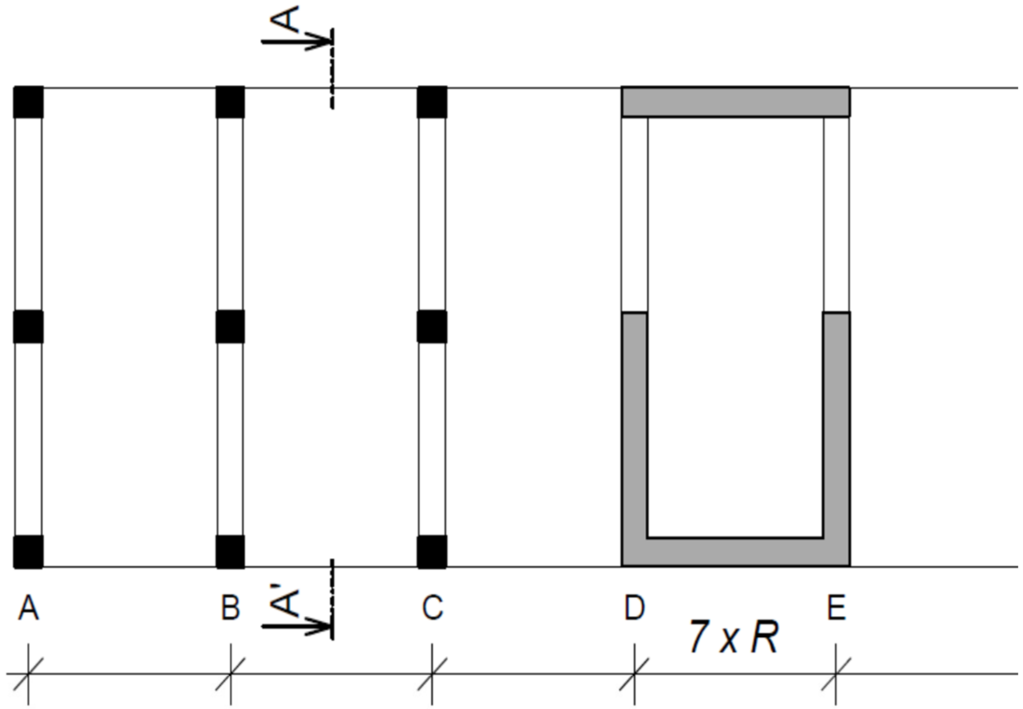
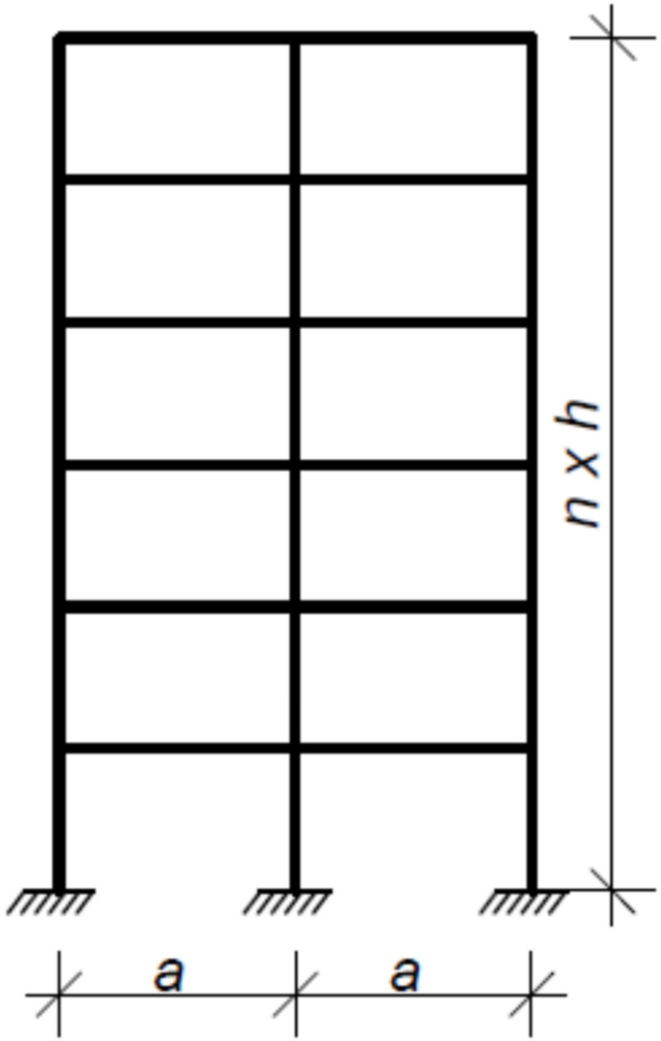
# 1st task:
# **Frame Structure**



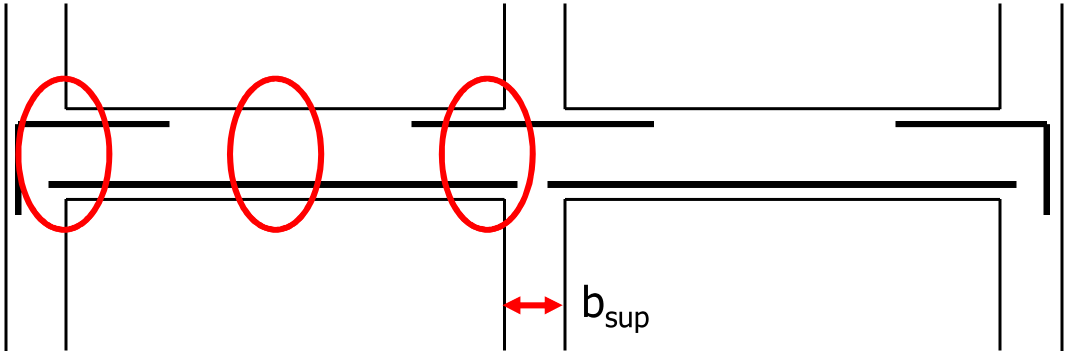



# Design of reinforcement

- Design the reinforcement of the frame in the 1st floor
- Bending reinforcement of the beam
- Shear reinforcement of the beam
- **Use the maximum values of internal forces from the „envelope“ of internal forces**

# Bending reinforcement

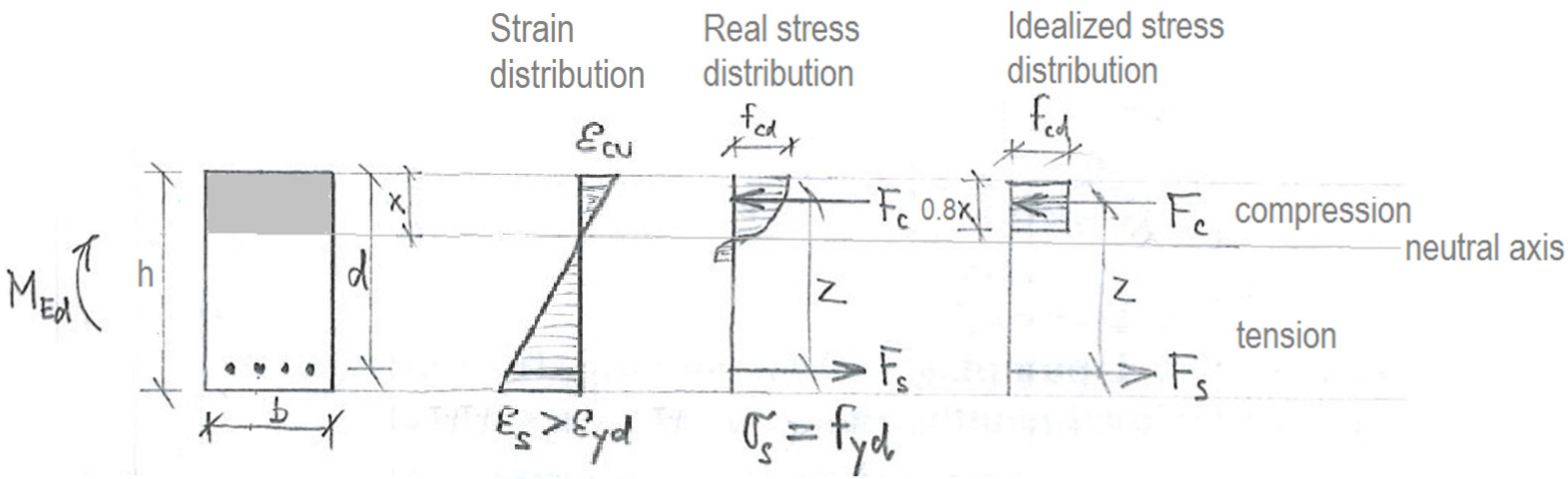
- Design the tensile reinforcement in 3 cross-sections




- In supports, maximum values from FEM calculation should be reduced to values in the face of the column:

$$\left|M_{\text{Ed,red}}\right| = \left|M_{\text{Ed,FEM}}\right| - \left|V_{\text{Ed,FEM}}\right| \frac{b_{\text{sup}}}{2}$$

# Bending reinforcement




$$M_{Rd} = M_{Ed}$$

$$F_c = F_s$$

# Bending reinforcement

- Design of reinforcement:

$$M_{Rd} = M_{Ed}$$

$M_{Ed,red}$ in supports, $M_{Ed,FEM}$ in midspan

$$F_s z = M_{Ed}$$

$$A_{s,rqd} f_{yd} z = M_{Ed}$$

$$A_{s,rqd} = \frac{M_{Ed}}{z f_{yd}} = \frac{M_{Ed}}{0.9 d_B f_{yd}} \Rightarrow \text{Propose } A_{s,prov} \geq A_{s,rqd}$$

Effective height of beam

$$d_B = h_B - \frac{\varnothing}{2} - \varnothing_{sw} - c$$

Stirrups, 6-12 mm

Bending reinforcement, 16-25 mm (more only if necessary)

*Example:* **DESIGN**: 3x Ø16 ($A_{s,prov}$ = 603 mm$^2$)

# Bending reinforcement

- Check of the design:

$$F_c = F_s$$

$$A_c f_{cd} = A_s f_{yd}$$

$$0.8xbf_{cd} = A_{s,prov} f_{yd}$$

$$x = \frac{A_{s,prov} f_{yd}}{0.8bf_{cd}}$$

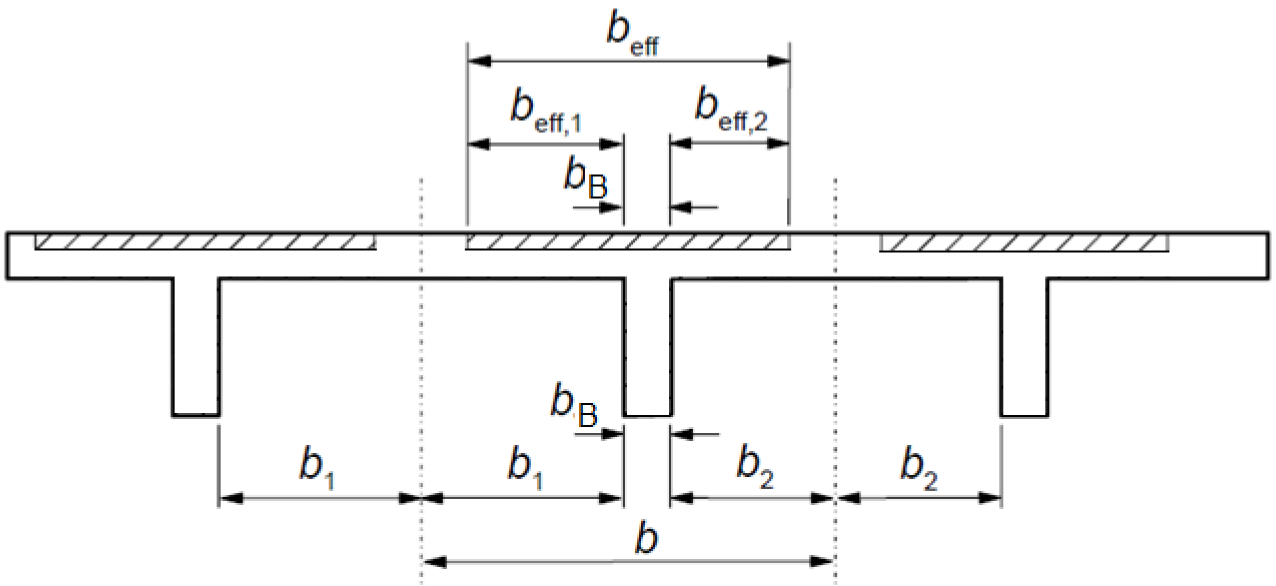
Width of compressed part of the cross-section, $b_B$ in supports, $b_{eff}$ in midspan

$$\Rightarrow z = d_B - 0.4x$$

$$\Rightarrow M_{Rd} = A_{s,prov} f_{yd} z \geq M_{Ed}$$

# Effective width $b_{eff}$

- Midspan – T-shaped section




$$b_{eff} = \sum_i b_{eff,i} + b_B \le b \quad \text{where} \quad b_{eff,i} = 0.2b_i + 0.1l_0 \le 0.2l_0 \quad \text{and} \quad b_{eff,i} \le b_i$$

Distance between zero moments on the beam,
for outer span of the beam **$l_0 \approx 0.85 l_B$**
for inner span of the beam $l_0 \approx 0.7 l_B$

# Detailing rules

Mean tensile strength of concrete, see table with properties of concrete classes from 1st class

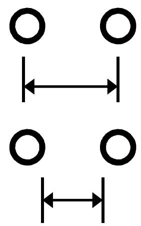
$$\xi = \frac{x}{d_B} \leq \min\left(\xi_{bal,1} = \frac{700}{700 + f_{yd}}; 0,45\right)$$

$$A_{s,prov} \geq A_{s,min} = \max\left(0.26\frac{f_{ctm}}{f_{yk}}b_B d_B; 0.0013 b_B d_B\right)$$

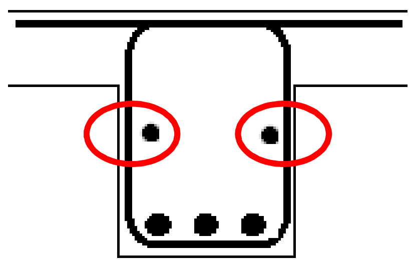
$$A_{s,prov} \leq A_{s,max} = 0.04 b_B d_B$$

Axial spacing of rebars → $s_a \leq s_{a,max} = \min\left(2h_B;\ 250\ \text{mm}\right)$

Clear spacing of rebars → $s_c \geq s_{c,min} = \max\left(20\ \text{mm};\ 1,2\varnothing\right)$

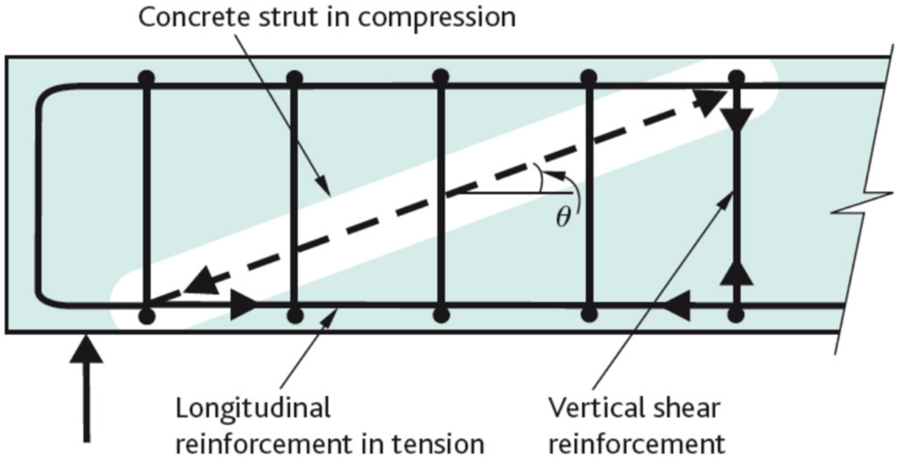


- If $h_B \geq 500$ mm, torsion reinforcement is necessary (add two 12 mm rebars to the middle of the beam)

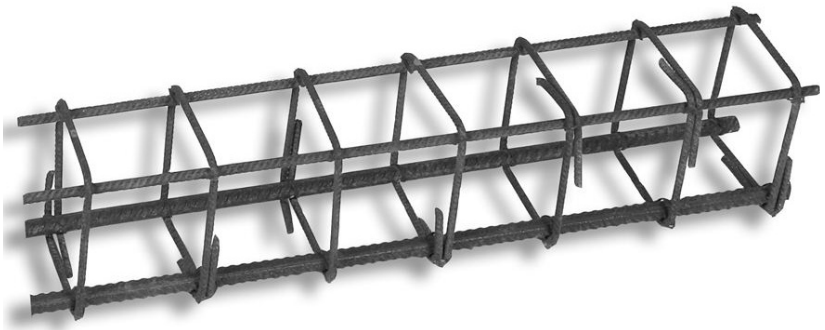


# Shear reinforcement

- Resistance of compressed concrete struts was already checked in preliminary design ($V_{Rd,max} \geq V_{Ed,max}$)

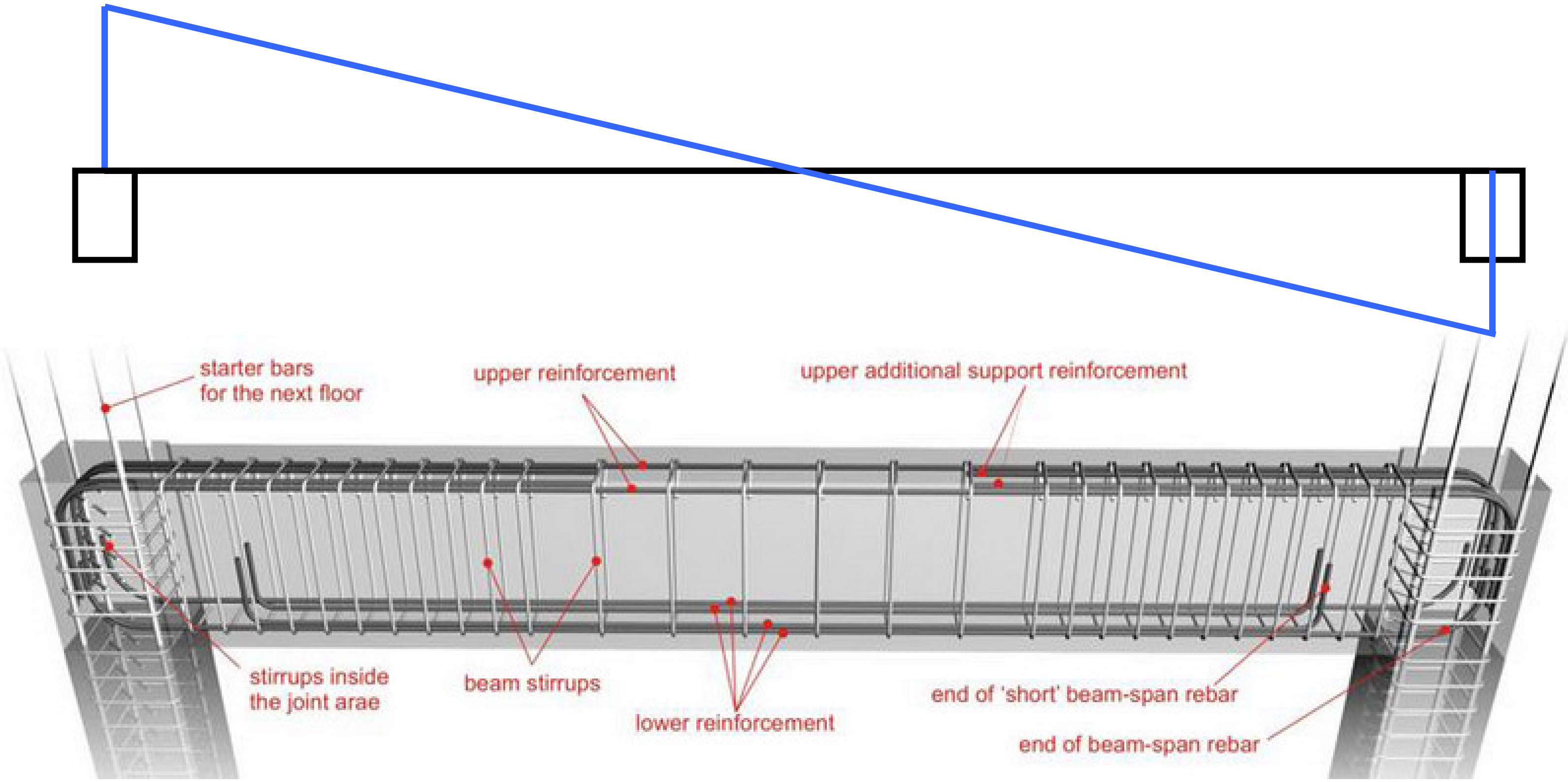



- Shear reinforcement = stirrups



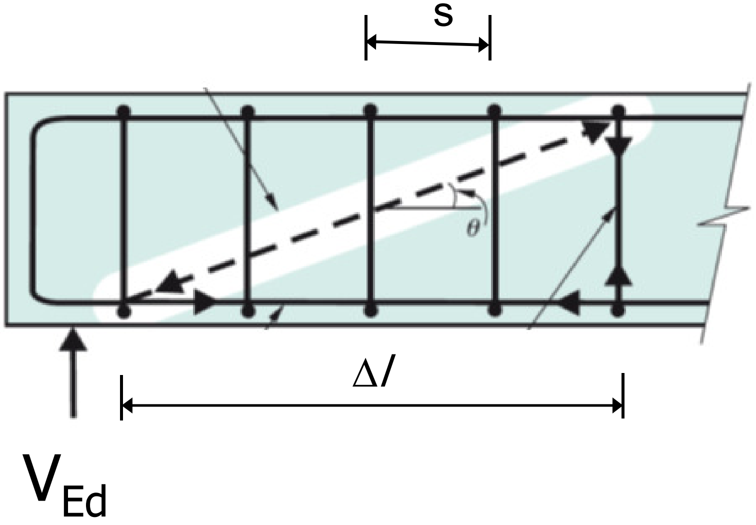
# Shear reinforcement – principle

- The higher the shear force, the denser the stirrups



# Shear reinforcement – principle

- Force imposed on the structure: $V_{Ed}$
- Load-bearing capacity of one stirrup: $A_{sw}f_{yd}$
- Spacing of stirrups: *s*
- Horizontal projection of shear crack: $\Delta l$



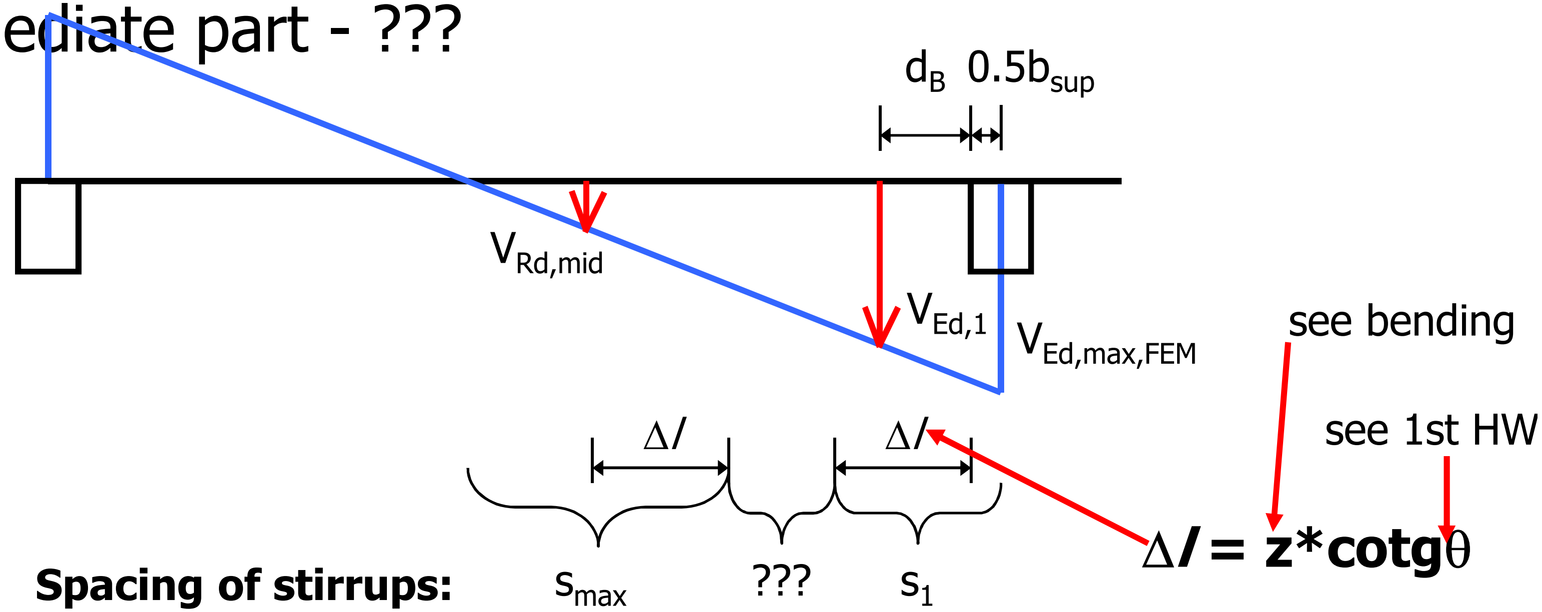

$$V_{Ed} = V_{Rd}$$

$$V_{Ed} = \frac{\Delta l}{s} A_{sw} f_{yd}$$

Number of stirrups required on the length of Δl

# Shear reinforcement – practice

- Direct support => we can reduce theoretical maximum shear force to the value in the distance $d_B$ from the face of the column ($V_{Ed,1}$)
- Up to the distance $\Delta l$ behind the support, we will design the stirrups in spacing $s_1$ (design force is $V_{Ed,1}$)
- In middle part of the beam, shear force is low => stirrups will be designed with maximum possible spacing $s_{max}$
- Intermediate part - ???



# Stirrups near the support ($s_1$)

- Design shear force – similar triangles

$$\left|V_{\mathrm{Ed,1}}\right| = \left|V_{\mathrm{Ed,max,FEM}}\right| \frac{v - \left(\frac{b_{\mathrm{sup}}}{2} + d_{\mathrm{B}}\right)}{v}$$

v – see slide 16

- Spacing of stirrups:

$$s_1 \leq \frac{A_{\mathrm{sw}} f_{\mathrm{yd}}}{V_{\mathrm{Ed,1}}} \Delta l$$

$$\text{and } s_1 \leq 0,75 d_{\mathrm{B}}$$

$$\text{and } s_1 \leq 400 \text{ mm}$$

$$\text{and } s_1 \geq 100 \text{ mm (recommended)}$$

Cross-sectional area of 1 stirrup

$$A_{\mathrm{sw}} = \frac{n\pi\varnothing_{\mathrm{sw}}^2}{4}$$

Number of legs of each stirrup, n=2

**DESIGN:** Stirrup $\varnothing_{sw}$ mm per $s_1$ mm

# Stirrups near the support ($s_1$)

- Check shear resistance:

$$V_{\mathrm{Rd,sw,1}} = \frac{A_{\mathrm{sw}} f_{\mathrm{yd}}}{s_1} \Delta l \geq V_{\mathrm{Ed,1}}$$

- Check shear reinforcement ratio

$$\rho_{\mathrm{sw,1}} = \frac{A_{\mathrm{sw}}}{b_{\mathrm{B}} s_1} \geq \rho_{\mathrm{sw,min}} = \frac{0,08\sqrt{f_{\mathrm{ck}}}}{f_{\mathrm{yk}}}$$

$$\rho_{\mathrm{sw,1}} = \frac{A_{\mathrm{sw}}}{b_{\mathrm{B}} s_1} \leq \rho_{\mathrm{sw,max}} = \frac{0,5\nu f_{\mathrm{cd}}}{f_{\mathrm{yd}}}$$

Coefficient expressing effect of shear cracks and transversal deformations

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

- If not checked, increase $ø_{sw}$ or decrease $s_i$

# Stirrups in the middle part ($s_{max}$)

- Design the spacing according to the condition:

$$s_{\mathrm{max}} \le \min\left(0,75 d_{\mathrm{B}}; 400\ \mathrm{mm}\right)$$

- Check shear reinforcement ratio

$$\rho_{\mathrm{sw,2}} = \frac{A_{\mathrm{sw}}}{b_{\mathrm{B}} s_{\mathrm{max}}} \ge \rho_{\mathrm{sw,min}} = \frac{0,08\sqrt{f_{\mathrm{ck}}}}{f_{\mathrm{yk}}}$$

$$\rho_{\mathrm{sw,2}} = \frac{A_{\mathrm{sw}}}{b_{\mathrm{B}} s_{\mathrm{max}}} \le \rho_{\mathrm{sw,max}} = \frac{0,5 \nu f_{\mathrm{cd}}}{f_{\mathrm{yd}}}$$

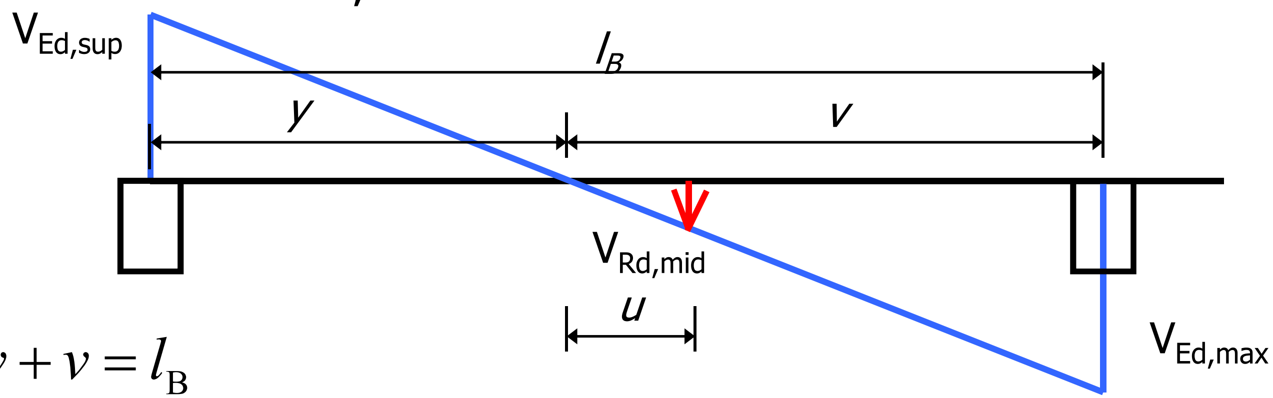
- If not checked decrease $s_{max}$

# Stirrups in the middle part ($s_{max}$)

- Shear force for which $s_{max}$ is sufficient

$$V_{\mathrm{Rd,mid}} = \frac{A_{\mathrm{sw}} f_{\mathrm{yd}}}{s_{\mathrm{max}}} \Delta l$$

- Position of $V_{Rd,mid}$ – similar triangles:




$$y + v = l_{\mathrm{B}}$$

$$\frac{V_{\mathrm{Ed,sup}}}{y} = \frac{V_{\mathrm{Ed,max}}}{v} \rightarrow v \qquad \frac{V_{\mathrm{Rd,mid}}}{u} = \frac{V_{\mathrm{Ed,max}}}{v} \rightarrow u$$

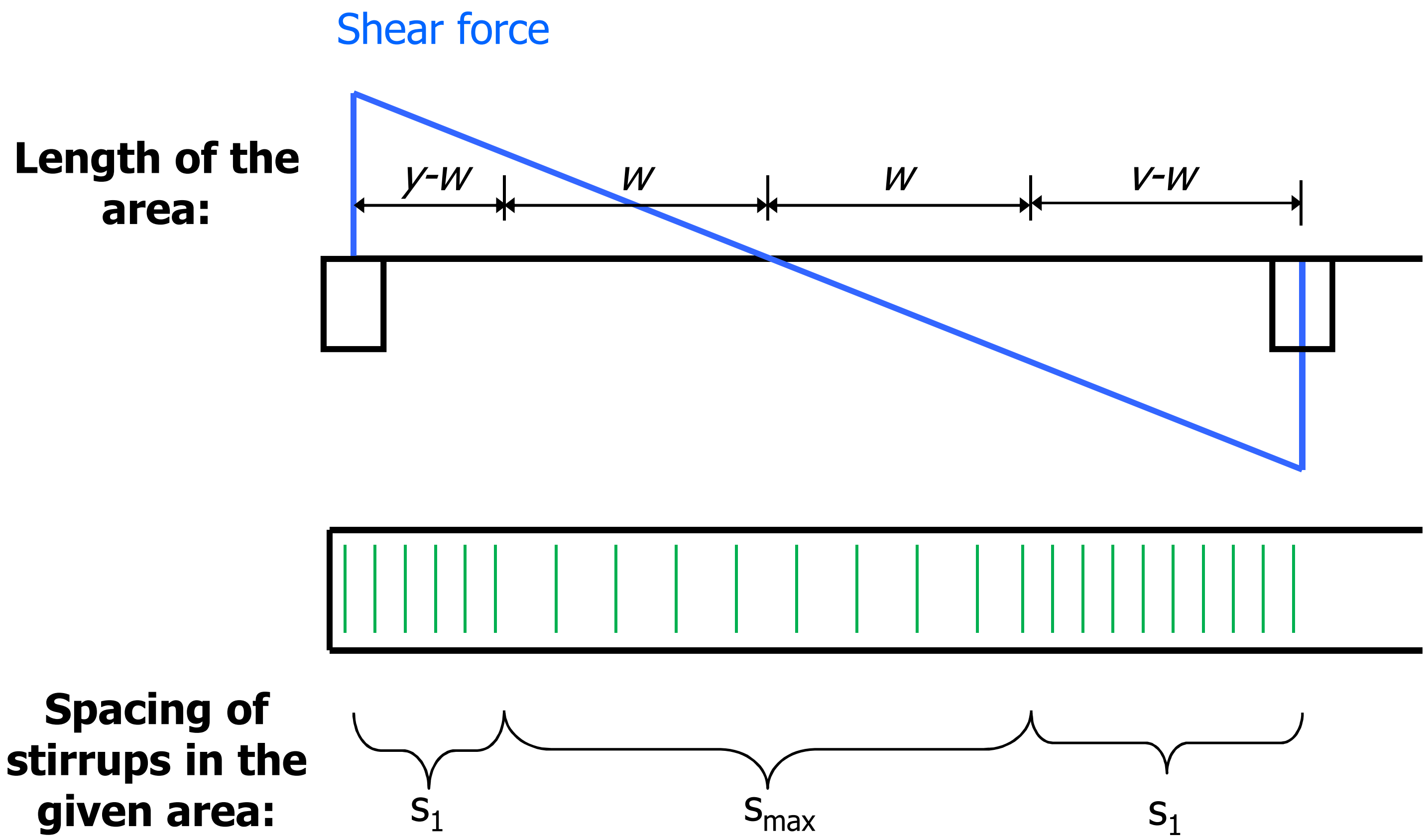
- Length of the area reinforced by stirrups with spacing $s_{max}$:

$$w = u + \Delta l$$

# Stirrups in the intermediate part

- Theoretically, we could calculate $V_{Ed,2}$ using similar triangles and design spacing $s_2$ for the stirrups in the intermediate part ($s_1 < s_2 < s_{max}$)
- Position of $V_{Ed,2}$: 2*$\Delta$l from the face of the column
- BUT: this makes sense only for really long beams or beams with point forces
- In our case, we will **use $s_1$** in the intermediate part

# Layout of stirrups




- Draw the scheme above with **YOUR** numerical values in your homework !!!