Concrete and Masonry Structures 1

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→ Courses in English

→ Concrete and Masonry Structures 1

Office hours: Thu 16:00-16:45

Credit receiving requirements

- **General knowledge of design of concrete structures** (e.g. 133FSTD – Fundamentals of Structural Design)
- Working out of the homework assigned every week. Homework delivered:
  - the next week – 3 points
  - 1 week delay – 2 points
  - 2 weeks delay – 1 point
  - 3 or more weeks delay – 0 points, but you still have to deliver!!!
- Reach **at least 24 points** out of total of 36 points (12 pieces of homework)

https://eobchod.cvut.cz/ctu_study_notes/ctu_study_notes/design_procedures_for_reinforced_concrete_structures-150028012

Procházka, Jaroslav: DESIGN PROCEDURES FOR REINFORCED CONCRETE STRUCTURES

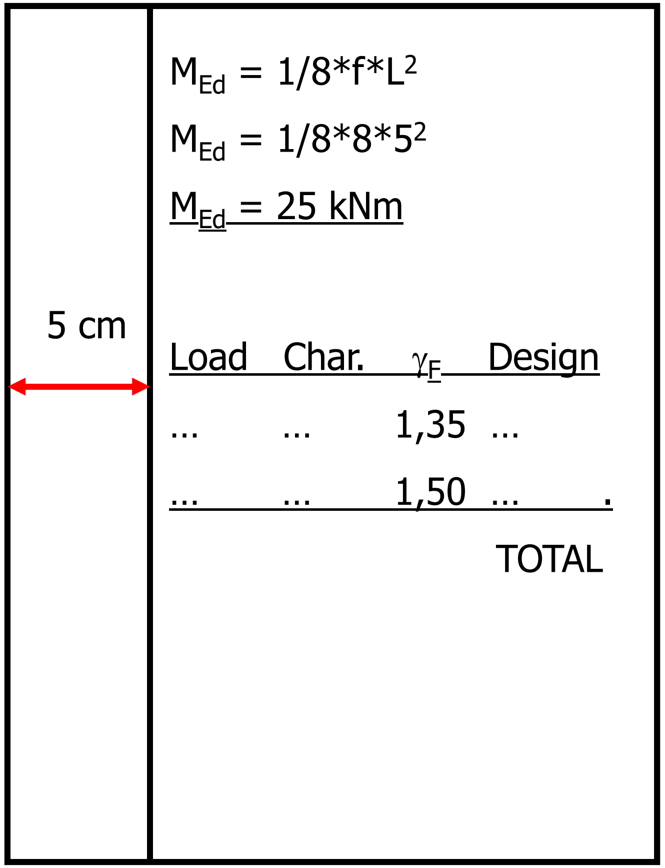
Other authors	Štemberk
Faculty	FSv
Version	1.D1.
Year of publishing	12/2012
Number of pages	Stran: 190, Obrázků: 164, Příloh: 0, CD: 0
Publisher	ČVUT, 01/2013
ISBN	978-80-01-04240-3

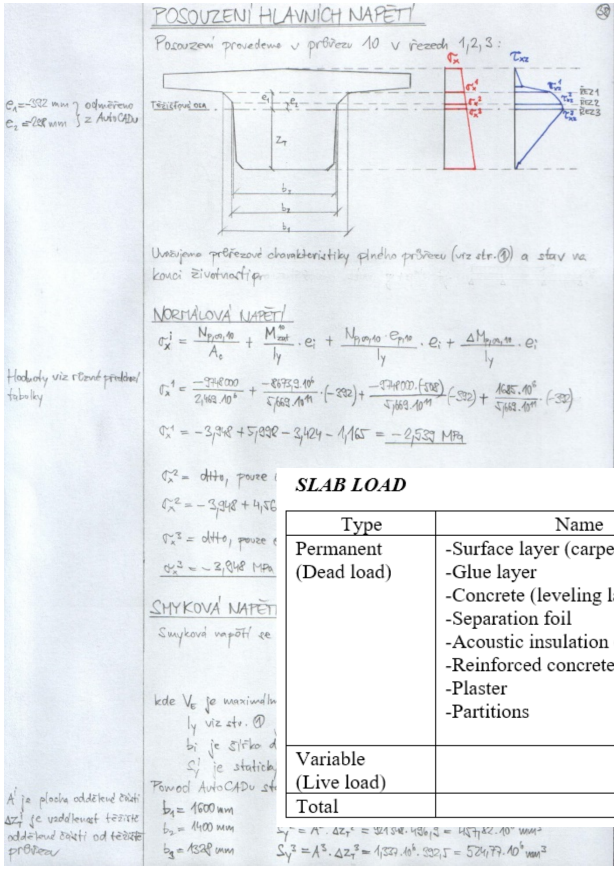
Price (Incl.VAT 10 %)	223 CZK
In Stock	57 pcs
Quantity	1 pcs

Add to basket

Homework – page layout

- 3 rows: Formula – insert numbers – evaluate
- Loads in tables
- Draw schemes – easier to understand





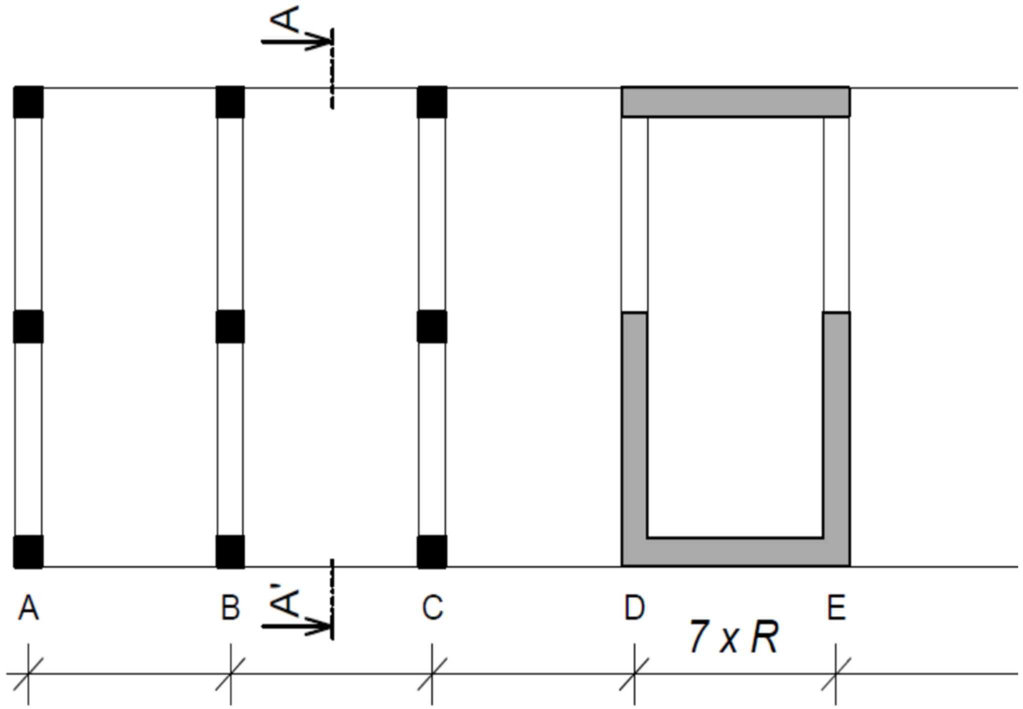
SLAB LOAD

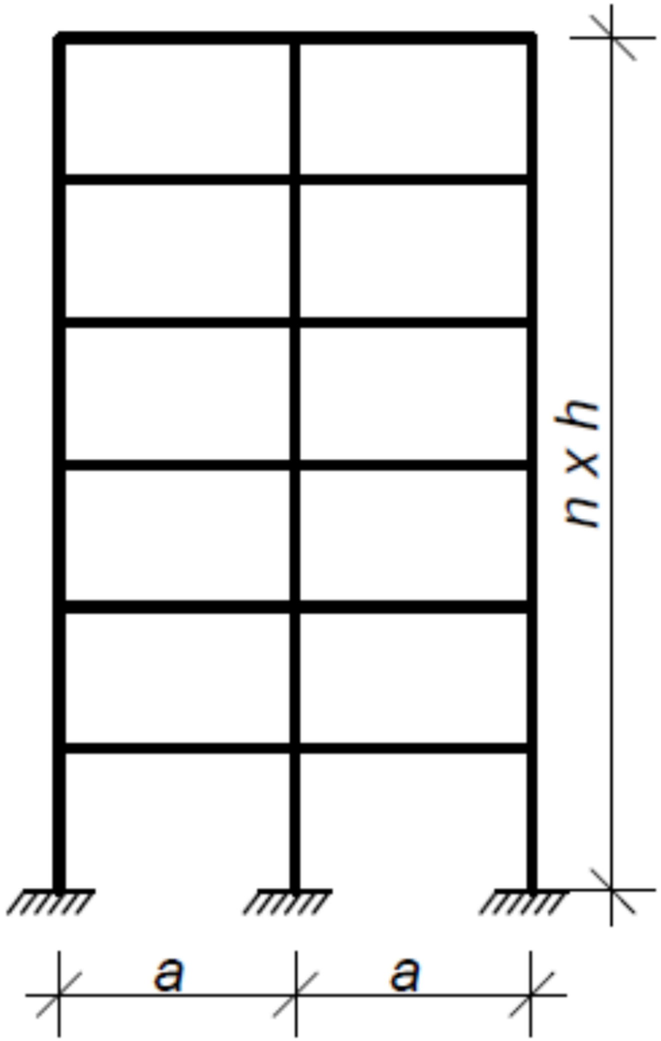
Type	Name	f_k [kN/m²]	γ_F	f_d [kN/m²]
Permanent (Dead load)	-Surface layer (carpet/ceramic)	0.20	1.35	0.27
	-Glue layer	0.01	1.35	0.01
	-Concrete (leveling layer)	1.25	1.35	1.69
	-Separation foil	0.01	1.35	0.01
	-Acoustic insulation (EPS/XPS)	0.05	1.35	0.07
	-Reinforced concrete	0.28*25=6.88	1.35	9.28
	-Plaster	0.06	1.35	0.08
	-Partitions	0.11	1.35	0.15
Variable (Live load)		2.00	1.50	3.00
Total		∑ = 10.57		∑ = 14.56

Rules for structural analysis elaboration

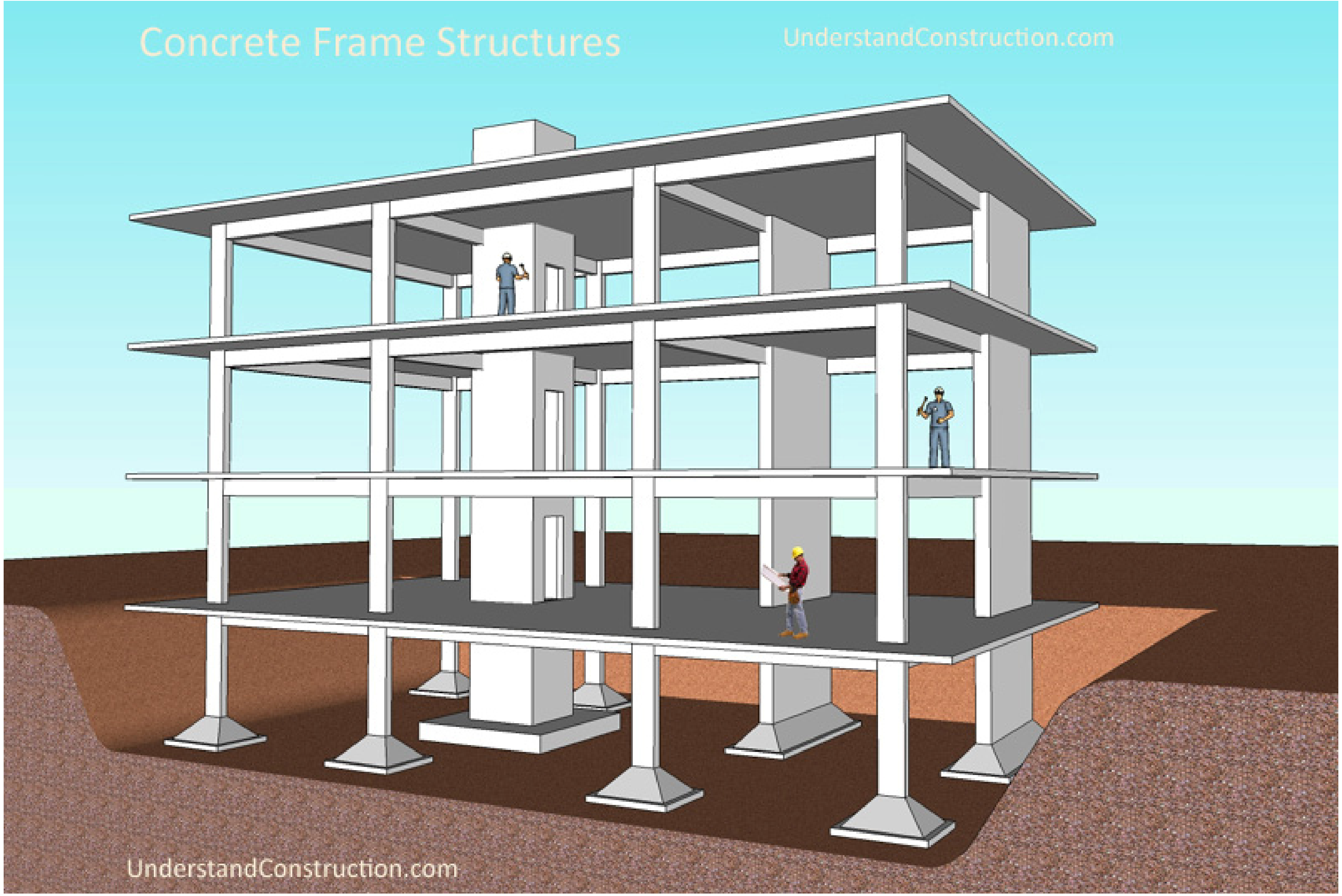
- Well-arranged, clear, controllable
- Page numbers (cross reference to previous calculations and results)
- All calculations, assumptions write down in the analysis
- State formula $\rightarrow$ substitute $\rightarrow$ calculate results, quote units
- Calculation of loads in tables
- Sketches, figures

1st task:
Frame Structure





1st task:
Frame Structure



Individual Parameters – see excel spreadsheet

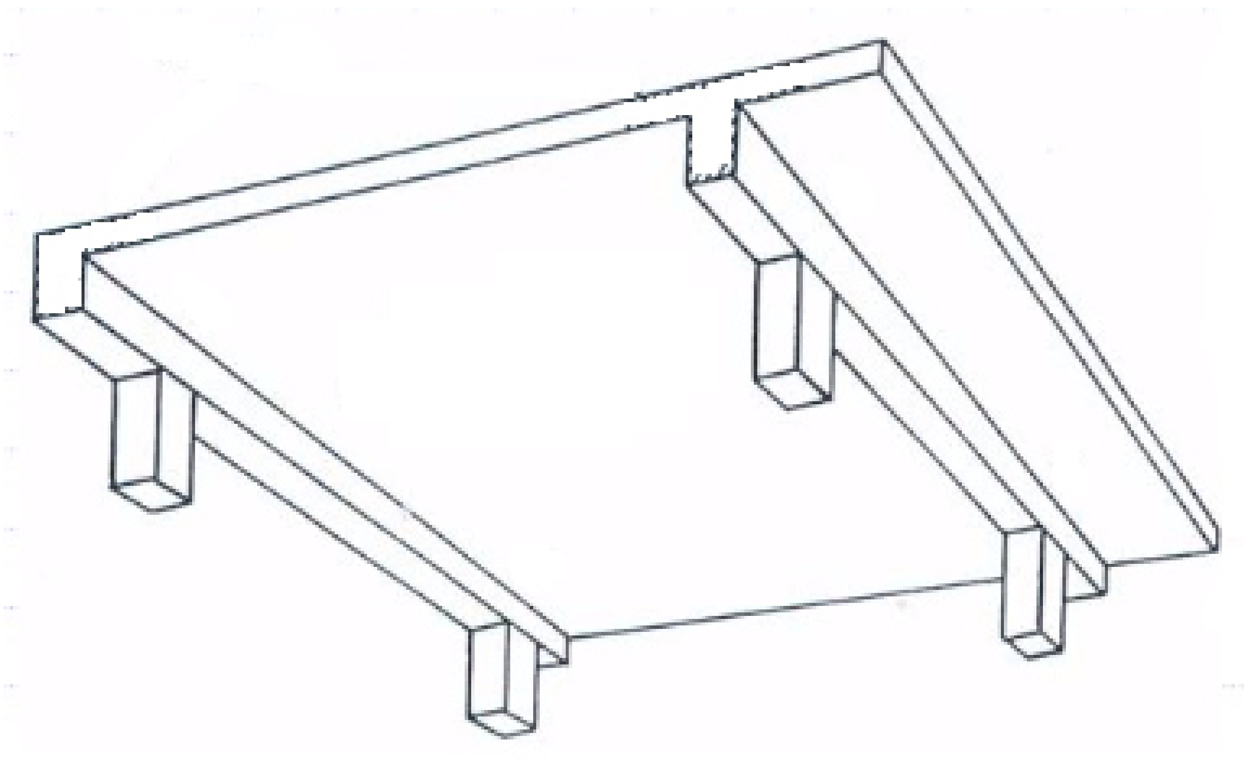
- R, a [m] distance between supports in the plan (spans)
- h [m] floor height
- n number of floors
- Concrete class
- Permanent load (except self weight) for typical floor $(g\text{-}g_0)_{\text{floor,k}}$ [kN/m ^{2}]
- Permanent load (except self weight) for roof $(g\text{-}g_0)_{\text{roof,k}}$ [kN/m ^{2}]
- Variable load for typical floor $q_{\text{floor,k}}$ [kN/m ^{2}]
- Variable load for roof q_k = 0,75 kN/m^2
- Exposure class related to environmental conditions
- Design working life

Our goal will be to:

- Design dimensions of all elements
- Do detailed calculation of 2D frame - calculation of bending moments, shear and normal forces using FEM software
- Design frame reinforcement
- Draw layout of reinforcement

Design of dimensions

- Depth of the slab
- Cross-sectional dimensions of the beam
- Cross-sectional dimensions of the column
- Sketch of the structure



Depth of the slab h_s

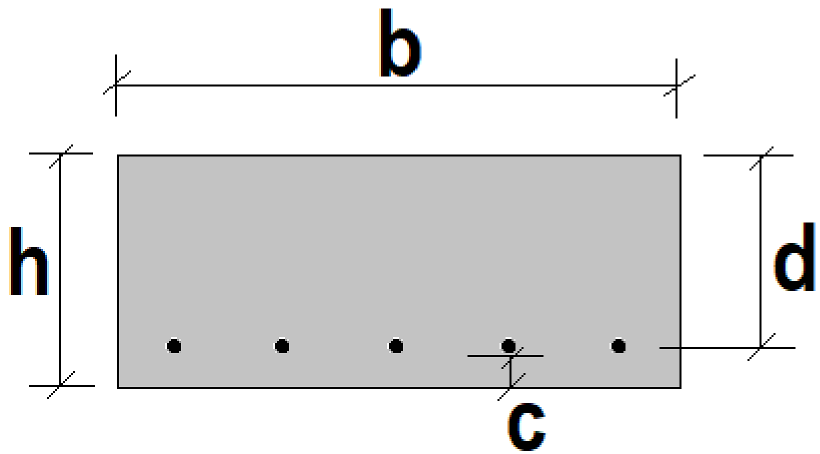
- <u>One-way slab</u>

- Empirical estimation: $$h_s = \left(\frac{1}{30} \sim \frac{1}{25}\right) l$$

- Effective depth *d*: $$d = h_s - c - \frac{\varnothing}{2}$$

Diameter of steel bars, 10 mm

Cover depth



Cover depth *c*

$$c = c_{\min} + \Delta c_{\text{dev}}$$

$$c_{\min} = \max\left(c_{\min,\text{b}}; c_{\min,\text{dur}}; 10\ \text{mm}\right)$$

- Δc_{dev} = 10 mm (technology allowance)
- $c_{min,b}$ = 10 mm (cover depth necessary for good mechanical bond between steel and concrete, equal to diameter of steel bars)
- $c_{min,dur}$ – see table (cover depth necessary for good resistance to unfavourable effects of the environment)

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

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							

Depth of the slab h_s

- Span/depth ratio (deflection control):

See table, for slabs consider the value for 0,5 % reinf. ratio

$$\lambda = \frac{l}{d} \leq \lambda_{\text{lim}} = \kappa_{c1}\kappa_{c2}\kappa_{c3}\lambda_{d,\text{tab}}$$

Effect of shape 1.0

Effect of span 1.0

Effect of reinforcement 1.2

- If $\lambda \leq \lambda_{min}$, detailed calculation of deflections may be omitted
- However, usually the slab is uneconomical if the condition is satisfied

$\lambda_{d,tab}$ 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

$\lambda_{d,tab}$ for inner 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 %	21,9	23,7	25,5	27,8	30,8	38,6	48
1,5 %	18,3	18,9	19,5	20,3	21	22,5	24

Depth of the slab h_s

- Usually the slab is uneconomical if the span/depth condition is satisfied
- => only adjust the empirical design with respect to span/depth ratio, do not try to satisfy this condition
- If $\lambda > \lambda_{min,}$ increase the depth of the slab by some 10 – 40 mm, depending on the difference between empirical design and design according to span/depth ratio

Design of the beam

- Empirical estimation

$$h_{\mathrm{B}} = \left(\frac{1}{12} \sim \frac{1}{10} \right) l_{\mathrm{B}} \qquad b_{\mathrm{B}} = \left(\frac{1}{3} \sim \frac{2}{3} \right) h_{B}$$

- To reach sufficient stiffness of the beam:

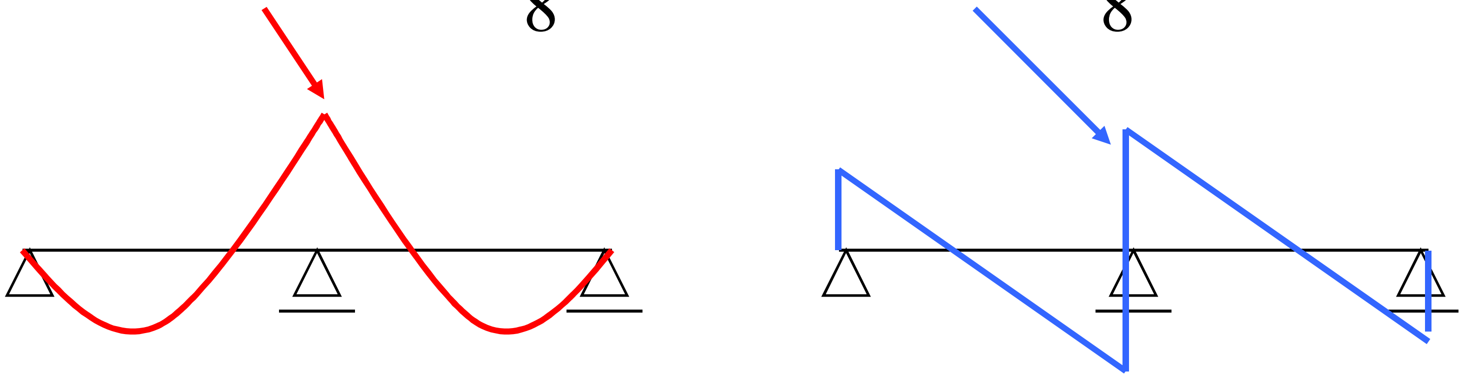
$$h_{\mathrm{B}} \geq 2.5 h_{\mathrm{S}}$$

Preliminary check of the beam

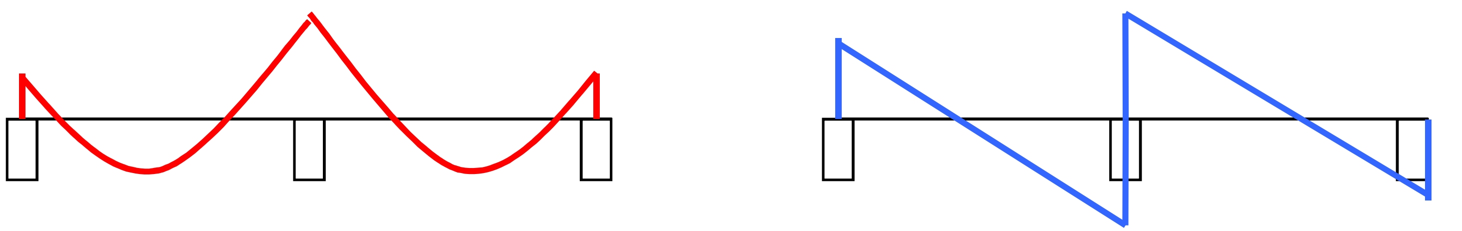
- To avoid troubles during detailed check
- Theoretical maximum values of internal forces in the beam:

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

Load per 1 m of the beam in kN/m



- Real internal forces will be lower



Preliminary check of the beam

- <u>Preliminary check of bending</u>

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

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

Effective height of the beam, estimated diameter of rebars 16 – 22 mm

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

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	[illegible]	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 $\xi \in$ <0.15 – 0.40> design is correct
- If ξ < 0.15 – you should decrease h_{B} and/or b_{B}
- If ξ > 0.40 – you have to increase h_{B} and/or b_{B}

Preliminary check of the beam

- <u>Preliminary check of reinforcement ratio</u>

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

Required reinforcement ratio

Relative value of lever arm of internal forces (z/d)

table (see web)

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	[illegible]	[illegible]	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 $\rho_{s,rqd} > 0.04$ – you have to increase h_B and/or b_B

Preliminary check of the beam

- Preliminary check of load-bearing capacity in shear („compression diagonals")

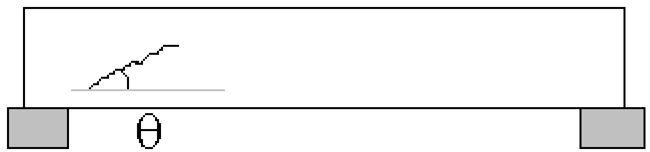
$$V_{\mathrm{Rd,max}} = \nu \cdot f_{\mathrm{cd}} \cdot b_{\mathrm{B}} \cdot \zeta \cdot d_{\mathrm{B}} \cdot \frac{\cot\theta}{1+\cot^2\theta} \geq V_{\mathrm{Ed,max}}$$

Load-bearing capacity of compression diagonals in shear

Coefficient expressing effect of shear cracks and transversal deformations

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

Cotangent of angle of shear cracks, cot θ = 1,5



- If the condition is not checked, you have to increase h_{B} and/or b_{B}

Preliminary check of the beam

- Span/depth ratio (deflection control) – same procedure as for slabs
- Select a row in the table for $\lambda_{d,tab}$ (outer span) according to value of $\rho_{s,rqd}$ calculated
- If the condition is not checked, you have to increase h_B (unlike slabs, it is usually a good idea to meet the span/depth condition for beams)

Dimensions of the column

- Calculate design load in the foot of the column (N_{Ed})

$$N_{Ed} \leq N_{Rd}$$

0.02 A_c 400 MPa

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

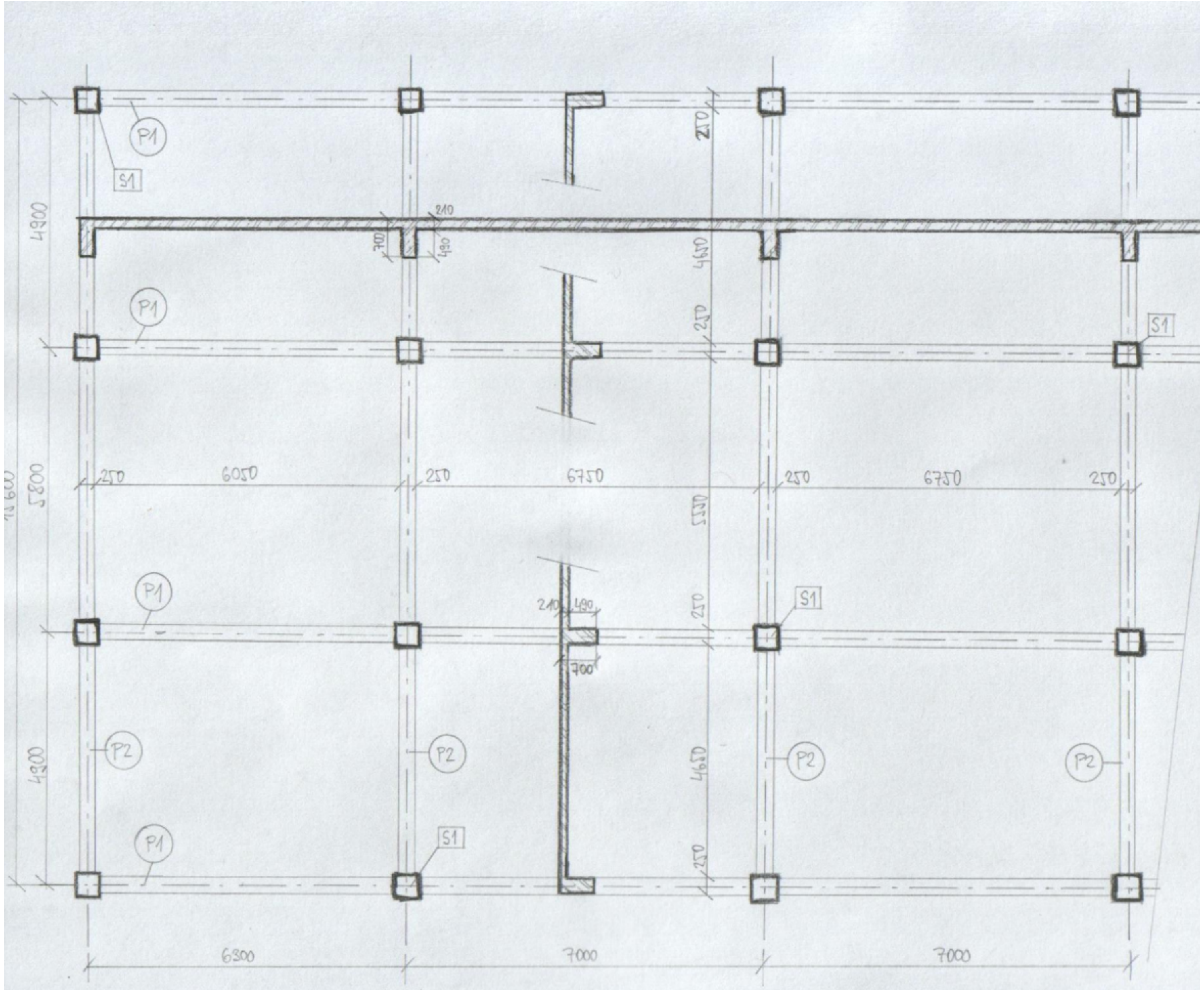
$$A_c \geq \frac{N_{Ed}}{0.8 f_{cd} + 0.02 \sigma_s}$$

=> dimensions of rectangular column

Adjustment of dimensions

- Round dimensions to 50 mm
- Round slab dimensions to 10 mm
- Round beam dimensions to 50 mm
- If the difference between column width and beam width is less than 100 mm, use the bigger dimension for both elements
- Reason: dimensions of formwork systems

Sketch of the structure



For the next week...

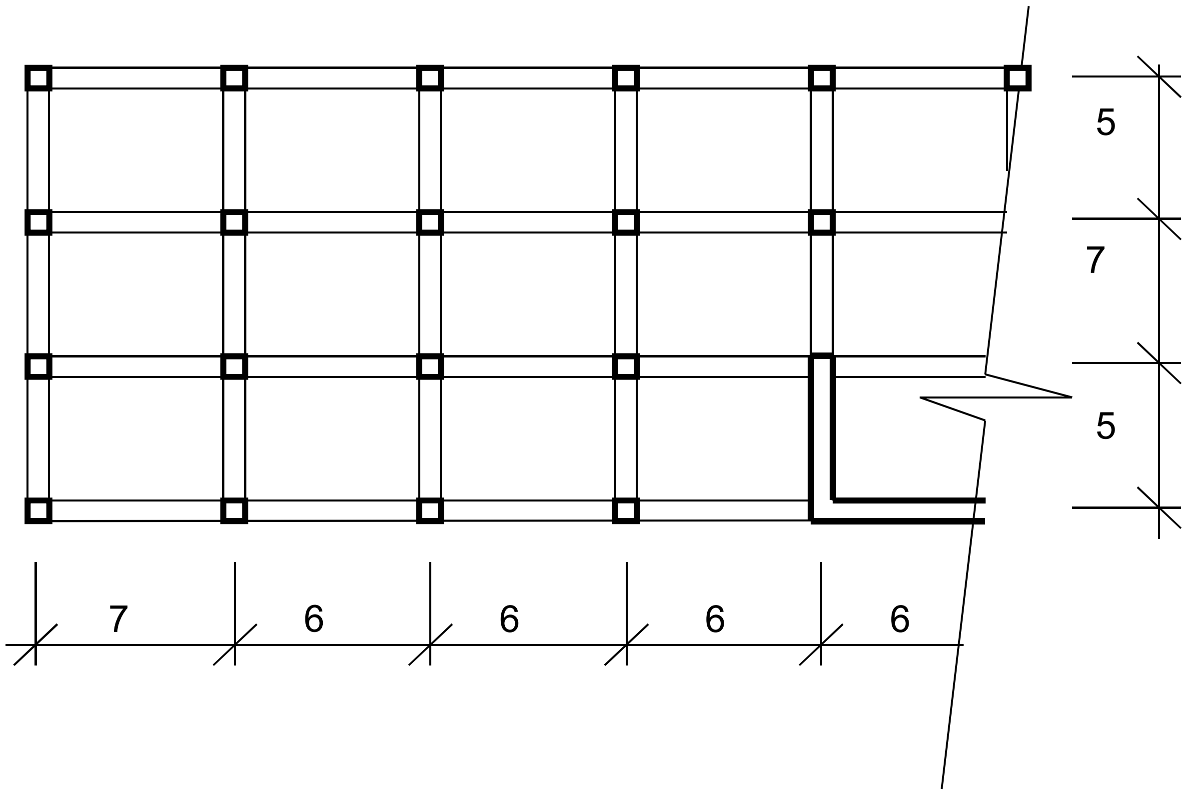
- We will focus on detailed calculation of internal forces
- Are you able to use any Finite Element Analysis software?
- If not, check easy-to-use software „Idea Statica" on https://www.ideastatica.com/educational-license/

… and register to get the student licence

Example (different structure!!!)

<u>Two-way</u> slabs supported on four sides

concrete class C30/37, cover depth 25 mm, 6 mm steel bars, 4 floors



Slab depth design

$$h_S = \frac{l_x + l_y}{75} = \frac{7000 + 6000}{75} = 173\ mm$$

$$d = h_s - c - \frac{\varnothing}{2} = 173 - 25 - \frac{6}{2} = 145\ mm$$

Deflection control:

$l\,/d$ = 6000 / 145 = 41 $\nleq$ λ_{lim} = 1,0*1,0*1,2*30,8 = 37

=> h_s has to be increased

Slab height $\boldsymbol{h_S}$ **= 190 mm**

Calculation of loads

Slab load					
			charakteristic	γ_F	design
			kN/m^2		kN/m^2
Permanent					
	other permanent load		0,50		
	self weight	0,19m . 25kN/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 load					
			charakteristic	γ_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

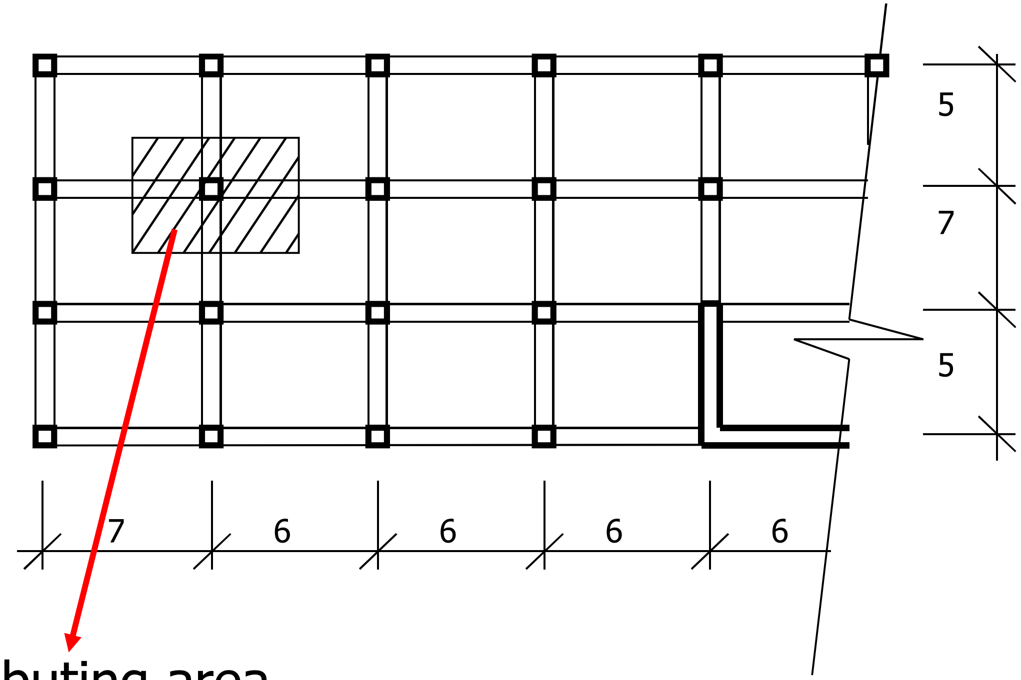
Beam

$$h_B = \left(\frac{1}{15} \div \frac{1}{12} \right) l = \left(\frac{1}{15} \div \frac{1}{12} \right) \cdot 7 \cong 0,5\ m$$

$$h_B \geq 2.5 h_S$$

$$b = (0,33 \div 0,5) h = 0,25\ m$$

Column



tributing area

A = 6,5 x 6 = 39m^2

load from the slab

3x typical floor 3 x 39 m2 x 11,59 kN/m2 = 3x 452 = 1356 kN

1x roof 1 x 39 m2 x 10,24 kN/m2 = 339,4 kN

1755,4 kN

load from the beam

(0,5-0,19)m x 0,25m x 25 kN/m3 = 0,08 * 25 = 2 kN/m

(6,5 + 6)m * 2 kN/m= 25 kN

x 4 floors = 100kN

estimate self weight of the column ≈ 25kN

N_{Ed} = 1755 + 100 + 25 = 1880

$$N_{Ed} = 0{,}8A_c \cdot f_{cd} + A_s \cdot \sigma_s$$

$$1880 = 0{,}8A_c \cdot 20000 + 0{,}02A_C \cdot 400000$$

min. area: $A_c = 0{,}078m^2$

→ <u>column 300 x 300 mm</u>