Ed}$$

Area of the cross-section ($A_c = b_c h_c$)

Reinforcement area (assume as 0.02 $A_c$)

Reinforcement stress (assume as 400 MPa)

from which, the condition for column cross-sectional area can be derived

$$A_c \geq \frac{N_{Ed}}{0.8 f_{cd} + 0.02\sigma_s}$$
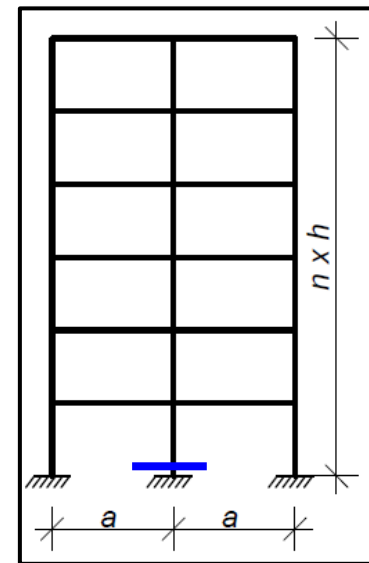
**Design the column cross-section (width and height) in such a way that the condition above is satisfied.** The dimensions must be **multiples of 50 mm**.

# Task 1 – part 1

*Sketch of the structure*

# Sketch of the structure

After designing the dimensions of all the elements, we have to make a **sketch of the structure**. The sketch must include:
* **plan view** of the structure (at least 2 fields in each direction),
* the **edges** of columns, beams and slabs,
* plan **dimensions**,
* **cut of the structure** perpendicular to the beams.

**The sketch must show all designed dimensions of the elements.**

# Sketch of the structure



This is an example drawing from a different structure!
**Your drawing will be slightly different!**

After designi[...] make a **sketch of the structure**[...]
- **plan view** o[...]
- the **edges** o[...]
- plan **dimen**[...]
- **cut of the s**[...]

**The sketch m**[...]

# Task 1 – part 1

*Examples of calculations used in the HW*

# Slab depth

Empirical estimation of slab depth for a slab with 6 m span:

$$h_s = \frac{L_s}{30} \text{ to } \frac{L_s}{25} = \frac{6000}{30} \text{ to } \frac{6000}{25} = 200 \text{ mm to } 240 \text{ mm} \rightarrow 200 \text{ mm}$$

Deflection control:

$$\frac{l}{d} = \frac{6000}{165} = 36.4 < 1.0 \cdot 1.0 \cdot 1.2 \cdot 33.5 = 40.2$$

Deflection control is satisfied –> $h_s$ can be decreased.

Final design: $h_s = 190 \text{ mm}$

Effective slab depth:

$$d = 190 - 20 - \frac{10}{2} = 165 \text{ mm}$$

# Slab loads

Loads on the floor slab for other permanent loads $0.5\,\mathrm{kN/m^2}$ and variable load $3.0\,\mathrm{kN/m^2}$.

| Slab load | | | | | |
|---|---|---|---|---|---|
| | | | charakteristic $\mathrm{kN/m^2}$ | $\gamma_F$ | design $\mathrm{kN/m^2}$ |
| **Permanent** | | | | | |
| | other permanent load | | 0,50 | | |
| | self weight | $0{,}19\mathrm{m}$ . $25\mathrm{kN/m^3}$ | 4,75 | | |
| | Total | | $g_k =\ 5{,}25$ | 1,35 | $g_d =\ 7{,}09$ |
| **Variable** | | | | | |
| | (kategorie C1) | | $q_k =\ 3{,}00$ | 1,5 | $q_d\ =\ 4{,}50$ |
| **Total** | | | $(g{+}q)_k =\ 8{,}25$ | | $(g{+}q)_d = 11{,}59$ |

# Roof loads

Loads on the roof slab for other permanent loads $2\,\text{kN/m}^2$ and inaccessible roof $(0.75\,\text{kN/m}^2)$.

| Roof load | | | | | |
|---|---|---|---|---|---|
| | | charakteristic | | $\gamma_F$ | design |
| | | kN/m$^2$ | | | kN/m$^2$ |
| **Permanent** | | | | | |
| | other permanent load | 2,00 | | | |
| | self weight | 0,19m . 25kN/m$^3$ | 4,75 | | |
| | Total | | $g_k =$ 6,75 | 1,35 | $g_d =$ 9,11 |
| **Variable** | | | | | |
| | (kategorie C1) | | $q_k =$ 0,75 | 1,5 | $q_d =$ 1,125 |
| **Total** | | | $(g+q)_k =$ 7,5 | | $(g+q)_d =$ 10,24 |

# Beam dimensions

Empirical design of beam height for a beam with 7 m span:

$$h_B = \frac{L_B}{15} \text{ to } \frac{L_B}{12} = \frac{7000}{15} \text{ to } \frac{7000}{12} = 467 \text{ mm to } 538 \text{ mm} \rightarrow h_B = 500 \text{ mm.}$$

Empirical design of beam width for a beam with 500 mm height:

$$b_B = \frac{h_B}{3} \text{ to } \frac{2h_B}{3} = \frac{500}{3} \text{ to } \frac{1000}{3} = 167 \text{ mm to } 333 \text{ mm} \rightarrow h_B = 250 \text{ mm.}$$

# Tributing area or a column

When determining the point load acting on column from a single floor, we must assign all of the loads inside the tributing area to the column.
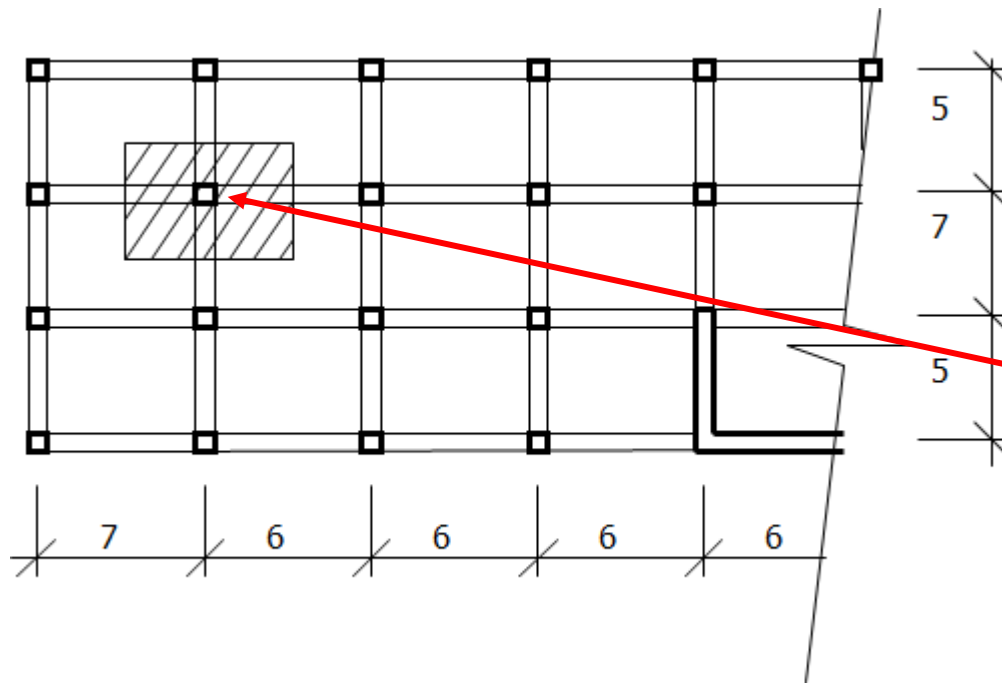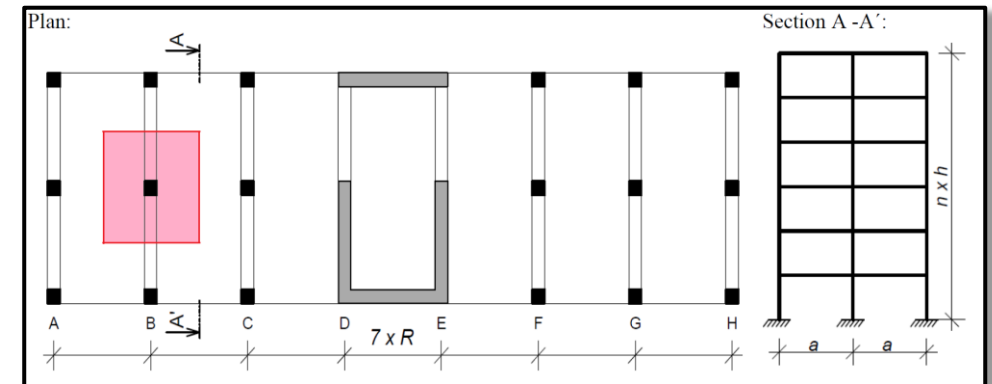


tributing area:

$$A = \left(\frac{7}{2} + \frac{6}{2}\right) \times \left(\frac{7}{2} + \frac{5}{2}\right) = 39 \text{ m}^2$$

# Loading of a column

Point load for the internal column (column dimensions estimated as 300 mm × 300 mm and column height is 3.5 m) in a 6 floor structure.



| Point load of a column | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Load type | Load name | $f_{a,d}$ | tributing area | $f_{lin,d}$ | tributing length | $F_{1,d}$ | number of members | $F_d$ |
| - | - | kN/m² | m² | kN/m | m | kN | pcs | kN |
| AREA LOADS ($f_a$) | floor slab | 11.59 | 39 | - | - | 452.0 | 5 | 2260.1 |
| | roof slab | 10.24 | 39 | - | - | 399.4 | 1 | 399.4 |
| LINEAR LOADS ($f_{lin}$) | beam self weight | - | - | $(0.5{-}0.19){\cdot}0.25{\cdot}25{\cdot}1.35 = 2.62$ | 7 | 18.34 | 6 | 110.0 |
| | column self weight | - | - | $0.3{\cdot}0.3{\cdot}25{\cdot}1.35 = 3.04$ | 3.5 | 10.6 | 6 | 63.8 |
| SUM | | | | | | | $F_d =$ | 2833.3 |

33

# Design of column dimensions

From the centric load condition

$$N_{Ed} = 0.8 A_c \cdot f_{cd} + A_s \sigma_s$$

$$2.833 \text{ MN} = 0.8 A_c \cdot 20 \text{ MPa} + (0.02 A_c) \cdot 400 \text{ MPa}$$

minimal cross-sectional area is derived

$$2.833 \text{ MN} = 24 A_c$$
$$A_{c,min} = 0.118 \text{ m}^2$$

$\longrightarrow$ column **350 mm $\times$ 350 mm** ($A_c = 122\,500 \text{ mm}^2$).

# Next week

# Next week

Next week we will focus on detailed **calculation of internal forces using FEM software**.

Are you able to use any Finite Element Analysis software?

If not, **apply for student license** for the **SCIA Engineer software**.
When applying, **use your school student email** (e.g., "name.surname@estp.fr").

thank you for your attention