

#### CM01 – Concrete and Masonry Structures 1 HW7 – Flat slab (dimensions, moment)



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#### Task 3



#### Task 3 – Flat slab

In Task 3, a two-way flat slab (slab supported by columns) will be designed.



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#### Comparison of Tasks 1 to 3







Two-way slab supported on 4 sides – **Task 2** 

Two-way flat slab – **Task 3** 



■ Beam (frame) – ■ beton4life Task 1

Task 3 – Assignment

#### Task 3: Two-way slab supported on columns Two-way slab supported on columns, edge beam in axes A and D, walls in axes 1 and 6. Scheme of the structure: D р С Parapet beam - choose dimensions in the following ranges: 0 width 200 - 250 mm, height 800 - 1000 mm. в 0 п 2 3 4 5 1 Individual parameters (parameters in **bold** you can find on teacher's website): a, b, d [m] – horizontal dimensions of the structure (a see 1st task, b see 2nd task), n – number of floors Geometry: (see 1st task) Materials: see 1st task see 1st task, values for typical floor (except the self-weight, which will be different) Loads: Please work out: Design of the dimensions of the load-bearing elements (slab, columns). Choose the thickness of the wall as 200 mm or 250 mm. 2. Sketch of the structure. 3. Structural analysis of the slab: Bending moments in strips C and 3 using the Direct design method. ٠ Draw moment curves for both strips. ٠ Design slab reinforcements (rebars) for the calculated moments. ٠ Design the punching reinforcement for column C3.

Layout of reinforcement (separately for upper and lower layer of reinforcement).

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# Task 3 – Assignment goals

- 1) Design of the dimensions of the load-bearing elements and sketch the structure.
- 2) Preliminarily check punching.
- 3) Calculate **bending moments** in lanes C and 3.
- 4) Design slab **bending reinforcements** (rebars) for the calculated moments.
- 5) Design the **punching reinforcement** for column C3.
- 6) Draw a layout of the reinforcement .

## 1) Design of dimensions

# Design of dimensions

We need to design the dimensions of all structural elements, i.e.:

- thickness of the concrete slab,
- thickness of the concrete wall,
- dimensions of the perimeter beam,
- dimensions of the column.

#### Slab thickness

We will design the slab thickness using the **empirical relationship** and check the **span/depth** ratio (as in Task 1).





Minimal slab thickness for a slat slab is 200 mm!

ρ <b>[%]</b>									
	C 12/15	C 16/20	C 20/25	C 25/30	C 30/37	C 35/45	C 40/50	C 45/55	<del>C 5</del> 0/60
0,5	17,5	19,0	20,4	22,2	24,6	27,6	30,9	34,5	38,4
1,5	14,6	15,1	15,6	16,2	<mark>16</mark> ,8	17,4	18,0	18,6	19,2

#### Wall thickness

For  $a \le 6$  m, design the wall as 200 mm thick.

For a > 6 m, design the wall as 250 mm thick.



Note: This is a BIG simplification used only for this task. Do not design walls in this way in real projects!

#### Perimeter beam dimensions

For the perimeter beam, choose the dimensions anywhere in the following ranges:

- width 200 mm to 250 mm,
- height 800 mm to 1000 mm.

Both width and height should be a **multiple of 50 mm**.



**Note:** This is a BIG simplification used only for this task. **Do not design walls in this way in real projects!** 

# Column dimensions

Design the column dimensions in the same way as in Task 1 - i.e.:

- 1) Calculate the total area load of the slab  $f_d [kN/m^2]$  (apart from self-weight, all other loads are the same as in Task 1).
- 2) Calculate the tributing area of the column.
- 3) Determine the normal force at the foot of the 1st floor column ( $N_{Ed}$ ).
- 4) Assuming the centric-load condition, we calculate the **required cross-sectional area**:

$$A_{c,req} = \frac{N_{Ed}}{0.8f_{cd} + 0.02 \cdot 400 \text{ MPa}}$$

5) Design a square cross-section with cross-sectional area  $(A_c)$  greater than the required cross-sectional area  $(A_{c,req})$ .

#### Sketch

After you design all dimensions, do a simple sketch of the plan of your structure with your dimensions (i.e., the given floor dimension and designed member dimensions).

# 2) Preliminary check of slab punching

# Slab punching

Flat slab have **no beams**  $\rightarrow$  **load from a large area** of the slab is transferred directly to the column **through a small area**  $\rightarrow$  **big concentrated stresses** occurs **near the column**  $\rightarrow$  this can lead to **slab punching** (a shear failure of the flat slab).



# Slab punching

Flat slab have **no beams** transferred directly to **big concentrated stresses slab punching** (a shear failu



**large area** of the slab is **ugh a small area**  $\rightarrow$ **blumn**  $\rightarrow$  this can lead to

# Punching reinforcement

To avoid punching of the slab, punching reinforcement must be placed near the column.



# Types of punching failure

#### There are **two types of punching failure which can occur** in the slab.

Failure of compressed concrete

Failure of punching reinforcement





# Types of punching failure

There are **two types of punching failure which can occur** in the slab.

Failure of compressed concrete (at  $u_0$  perimeter)











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#### Control perimeters

The control perimeters, in which the punching is assumed to occur, are at the face of the column  $(u_0)$  and at the distance of 2d from the face of the column  $(u_1)$ .



## Failure of compressed concrete

In perimeter  $u_0$ , the shear force induces high compressive stress in concrete. We must check whether the **load-bearing capacity of compressed concrete** (i.e., the "*Maximum punching shear resistance*") is sufficient.



## Failure of compressed concrete

If the condition for the *maximum punching shear resistance* is **not satisfied**, the structure will fail due to crushing of concrete, no matter how much reinforcement you provide.

Thus, you **must adjust your design** and **recalculate the condition** with the new values.

# Adjusting the design

If the condition for the maximum punching shear resistance is not satisfied, you can:

• ?

$$v_{\rm Ed,0} = \frac{\beta V_{\rm Ed}}{u_0 d} \le v_{\rm Rd,max} = 0.4 \nu f_{\rm cd}$$

# Adjusting the design

If the condition for the maximum punching shear resistance is not satisfied, you can:

- increase depth of the slab (not effective because the self-wight is also increased),
- increase dimension of the column (effective, but floor area is decreased),
- increase concrete class (expensive),
- design a slab with drops or flat beams (complicated),
- design columns with **hidden caps**.

# Columns with hidden caps

In the homeworks, we will use steel flanged caps/collars (welded steel details) that are put into the slab-column joint.





# Columns with hidden caps

The cap increases both control perimeters:

$$u_0 = 4 \cdot (a + 2a_h)$$
  
$$u_1 = 4 \cdot (a + 2a_h) + 2\pi 2d$$



Thanks to the increased control perimeters, the stresses in the control perimeters will decrease. (Note: Only the stresses will be affected. Resistances will not be changed.)

$$\underbrace{v_{\rm Ed,0}}_{\rm Ed,0} = \frac{\beta V_{\rm Ed}}{u_0 d} \le v_{\rm Rd,max} = 0.4 \nu f_{\rm cd}$$

# Failure of punching reinforcement

We will design and assess the **punching reinforcement at** <u>later</u> stages of the task.

However, at this point, we must assess whether we will be able to anchor the punching reinforcement.

# Failure of punching reinforcement

Condition for the anchorage of the punching reinforcement in concrete:

R R

U P

S

$$v_{\text{Ed},1} = \frac{\beta V_{\text{Ed}}}{u_1 d} \le k_{\text{max}} \cdot v_{\text{Rd,c}} = k_{\text{max}} \cdot C_{\text{Rd,c}} \cdot k \cdot \sqrt[3]{(100\rho_l \cdot f_{\text{ck}})}$$
Reinforcement ratio of tensile reinforcement (estimate as 0.005)  
Effect of depth:  $k = 1 + \sqrt{\frac{200}{d}} \le 2,0$   
Reduction factor (0.12)  
Coefficient of maximum resistance, see table below.

*d* ≤ 200 mm

200 mm ≤ *d* ≤ 700 mm

*d* ≥ 700 mm

Double-headed studs connected to a spacer bar

1,45

interpolation

1,70

1,80

# Failure of punching reinforcement

If the condition for the anchorage is **not satisfied**, the punching reinforcement (needed to withstand the loads) will not be anchored in concrete sufficiently, and therefore, the structure will fail.

Thus, you **must adjust your design** and **recalculate the condition** with the new values.

You can adjust the design using the same changes as presented above for the first condition (e.g., steel caps).

#### 3) Calculate bending moments



#### Calculation of bending moments

We must calculate the bending moments in both directions of the slab.



# Calculation of bending moments

We will calculate the bending moments only in **lane C** and **lane 3**, and we will use the **Direct Design Method** to calculate them.



# Calculation of bending moments

In each lane, we will calculate the moments only in the first two panels (outer panel and the adjacent inner panel).



# Total bending moment

In each panel, we first must calculate the **Total bending moment**  $(M_{tot})$  as

$$M_{\rm tot} = \frac{1}{8} f_{\rm d} b l_{\rm n}^2$$

Note: The total bending moment is in kNm (per whole panel width).





### Support and mid-span moments

Using precalculated coefficients  $\gamma$ , we can divide the Total moment into support and mid-span moments:

 $M = \gamma_i M_{tot}$ 

Note:

The support and mid-span moments are in kNm (per whole panel width).



#### Support and mid-span moments

The precalculated coefficients  $\gamma$  are:



The real distribution of bending moments in the slab is a 2D curve.



However, from practical point of view, it is impossible to provide reinforcement exactly for these moments, and therefore, we need to calculate **"representative moments"** for particular **strips of the slab**.



We must divide the lanes into **column strips** (more loaded) and **middle strips** (less loaded). b  $\frac{1}{2}$  middle strip The width of the column strip is ¼ of the shorter span of the 1/4 I<sub>min</sub>/ panel. Column strip The width of the middle strip is 1/2 middle strip the rest of the width of the panel. beton4life 39

After we determine the column and middle strips, we must **split the** support moments ( $\gamma_1 M_{tot}$  and  $\gamma_3 M_{tot}$ ) and mid-span moments ( $\gamma_2 M_{tot}$ ) **into moments in column and middle strips**.



We split the support and mid-span moments into column and middle strips using precalculated coefficients  $\omega$ , and the **moments in the column and middle strips** are:

 $M_{col} = \omega \times (\gamma_i M_{tot}),$  $M_{mid} = (1 - \omega) \times (\gamma_i M_{tot}).$ 

Note: The column and middle strip moments are in kNm (per strip width).

Example:

Support moment in inner panel:  $M = M_{tot} \cdot \gamma_1 = 100 \text{ kNm}$  (per panel width). Moment in column strip:  $M_{col} = 100 \cdot 0.75 = 75 \text{ kNm}$  (per column strip width). Moment in middle strip:  $M_{mid} = 100 \cdot (1 - 0.75) = 25 \text{ kNm}$  (per middle strips width).

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The precalculated coefficients  $\omega$  are:

• in mid-span:  $\omega = 0.6$ ,



• at wall:  $\omega$  is not used.

# Rigidity of the edge beam

Rigidity coefficient of edge beam is:

$$\beta_{\rm t} = \frac{I_{\rm t}}{2I_{\rm s}}$$

# Rigidity of the edge beam

The moment of inertia  $I_s$  of the slab in lane 3 is:



The torsion moment of inertia of edge beam  $I_t$  is:



# Rigidity of the edge beam

We must divide the cross-section of the edge beam into parts (2 alternatives):



Calculate  $I_t$  for both alternatives and use the higher value to calculate  $\beta_t$ .

#### Moments near wall

For the **support at a wall**, we **don't split** the moment into column and middle strip, and we assume that the support moment is **uniformly distributed** along the panel width.



## Moments per 1 meter

Finally, we will **calculate bending moments per 1 meter width** by dividing the moments in the column and middle strips (which are in kNm per strip width) by the widths of column or middle strips.  $T = \frac{1}{1 + 1} \frac{1}{1 +$ 

#### The final moments will be in kNm/m.



Example:

Moment in column strip:  $M_{col} = 75$  kNm (per column strip width). Column-strip width:  $b_{col} = 3.25$  m.

Unit moment in column strip:  $m_{col} = 75/3.25 = 23.1 \text{ kNm/m}$ .

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#### Moments per 1 meter near wall

Remember, at the **support at a wall**, we **did not split** the moment into column and middle strip, and we assumed that the support moment is **uniformly distributed** along the lane width.

Therefore, at the wall, the bending moments per 1 meter width is calculated by dividing the moment above support (which is in kNm per panel width) by the widths of the panel.



# Moment drawing

Finally, when we get all of the bending moment values, we can draw moment curves for calculated moments per 1 meter. There will be 4 curves:

- Belt C column strip
- Belt C middle strip
- Belt 3 column strip
- Belt 3 middle strip





#### Homework format

Calculate **total moments and support/midspan moments by hand**, then input them into table and calculate **column/middle strip moments in the table**. See <u>example calculation</u>.

Moments in column and middle strips										
Panel	Cross-section	Positive/negative moment M <sub>i</sub> [kNm]	Strip	ω	Moment in column/middle strip M <sub>j</sub> [kNm]	Width of the strip s <sub>j</sub> [m]	Moment per 1 m of the slab m <sub>j</sub> [kNm/m]			
	1 (left support)	179,76	no division	1,00	179,76	5,90	30,47			
Co	2 (midspan)	96,80	Column Middle	0,60	58,08 38,72	2,65 3,25	21,92 11,91			
	3 (right support)	179,76	Column Middle	0,75	134,82 44,94	2,65 3,25	50,88 13,83			
	1 (left support)	313,20	Column Middle	0,75	234,90 78.30	2,95 2,95	79,63 26,54			
C <sub>in</sub>	2 (midspan)	168,66	Column Middle	0,60	101,20 67,46	2,95 2,95	34,30 22,87			
	3 (right support)	313,20	Column Middle	0,75	234,90 78,30	2,95 2,95	79,63 26,54			
	1 (left support)	119,11	Column Middle	0,99	117,44 1,67	2,95 4,05	39,81 0,41			
3 <sub>0</sub>	2 (midspan)	198,50	Column Middle	0,60	119,10 79,40	2,95 4,05	40,37 19,60			
	3 (right support)	277,92	Column Middle	0,75	208,44 69,48	2,95 4,05	70,66 17,16			
	1 (left support)	258,07	Column Middle	0,75	193,55 64,52	2,95 4,05	65,61 15,93			
3 <sub>in</sub>	2 (midspan)	138,96	Column Middle	0,60	83,38 55,58	2,95 4,05	28,26 13,72			
	3 (right support)	258,07	Column Middle	0,75	193,55 64,52	2,95 4,05	65,61 15,93			



# thank you for your attention

