FAKULTA
STAVEBNÍ
ČVUT V PRAZE

CM01 – Concrete and Masonry Structures 1

HW1 – Preliminary design of frame structure

7bratrstvo

beton4life

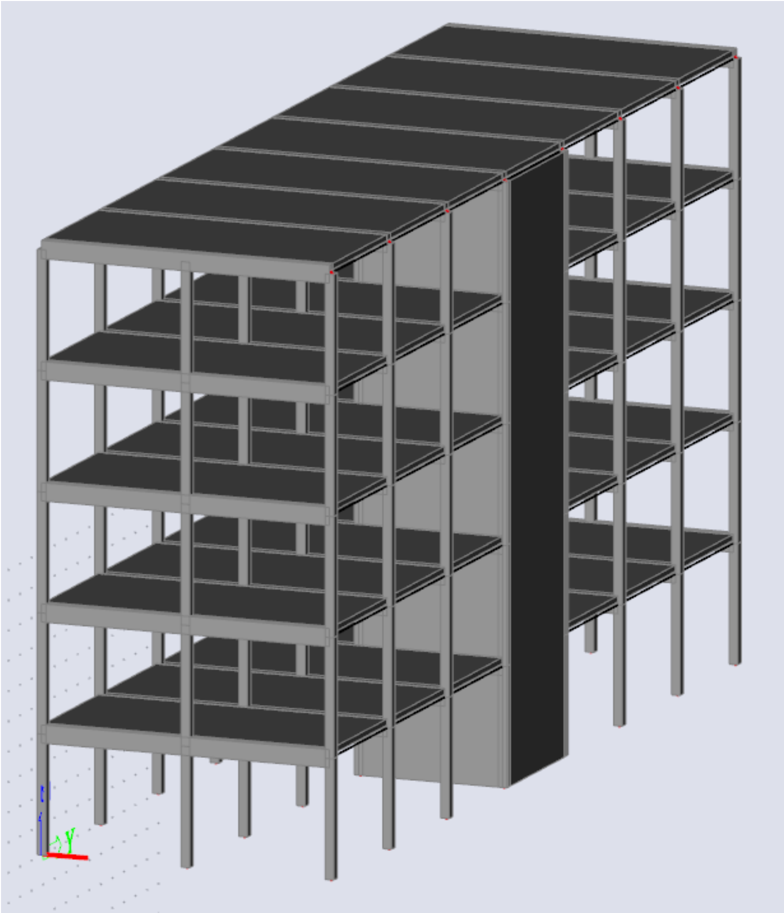
Author: Jakub Holan

Last update: 23.09.2023 21:52

Task 1

Task 1 – Frame structure

In Task 1, a frame structure will be designed.



Task 1 – Assignment

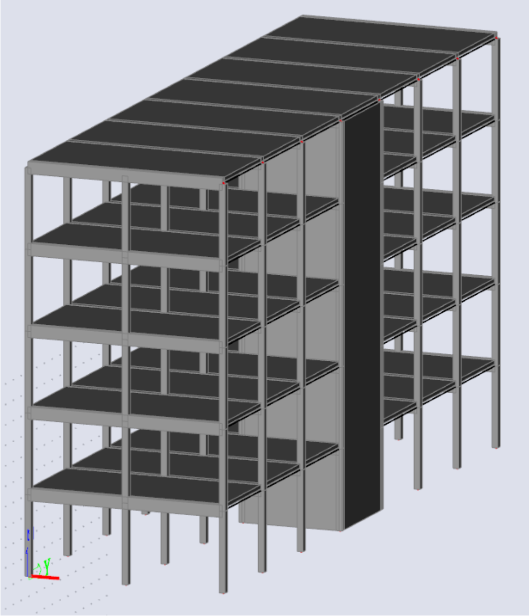
Geometry: ***R***, ***a*** [m] – horizontal dimensions, ***h*** [m] – floor height, ***n*** – number of floors

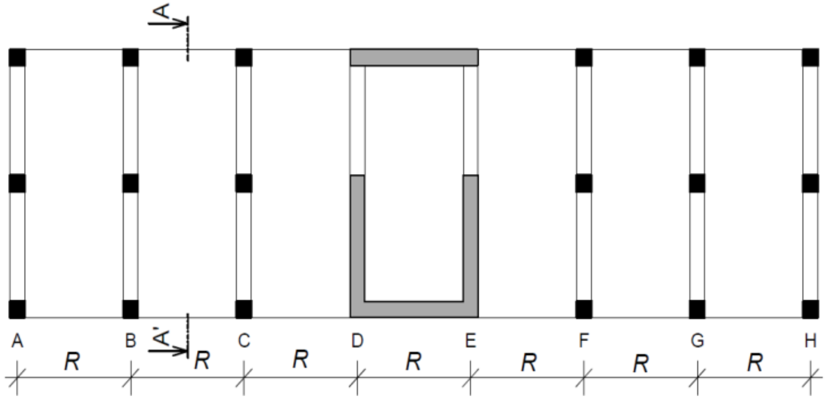
Materials: Concrete – **concrete class**
Steel B 500 B (f_{yk} = 500 MPa)

Loads:		
	Other permanent load of typical floor	$(\boldsymbol{g-g_0})_{\mathbf{floor,k}}$ [kN/m^2]
	Other permanent load of the roof	$(\boldsymbol{g-g_0})_{\mathbf{roof,k}}$ [kN/m^2]
	Live load of typical floor	$\boldsymbol{q}_{\mathbf{floor,k}}$ [kN/m^2]
	Live load of the roof	$q_{roof,k}$ = 0,75 kN/m^2
	Self-weight of the slab	$g_{0,k}$ (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_ow3MIwgZSEDgnW8/

Task 1 – Assignment goals

<u>Our goal</u> will be to:

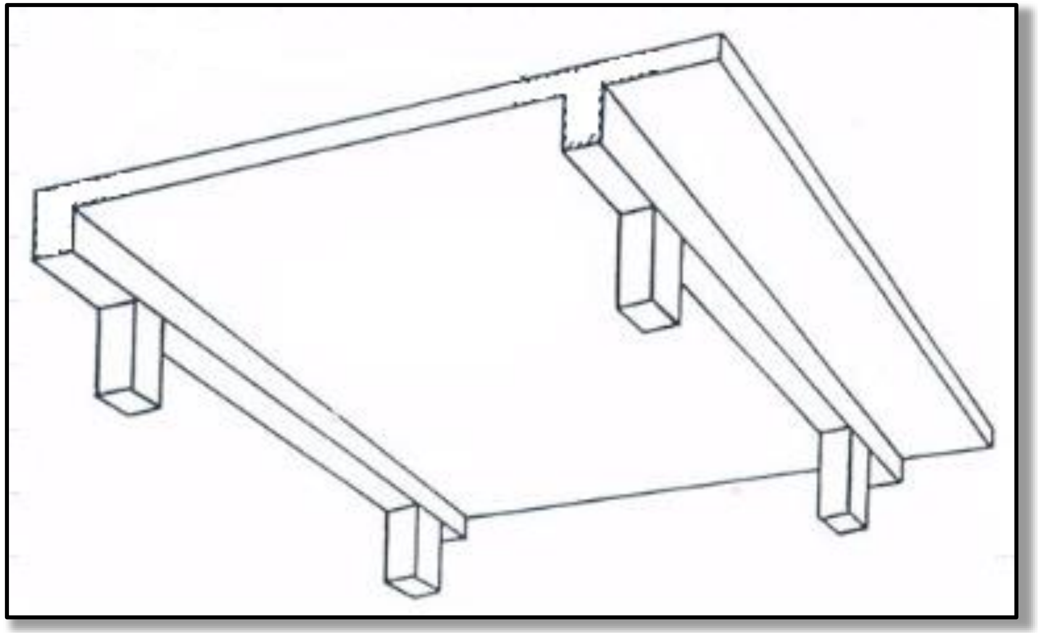
- **Design the dimensions** of all elements.
- Do detailed **calculation of 2D frame** – calculation of bending moments, shear and normal forces using FEM software.
- **Design steel reinforcement** in the members.
- **Draw layout** of the reinforcement.

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

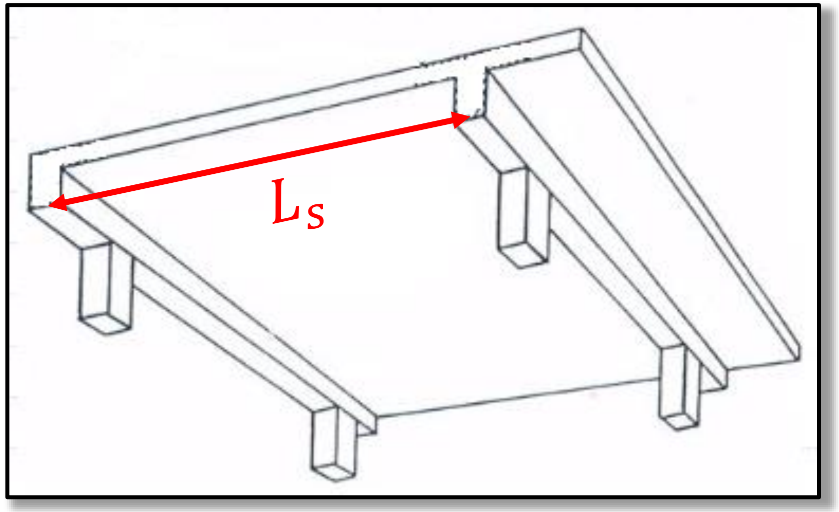
Slab

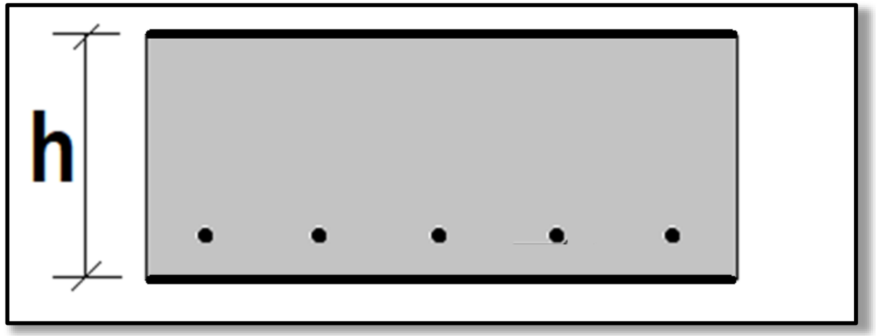
Depth of a one-way slab

Empirical estimation of slab depth:

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

The slab depth must be multiple of 10 mm.





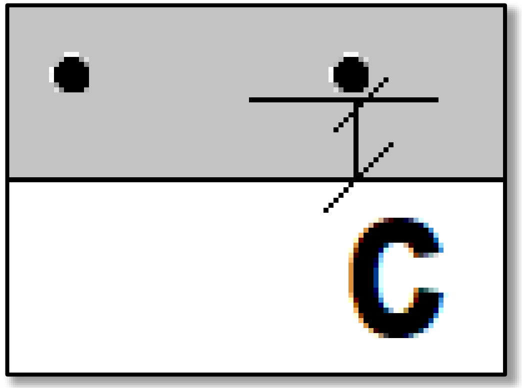
Cover depth c

Concrete cover for reinforcement is calculated using the equation:

$$\boxed{c \geq c_{min} + \Delta c_{dev},}$$

where

$$c_{min} = \max(c_{min,b}, c_{min,dur}, 10\text{ mm}),$$
$$\Delta c_{dev} = 10\text{ mm}.$$

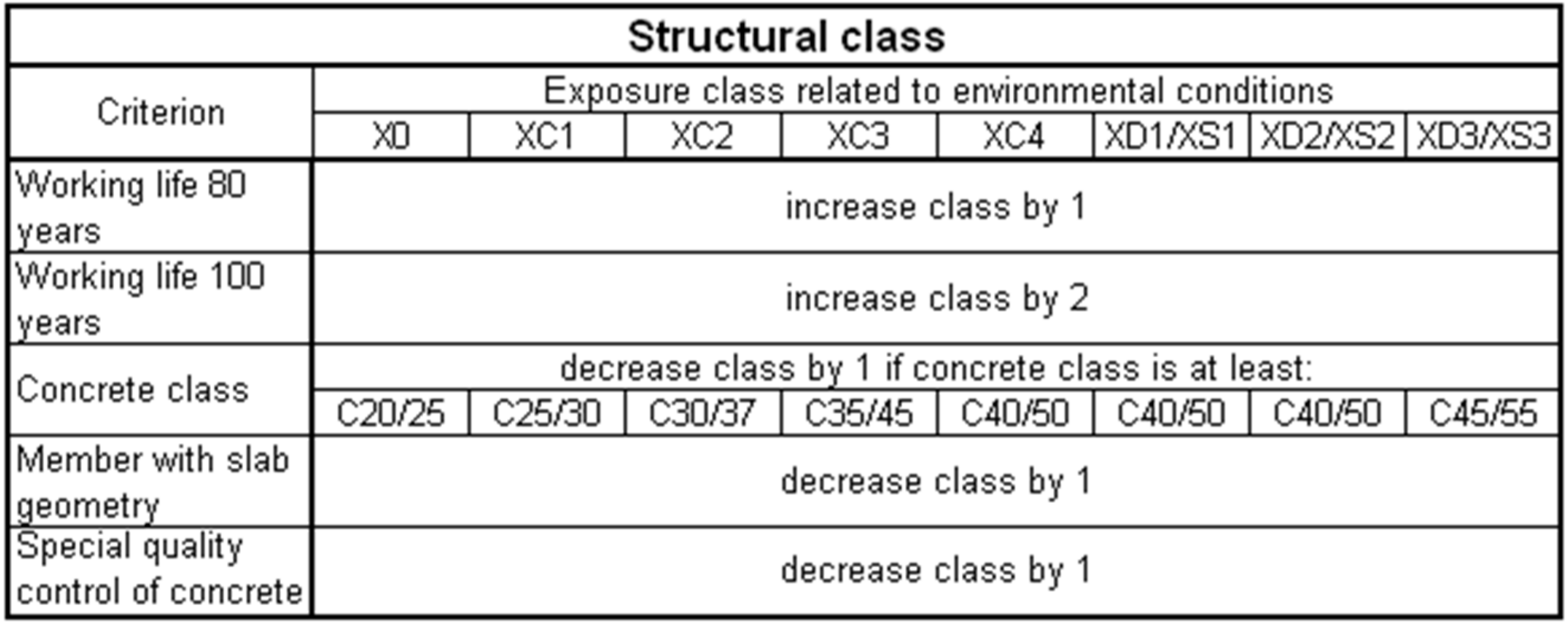


$c_{min,b}$ is the cover depth necessary for good mechanical bond between steel and concrete, and it is equal to diameter of steel bars ($c_{min,b} = 10$ mm).

$c_{min,dur}$ is the cover depth necessary for good resistance to unfavourable effects of the environment, and it is obtained using the following table.

Cover depth $c_{min,dur}$

Step 1: Determine structure class (default is S4).

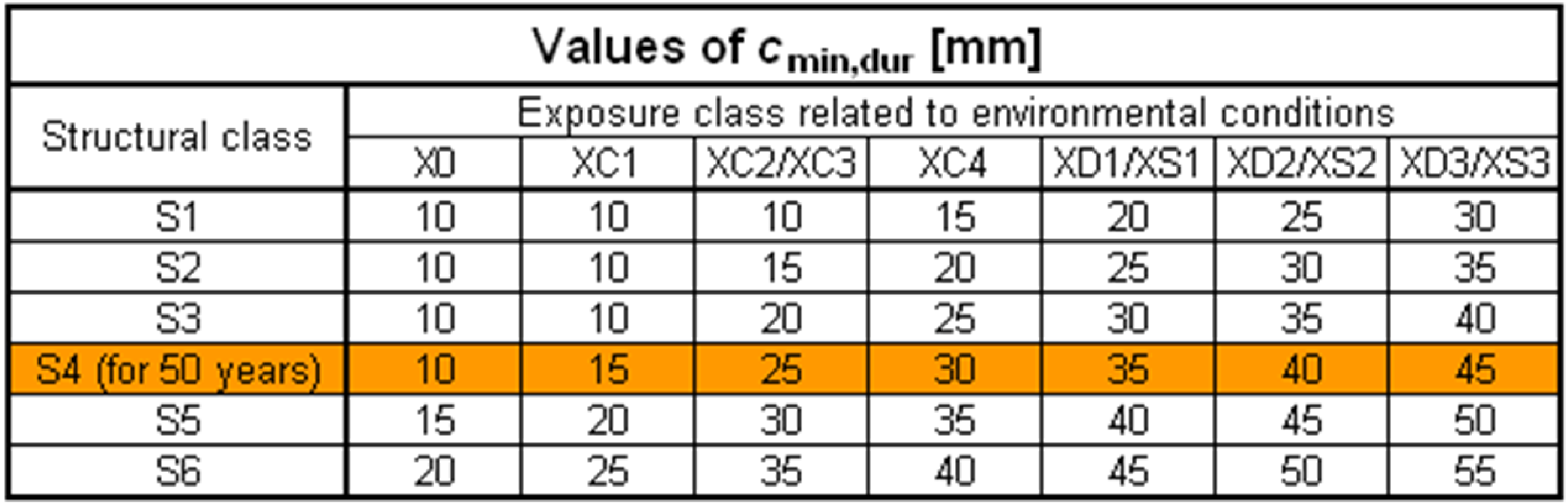


Structural class

Criterion	Exposure class related to environmental conditions							
	X0	XC1	XC2	XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
Working life 80 years	increase class by 1							
Working life 100 years	increase class by 2							
Concrete class	decrease class by 1 if concrete class is at least:							
	C20/25	C25/30	C30/37	C35/45	C40/50	C40/50	C40/50	C45/55
Member with slab geometry	decrease class by 1							
Special quality control of concrete	decrease class by 1							

Cover depth $c_{min,dur}$

Step 2: Determine cover depth.

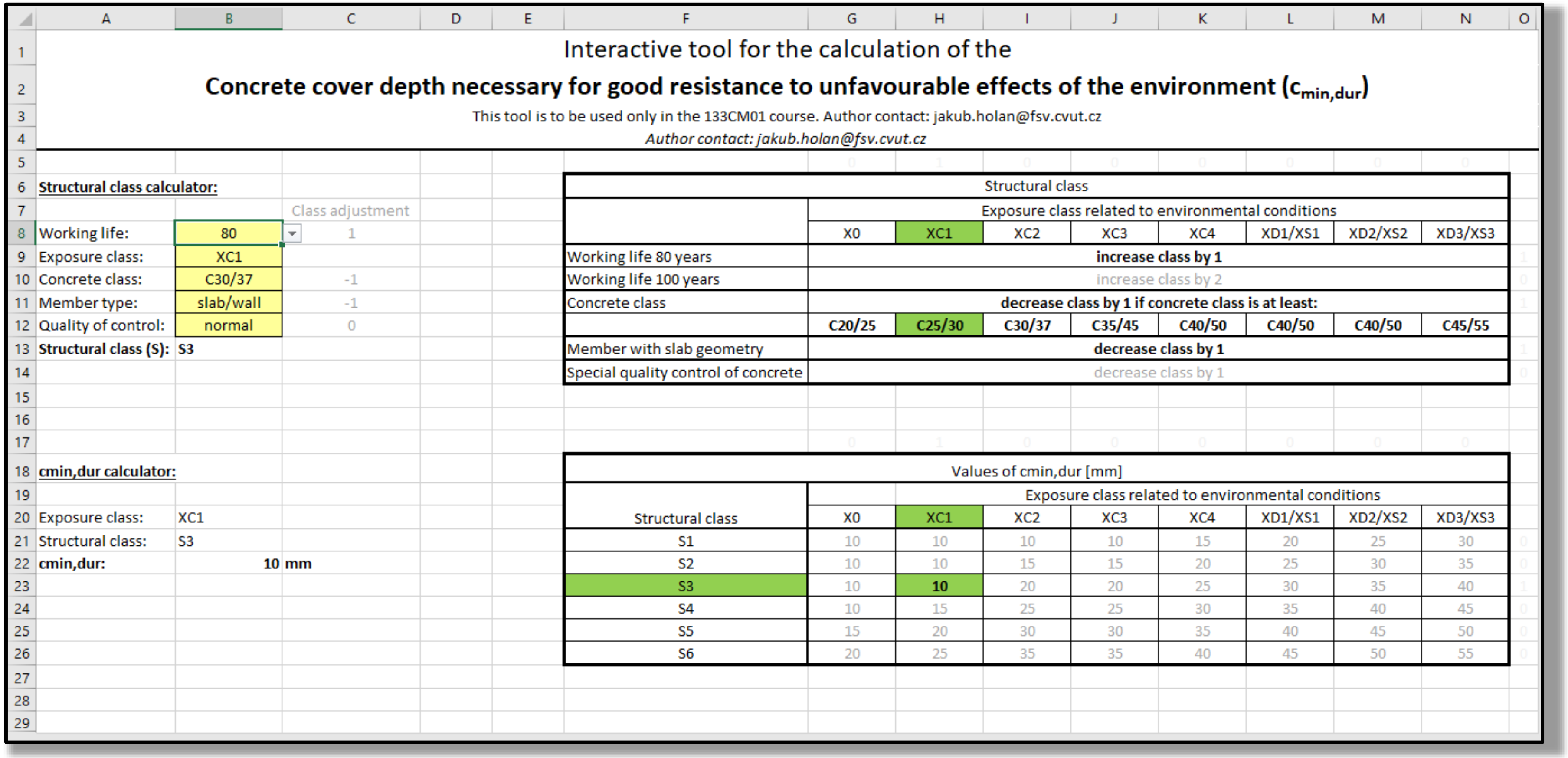


Values of $c_{min,dur}$ [mm]

Structural class	Exposure class related to environmental conditions						
	X0	XC1	XC2/XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
S1	10	10	10	15	20	25	30
S2	10	10	15	20	25	30	35
S3	10	10	20	25	30	35	40
S4 (for 50 years)	10	15	25	30	35	40	45
S5	15	20	30	35	40	45	50
S6	20	25	35	40	45	50	55

Cover depth $c_{min,dur}$

You can check your calculation using this interactive tool.



Interactive tool for the calculation of the

Concrete cover depth necessary for good resistance to unfavourable effects of the environment ($c_{min,dur}$)

This tool is to be used only in the 133CM01 course. Author contact: jakub.holan@fsv.cvut.cz

Author contact: jakub.holan@fsv.cvut.cz

Structural class calculator:

		Class adjustment
Working life:	80	1
Exposure class:	XC1	
Concrete class:	C30/37	-1
Member type:	slab/wall	-1
Quality of control:	normal	0
Structural class (S):	**S3**	

Structural class								
	Exposure class related to environmental conditions							
	X0	XC1	XC2	XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
Working life 80 years	**increase class by 1**							
Working life 100 years	increase class by 2							
Concrete class	**decrease class by 1 if concrete class is at least:**							
	C20/25	**C25/30**	**C30/37**	**C35/45**	**C40/50**	**C40/50**	**C40/50**	**C45/55**
Member with slab geometry	**decrease class by 1**							
Special quality control of concrete	decrease class by 1							

cmin,dur calculator:

Exposure class:	XC1	
Structural class:	S3	
cmin,dur:		**10 mm**

Values of cmin,dur [mm]								
	Exposure class related to environmental conditions							
Structural class	X0	XC1	XC2	XC3	XC4	XD1/XS1	XD2/XS2	XD3/XS3
S1	10	10	10	10	15	20	25	30
S2	10	10	15	15	20	25	30	35
S3	10	**10**	20	20	25	30	35	40
S4	10	15	25	25	30	35	40	45
S5	15	20	30	30	35	40	45	50
S6	20	25	35	35	40	45	50	55

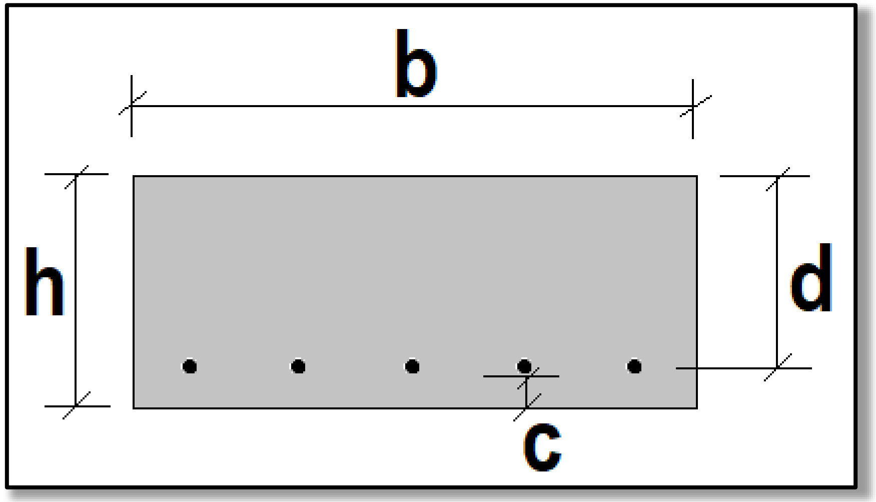
Effective depth of slab

Calculation of slab effective depth:

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

Diameter of steel bars (assume 10 mm)

Cover depth



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

	Concrete class						
ρ	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.

Assessment of slab depth

Usually, the slab is uneconomical if the span/depth condition is satisfied. Therefore, **do not try to satisfy this condition**! Only adjust the empirical design with respect to the results of the condition.

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).

Task 1 – part 1

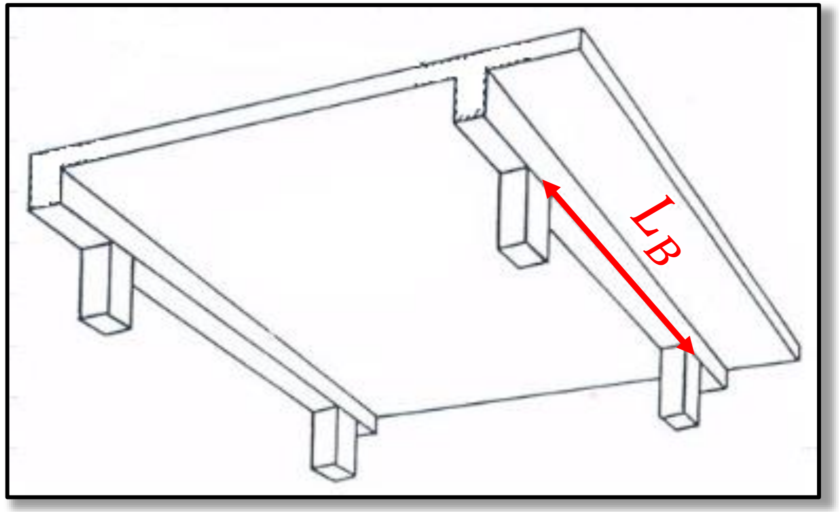
Beam

Cross-sectional dimension of the beam

Empirical estimation of beam height and width:

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

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



To reach sufficient stiffness of the beam, the following must be true:

$$h_B \geq 2.5\, h_s.$$

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

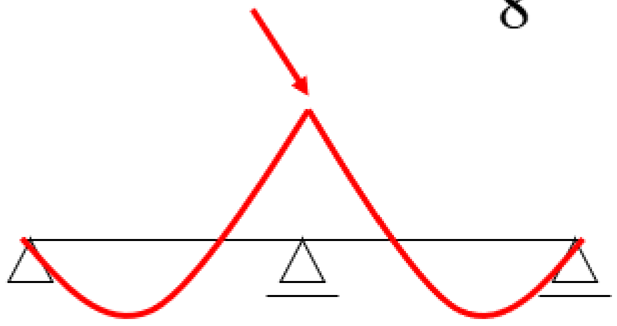
Preliminary check of the beam

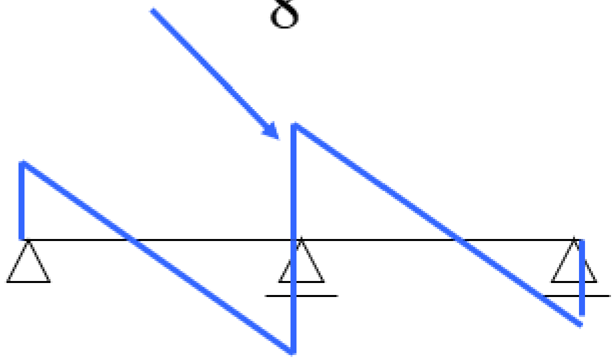
To avoid troubles during detailed assessment later (e.g., the beam is too thin and cannot be reinforced enough), a preliminary check must be done.

First, we **<u>estimate</u> theoretical maximum values of internal forces** in the beam.

$$M_{\mathrm{Ed,max}} = \frac{1}{8} f_{\mathrm{B}} l_{\mathrm{B}}^{2} \qquad V_{\mathrm{Ed,max}} = \frac{5}{8} f_{\mathrm{B}} l_{\mathrm{B}}$$

Load per 1 m of the beam in [kN/m]





Preliminary check of bending

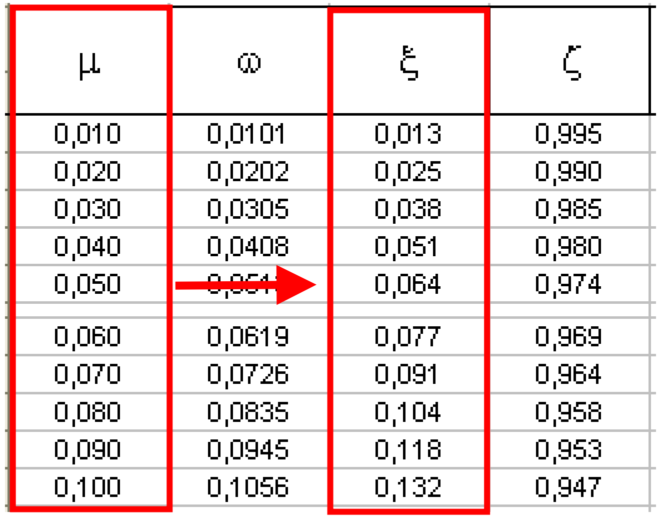
For the check of bending, we calculate *relative bending moment* and find corresponding *relative height of compressed part of the beam* in a table.

$$\mu = \frac{M_{\mathrm{Ed,max}}}{b_{\mathrm{B}} d_{\mathrm{B}}^2 f_{\mathrm{cd}}} \xrightarrow{\text{table (see web)}} \xi$$

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

Effective height 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)



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

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.

Preliminary check of reinforcement ratio

Reinforcement ratio must satisfy the condition:

$$\rho_{\mathrm{s,rqd}} = \frac{A_{\mathrm{s,rqd}}}{A_{\mathrm{c}}} = \frac{\dfrac{M_{\mathrm{Ed,max}}}{\zeta d_{\mathrm{B}} f_{\mathrm{yd}}}}{b_{\mathrm{B}} d_{\mathrm{B}}}$$

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)

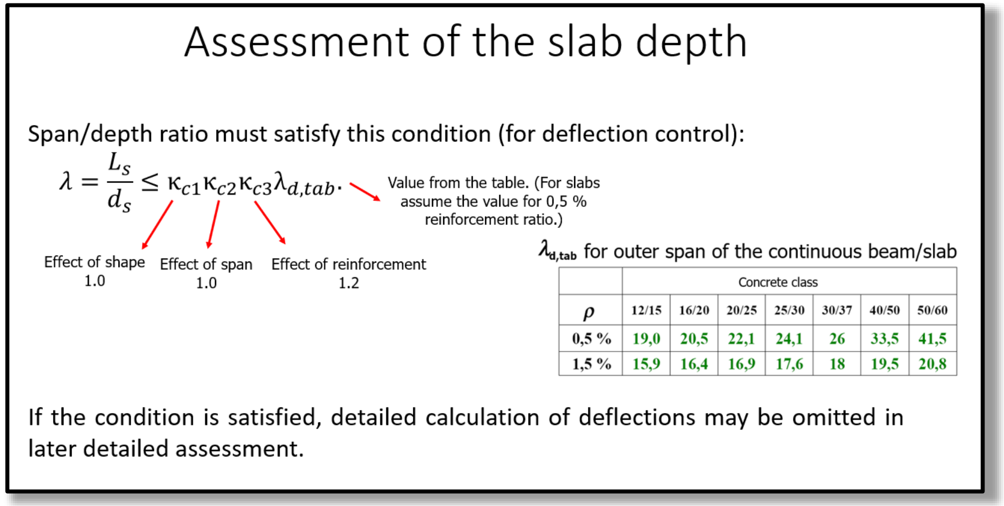
$$\nu = 0,6\left(1 - \frac{f_{\mathrm{ck}}}{250}\right)$$

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 $\boldsymbol{\lambda_{d,tab}}$** (outer span) **according to value of $\boldsymbol{\rho_{s,rqd}}$** calculated above.
- If the **condition is not satisfied, you must increase $\boldsymbol{h_B}$**.



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

	Concrete class						
ρ	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

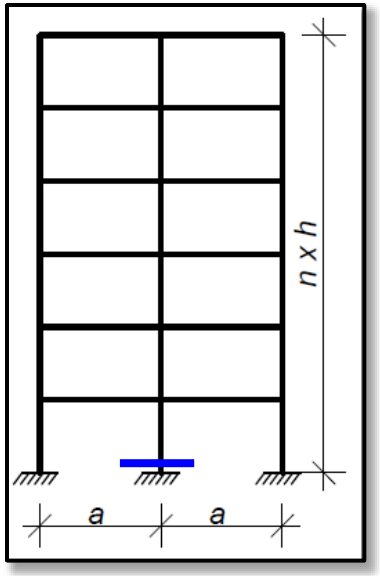
If the condition is satisfied, detailed calculation of deflections may be omitted in later detailed assessment.

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.

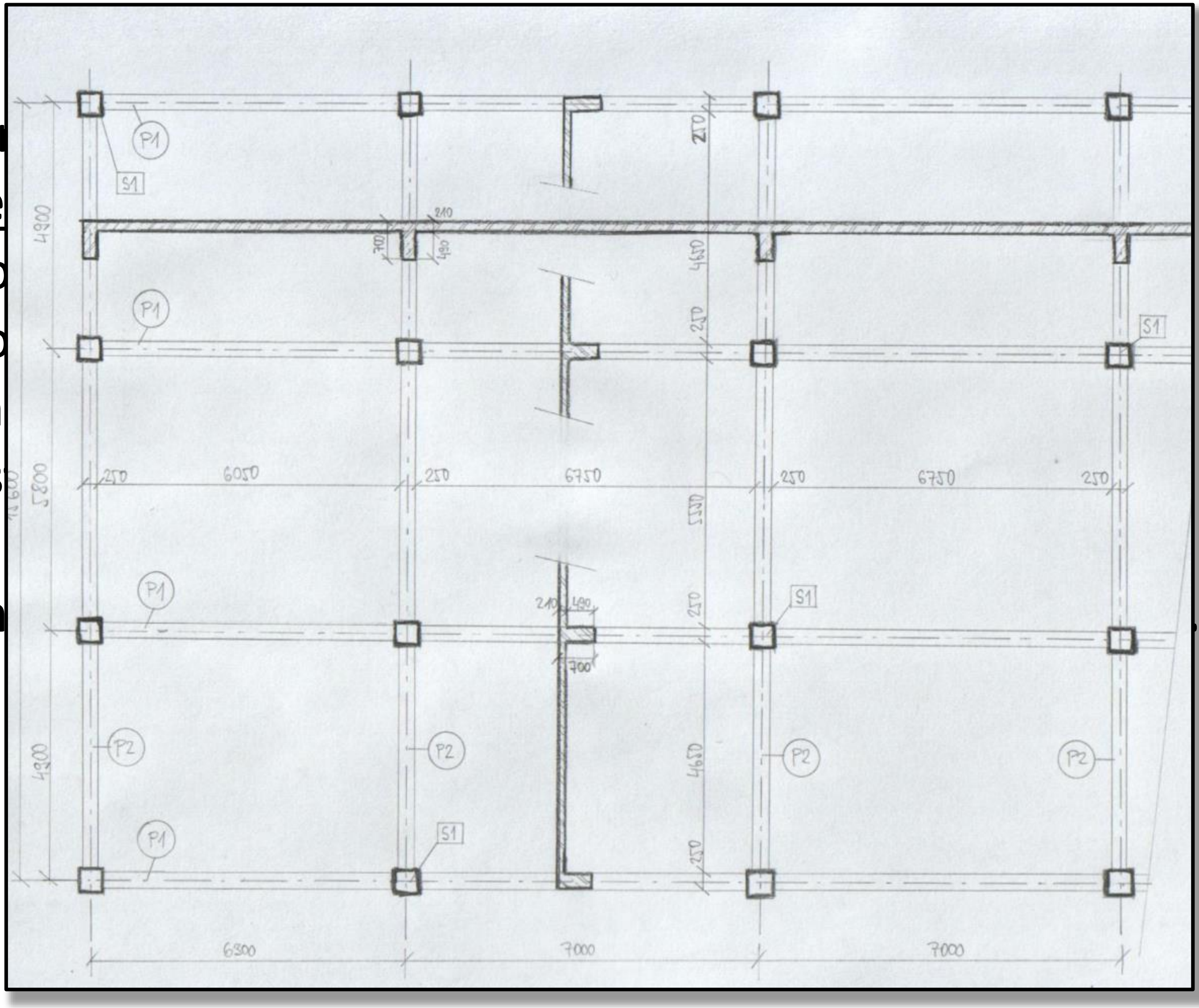
The sketch must show all designed dimensions of the elements.

Sketch of the structure

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	γ_F	design
			$\mathrm{kN/m^2}$		$\mathrm{kN/m^2}$
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 $2\,\mathrm{kN/m^2}$ and inaccessible roof $(0.75\,\mathrm{kN/m^2})$.

Roof load					
			charakteristic	γ_F	design
			$\mathrm{kN/m^2}$		$\mathrm{kN/m^2}$
Permanent					
	other permanent load		2,00		
	self weight	$0{,}19\mathrm{m} \;.\; 25\mathrm{kN/m^3}$	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:

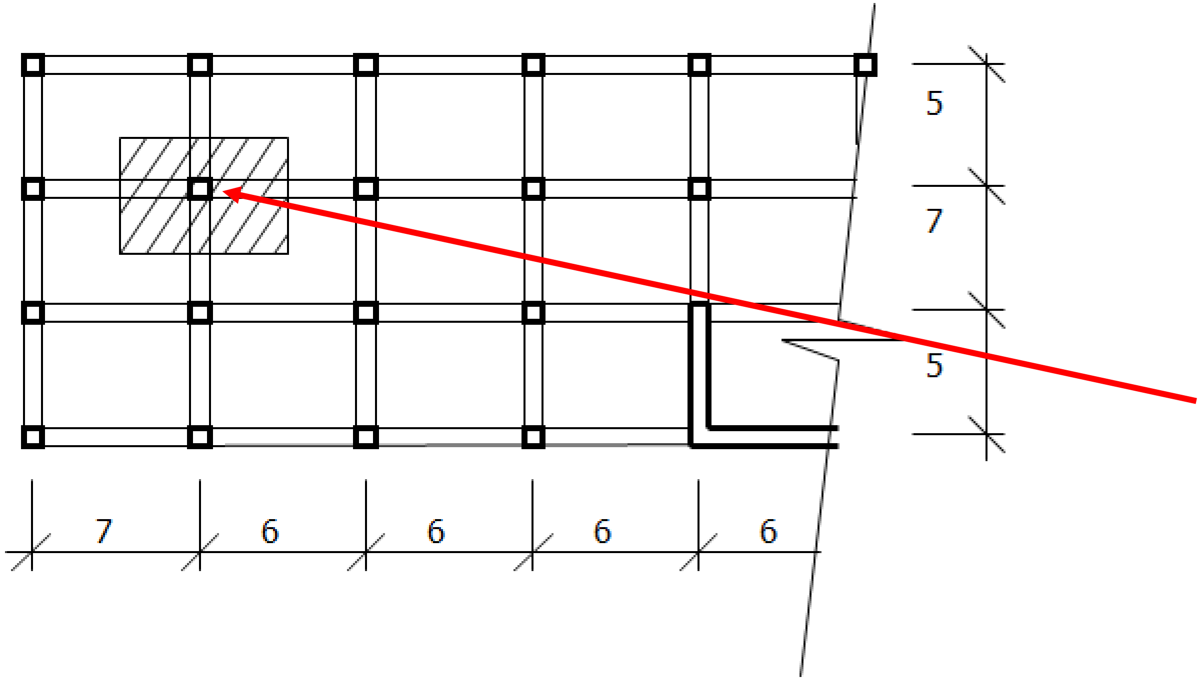
$$h_B = \frac{L_B}{15} \text{ to } \frac{L_B}{12} = \frac{7000}{15} \text{ to} \frac{7000}{12} = 467 \text{ mm to } 538 \text{ mm } \rightarrow h_B = 500 \text{ mm.}$$

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.

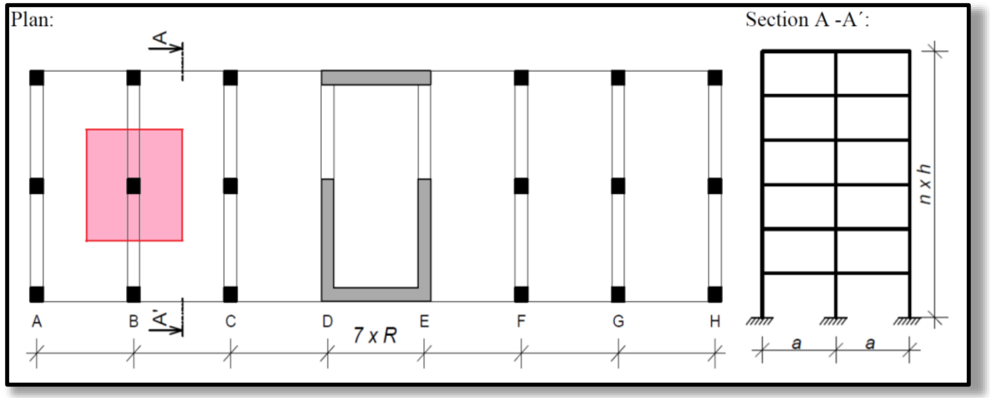


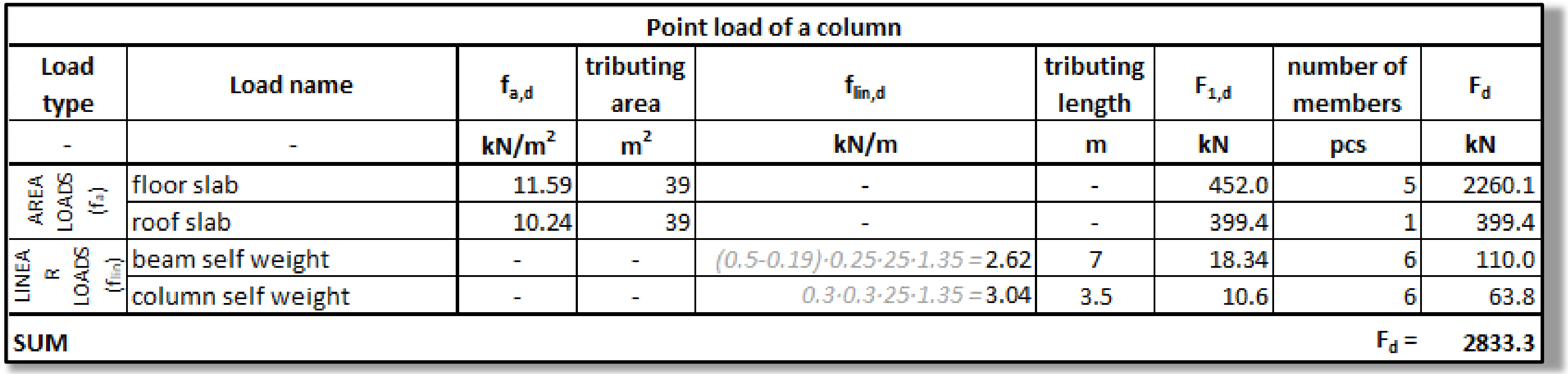
tributing area:

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

Loading of a column

Point load for the internal column (column dimensions estimated as $300\ \mathrm{mm} \times 300\ \mathrm{mm}$ and column height is $3.5\ \mathrm{m}$) 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/m^2	m^2	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
LINEA R LOADS (f_{lin})		beam self weight	-	-	$(0.5-0.19)\cdot0.25\cdot25\cdot1.35=2.62$	7	18.34	6	110.0
		column self weight	-	-	$0.3\cdot0.3\cdot25\cdot1.35=3.04$	3.5	10.6	6	63.8
SUM								$F_d =$	**2833.3**

Design of column dimensions

From the centric load condition

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

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

minimal cross-sectional area is derived

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

⟶ column $\mathbf{350\ mm} \times \mathbf{350\ mm}$ $(\mathrm{A_c} = 122\ 500\ \mathrm{mm}^2)$.

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