

Греда 1

Материали

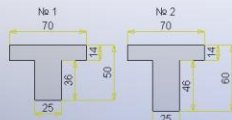
Бетон клас В20 с изчислително съпротивление на натиск $R_b = 11.5 \text{ MPa}$

Стомана за надлъжна арматура клас АIII с изчислително съпротивление на опън $R_{sc} = 375 \text{ MPa}$

Стомана за напречна арматура клас АI с изчислително съпротивление на опън $R_{sw} = 180 \text{ MPa}$

Коефициенти за условия на работа: $\gamma_b = 1.00$; $\gamma_s = 1.00$

Напречни сечения



Статическа схема и натоварване

Полета

№	L, м	Сечение	№	Тип	$R_{k,под}$	Вкл.под	$R_{k,над}$	Вкл.над
1	4	1	1	С	35	25	35	25
2	6	2	2	С	35	25	35	25
3	4	1	3	С	35	25	35	25
4	4	1	4	С	35	25	35	25

Опори

Състояние

№	Тип	Коеф.	№	Поло	Съст	q, kN/m	q ₂ , kN/m	γ , м	L, м	F, kN	M, kNm	A, м
1	П	1.2	1	1	40	40						
2	П	1.35	2	2	20	20						
3	Р	1.3	3	3	10	10						



Software Package

Design Expert version 2.0

RC Expert

Design of reinforced concrete elements

User Manual

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About the program

RC Expert is created for design of reinforced concrete elements with rectangular, T and I sections according to Bulgarian code and Eurocode 2. Calculations are performed for bending, compression or tension, shear force, torsion, cracks and deflection (last is to Bulgarian code only). Second order effects are included for columns if effective lengths are entered. Software is quick and easy to work, with rich functionality and friendly user interface. Input data and design results can be printed in a professional html report.




Entering data

Input data and results are divided into several pages:

You can switch between separate pages by clicking the corresponding tabs. Enter input data and click  **"Results"** to view the report. If file is not saved, you will be prompted to do that.

Input data in each page is filled in text fields or tables. You can move to the next field with left click or **Tab** key. With **Shift+Tab** key combination you can go back to the previous field.



Files

Input data for each problem is saved in a file with extension ***.stb**. Design output is written to a ***.stb.html** file in HTML format. You can open a file by the  **"Open"** button. You can save a file by the  **"Save"** button. If a file is saved for first time, a standard dialog appears where you should select file path and name. Otherwise, file is saved using current filename. You can change filename with the  **"New"** command. Input data remains unchanged. To enter multiple elements in one session: input the first, calculate and draw, click **"Save"**, click **"New"**, input the second, calculate and draw, click **"Save"** and so on.

Input data

Following input data is common for all design checks. There is additional data for different kinds of checks that is described in the respective chapters.


Design codes

You can select between two design codes – Bulgarian **"NPBStBK"**  and **"Eurocode 2"** . Other design codes may be developed in future versions.


Loads

Enter ultimate values for internal forces in the section – bending moment M_{Ed} , axial force N_{Ed} , shear force Q (V_{Ed}) and torsion T_{Ed} . Axial force is negative "–" for compression and positive "+" for tension.

Cross Section

Enter section dimensions directly into the picture on the right side of the window. You can see scaled preview of the section by clicking the  button. Section can be rectangular, T or I shaped. Enter zeroes for dimensions of flanges for rectangular section. Concrete cover d_1, d_2 (a, a') is measured from concrete edge to center of area of main reinforcement.

Materials

Select concrete grade and steel grades for main and shear reinforcement. You can view detailed tables with design properties of concrete and steel by clicking the  button. You can also modify material properties or add new materials.

Design to Bulgarian code (NPBStBK)

Bending with axial force

Input of strength reduction factors γ_b and γ_s is required additionally. To include second order effects check the "Column" box and enter element length L and buckling lengths in plane of bending L_{ox} and out of plane L_{oy} . You can enter initial compressive reinforcement $A_{s2,ini}$ that will be favorable for calculation of tension reinforcement. Compressive reinforcement may come from other load combination with opposite moment or may be required by design code. Option "Seismic loads" includes an additional factor of 0.85 for calculation of limit compression zone ratio ξ_R and an additional check $N/(A \cdot R_{bn}) < 0.5$ according to seismic code. Seismic factors γ_k are not included automatically. You should enter them in fields γ_b and γ_s by multiplying them to the respective strength reduction factors.

Design can handle all cases of combined bending and tension (+) or compression (-). Reinforcement can be either symmetrical or unsymmetrical.

Second order effects are included by the η factor, calculated according to NPBStBK, equation (19): $\eta = 1/(1 - N/N_{cr})$. Buckling force is calculated by equation (68):

$$N_{cr} := \frac{6.4 E_b}{l_0^2} \cdot \left[\frac{I_b}{\varphi_1} \cdot \left(\frac{0.11}{0.1 + \delta_e} + 0.1 \right) + \frac{E_s}{E_b} \cdot I_s \right]$$

Creep factor is determined by the formula $\varphi_1 = 1 + M_G/M$. Ratio $KG = M_G/M$ is the ratio of bending due to dead and permanent loads to total bending. It is entered next to loads as "Long term load factor".

Buckling force N_{cr} depends on second moment of inertia of reinforcement I_{st} and the reinforcement is still unknown. Several iterations are required in order to obtain I_{st} for the final reinforcement that is designed. Calculations are performed by clicking the "Results" button. Following values are calculated:

- A_s, A'_s – areas of bottom and top reinforcement;
- μ, μ' – respective reinforcement ratios;
- σ_{s}, σ'_s – stresses at centers of bottom and top reinforcement;
- x – height of compression zone.
- $A_{s,tot}$ – total column reinforcement for out of plane bucking.

Design is performed by numerical procedure for arbitrary section with general loading. Although this version supports only rectangular, T and I section it will be easy to add new shapes in the future (e.g. circular, ring etc.). Design is based on the following assumptions: Concrete stress is completely neglected in tension zone and all tension is carried by reinforcement. Concrete compression stress diagram is rectangular with constant value R_b . Unknown values are: A_s – tensile reinforcement area; A'_s – compressive reinforcement area; x – compression zone height. They are determined from the condition for balance of internal forces:

$$\mathbf{N} + \mathbf{N}_b + \mathbf{N}_s + \mathbf{N}_s' = 0 \quad (1)$$

$$\mathbf{M} + \mathbf{M}_b + \mathbf{M}_s + \mathbf{M}_s' = 0 \quad (2)$$

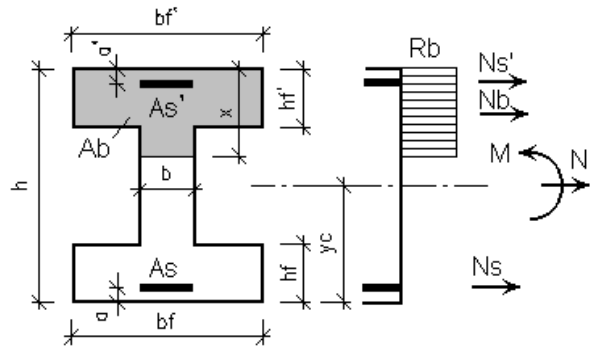
\mathbf{M} and \mathbf{N} are section loads. Internal forces for concrete and reinforcement and resulting moments in section center of are calculated as follows:

$$\mathbf{N}_b = \mathbf{A}_b \cdot \mathbf{R}_b; \quad \mathbf{M}_b = \mathbf{N}_b \cdot (\mathbf{h} - \mathbf{y}_c - \mathbf{x}/2);$$

$$\mathbf{N}_s = \mathbf{A}_s \cdot \sigma_s; \quad \mathbf{M}_s = \mathbf{N}_s \cdot (\mathbf{y}_c - \mathbf{a})$$

$$\mathbf{N}_s' = \mathbf{A}_s' \cdot \sigma_s'; \quad \mathbf{M}_s' = \mathbf{N}_s' \cdot (\mathbf{h} - \mathbf{y}_c - \mathbf{a}');$$

σ_s and σ_s' are stresses in bottom and top reinforcement respectively:

$$\mathbf{R}_{sc} \leq \sigma_{si} = - \frac{1 - \omega \mathbf{y}_{si} / \mathbf{x}}{1 - \omega / 1.1} \cdot \sigma_{sc,u} \leq \mathbf{R}_{sc} \quad \left| \begin{array}{l} \mathbf{y}_{si} = \mathbf{h}_0 - 3\mathbf{a} \sigma_s \\ \mathbf{y}_{si} = \mathbf{a}' - 3\mathbf{a} \sigma_s' \end{array} \right.$$


Formulas for stresses are based on equation (77), $\omega = 0.85 - 0.008 \cdot \mathbf{R}_b$.

Solution is found by an iterative algorithm as follows:

Initial values for reinforcement are assumed to be minimum allowed values by code.

Iterations are repeated until equation (2) is satisfied as follows:

Compressive zone height \mathbf{x} is determined by equation (1). This is also an iterative process: First interval $\{0; \mathbf{h}\}$ is calculated for $\mathbf{x} = 0$, $\mathbf{x} = \mathbf{h}/2$ and $\mathbf{x} = \mathbf{h}$. One of the two subintervals $\{0; \mathbf{h}/2\}$ and $\{\mathbf{h}/2; \mathbf{h}\}$ is selected where equation (1) has different signs in both ends. Calculations are repeated and continued the same way until

$\mathbf{N} + \mathbf{N}_b + \mathbf{N}_s + \mathbf{N}_s' < \delta$, where δ is the acceptable error.

Then the condition $\mathbf{M} + \mathbf{M}_b + \mathbf{M}_s + \mathbf{M}_s' < \delta$ is verified and if satisfied, calculations are finished.

If it is not satisfied then values of \mathbf{N}_s and \mathbf{N}_s' are calculated by equations for balance of moments about centers of bottom and top reinforcement, respectively:

$$\mathbf{N}_s = (\mathbf{M} - \mathbf{M}_b' + \mathbf{N} \cdot (\mathbf{h} - \mathbf{y}_c - \mathbf{a}')) / \mathbf{z}_s \quad \mathbf{N}_s' = - (\mathbf{M} - \mathbf{M}_b - \mathbf{N} \cdot (\mathbf{y}_c - \mathbf{a})) / \mathbf{z}_s$$

Moments about centers of bottom and top reinforcement due to concrete stress are as follows:

$$\left. \begin{array}{l} \mathbf{M}_b = \mathbf{N}_b \cdot \mathbf{z}_b \\ \mathbf{M}_b' = - \mathbf{N}_b \cdot (\mathbf{z}_s - \mathbf{z}_b) \end{array} \right\} \text{where } \mathbf{z}_b \text{ is the distance between the center of} \\ \text{compression zone and the bottom reinforcement}$$

and \mathbf{z}_s is the distance between centers of bottom and top reinforcement.

Necessary areas of bottom and top enforcement are calculated from the respective forces:

$$\mathbf{A}_s = \mathbf{N}_s / \mathbf{R}_s \text{ при } \mathbf{N}_s > 0; \mathbf{A}_s = - \mathbf{N}_s / \mathbf{R}_{sc} \text{ при } \mathbf{N}_s < 0;$$

In case of bending where $\xi = \mathbf{x}/\mathbf{h}_0 < \xi_R := \frac{\omega}{1 + \frac{\sigma_{sR}}{\sigma_{scu}} \cdot \left(1 - \frac{\omega}{1.1}\right)}$ or in case of compression/ tension

combined with bending, area of compression reinforcement is calculated:

$$\mathbf{A}_s' = \mathbf{N}_s' / \mathbf{R}_s \text{ if } \mathbf{N}_s > 0; \mathbf{A}_s' = - \mathbf{N}_s' / \mathbf{R}_{sc} \text{ if } \mathbf{N}_s' < 0;$$

Iteration is repeated.

Additional checks are performed for out of plane buckling due to axial force $\mathbf{N} < m \cdot \varphi \cdot (\mathbf{R}_b \cdot \mathbf{A} + \mathbf{R}_{sc} \cdot \mathbf{A}_{s,tot})$. Buckling factor φ is determined from Table 33 in Bulgarian code NPBStBK using effective length \mathbf{L}_{oy} . Total reinforcement area $\mathbf{A}_{s,tot}$ is calculated as a result.

Shear

Shear design is performed for elements with shear links and straight bars (no inclined bars). The following additional data is required:

n_w – number of shear link cuts;

d – shear link diameter;

c – critical crack projection.

Concrete capacity without shear reinforcement is also provided. Ultimate concrete stress is verified for combined shear and torsion. Influence of axial force N is taken into account. Compression flange is neglected. The following values are calculated as a result:

$Q_{b,min} = \varphi_{b3} \cdot \varphi \cdot R_{bt} \cdot b \cdot h_0$ – concrete capacity without shear reinforcement

$Q_{max} = 0.3 \cdot \varphi_{b1} \cdot \varphi_w \cdot R_b \cdot b \cdot h_0$ – ultimate concrete capacity.

If $Q > Q_{max}$, section size or concrete grade should be increased.

A_{sw} – area of shear reinforcement for one meter and one cut;

μ_w – ratio of shear reinforcement.

Shear reinforcement is calculated as follows:

The value of $M_b = \varphi_{b2} \cdot \varphi \cdot R_{bt} \cdot b \cdot h_0^2$ is found.

Projection of critical crack is $h_0 \leq c_0 = 2 \cdot M_b / Q \leq 2.25 \cdot h$. Equation (92) from NPBStBK is used where q_{sw} is replaced by formula (94a) for $Q = Q_{b,sw}$

If value of $c \neq 0$ is entered then c instead c_0 is used.

Shear capacity of concrete is: $Q_b = M_b / c_0 > Q_{b,min}$ – equation (88) from NPBStBK.

Load carried by shear reinforcement (kN/m) is: $q_{sw} = (Q - Q_b) / c_0 \geq Q_{b,min} / (2 \cdot h_0)$

Area of shear reinforcement (cm²/m) is: $A_{sw} = q_{sw} \cdot 100 / (n_w \cdot 0.8 \cdot R_{sw})$

Design tension resistance of shear reinforcement (without reduction) is noted as R_{sw} . Factors used in the above equations are calculated according to the design code as follows:

$$\varphi_w = 1 + 5 \cdot E_{sw} / E_b \cdot n_w \cdot A_{sw} / (b \cdot 100) \leq 1.3$$

$$\varphi_{b1} = 1 - 0.01 \cdot R_b; \varphi_{b2} = 1.5; \varphi_{b3} = 0.6; \varphi_{b4} = 1.5$$

$$\varphi = 1 + \varphi_f + \varphi_n \leq 1.5$$

$$\varphi_n = \begin{cases} -0.1 \cdot N / (R_{bt} \cdot A_{w0}) & \text{- за натиск } (N < 0) \\ -(0.2 \cdot N / (R_{bt} \cdot A_{w0}) \leq 0.8) & \text{- за опън } (N > 0) \end{cases}$$

The factor for T sections is neglected conservatively - $\varphi_f = 0$

Torsion

All section parts are included into calculations for I and T sections. Total torsional moment is distributed among separate parts proportionate to their torsional stiffness. Additional main and shear reinforcements are calculated to those by other analysis. Shear stress is calculated including shear force:

$$\tau = Q / A_{w0} + 1.2 \cdot T / W_t, \text{ where } A_{w0} = b_w \cdot h_0$$

$$\text{Requirement for shear reinforcement: } \tau > 0.6 \cdot R_{bt}$$

$$\text{Concrete capacity check: } \tau < 0.3 \cdot R_b$$

$$\text{Shear reinforcement: } A_{sw,t} = p \cdot 100 / (0.9 \cdot R_{sw})$$

Main reinforcement:

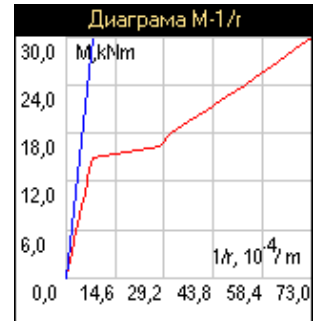
$$A_{s,tot} = \rho \cdot U_{ef} / (0.9 \cdot R_s);$$

$$\rho = T / (2 \cdot A_{ef}); \quad b_{ef} = b - 2 \cdot a_w; \quad h_{ef} = h - 2 \cdot a_w; \quad U_{ef} = 2 \cdot (b_{ef} \cdot h_{ef}); \quad A_{ef} = b_{ef} \cdot h_{ef}$$

Concrete cover a_w is defined to the center of main reinforcement.

Crack widths and deflection

The program calculates moment of cracking M_{cr} , crack widths a_{cr} and deflection for simply supported or cantilever beam. Deflection is compared to the admissible value in design code. In addition, curvature and ratio of nonlinear to linear stiffness are calculated. Curvature-moment diagram is provided as well. Linear curvature is drawn in blue and nonlinear is in red.



Required input data includes beam type (simply supported or cantilever), beam length L , nominal distributed load q_n or maximal moment M_n . Main reinforcement should be entered as actual number and diameter of bottom and top bars in the element. There is no option for different diameters on one side. Environment conditions for the structure are specified.

For calculation of bending due to permanent and long-term loads, "Long term load ratio" is used as defined in "Internal forces" section.

In version 2.0 calculations are to Bulgarian code only.

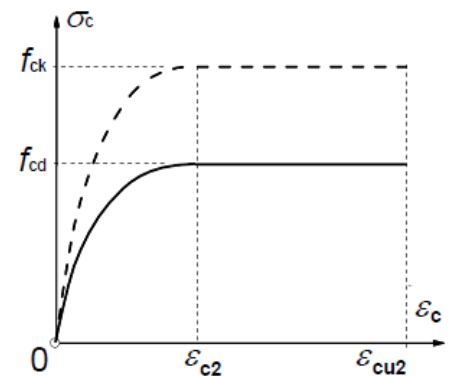
Design to Eurocode 2

Bending with axial force

Design can handle all cases of combined bending with tension (+) or compression (-). Reinforcement can be either symmetrical or unsymmetrical.

Following assumptions are used in the design:

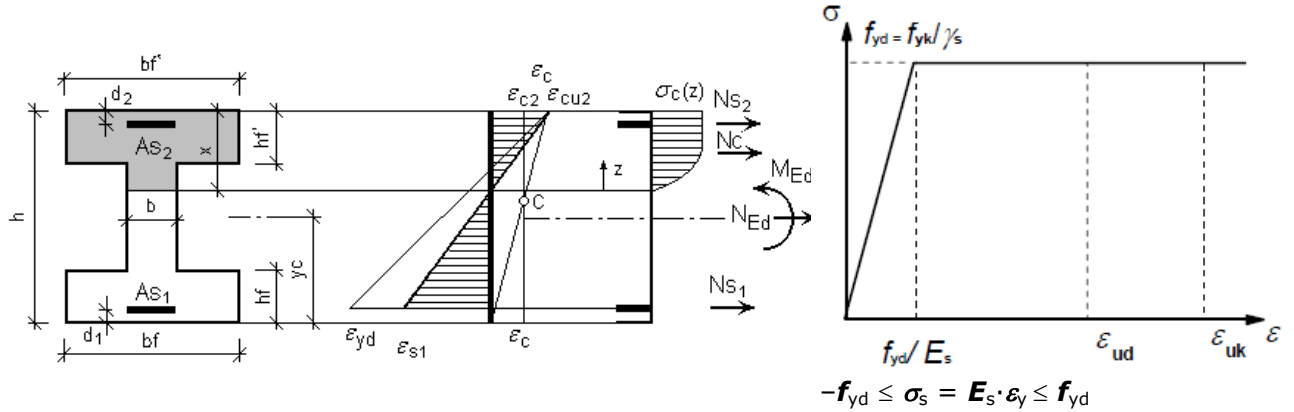
- concrete tensile stress is ignored and all tension is carried by the reinforcement;
- stress-strain relationship for concrete is parabolic-linear with maximum value of f_{cd} ;
- stress-strain relationship for steel is linear-plastic with maximum value of f_{yd} ;
- there is friction between concrete and reinforcement;
- plane sections remain plane after deformation (Bernoulli case);
- strain in reinforcement and concrete is limited and section capacity is reached when limit strain is achieved;
- internal forces in concrete and reinforcement should balance section forces due to external loads.



for $0 \leq \epsilon_c \leq \epsilon_{c2}$ -

$$\sigma_c = f_{cd} \left[1 - \left(1 - \frac{\epsilon_c}{\epsilon_{c2}} \right)^n \right]$$

for $\epsilon_{c2} \leq \epsilon_c \leq \epsilon_{cu2}$ - $\sigma_c = f_{cd}$



Unknown values are A_{s1} – tensile reinforcement area; A_{s2} – compressive reinforcement area; ε_{s1} – strain in tension reinforcement; ε_c – strain in compressed concrete edge or ε_{s2} – tension strain in top reinforcement for sections entirely in tension. Strain is limited to: $\varepsilon_{cu2} \leq \varepsilon_c \leq 0$ – for concrete and $\varepsilon_{c2} \leq \varepsilon_s \leq \varepsilon_{yd}$ – for reinforcement. For sections entirely in compression strain diagram should rotate around point **C**. Strain in point C is ε_{c2} and distance of point C to top edge is equal to $a_c = h \cdot (1 - \varepsilon_{c2} / \varepsilon_{cu2})$. Unknown values are determined by the condition for balance of internal forces:

$$N_{Ed} + N_c + N_{s1} + N_{s2} = 0 \quad (1)$$

$$M_{Ed} + M_c + M_{s1} + M_{s2} = 0 \quad (2)$$

where M_{Ed} and N_{Ed} are section loads. Internal forces for concrete and reinforcement and resulting moments in section center are calculated as follows:

$$N_c = \int_0^x \sigma_c(z) \cdot b(z) \cdot dz; \quad M_c = N_c \cdot (z_c + h - y_c - x); \quad z_c = \int_0^x \sigma_c(z) \cdot b(z) \cdot z \cdot dz / N_c$$

$$N_{s1} = A_{s1} \cdot \sigma_{s1}; \quad M_{s1} = N_{s1} \cdot (y_c - d_1);$$

$$N_{s2} = A_{s2} \cdot \sigma_{s2}; \quad M_{s2} = N_{s2} \cdot (h - y_c - d_2);$$

Solution is found by an iterative algorithm as follows:

Initial values for reinforcement are assumed to be minimum allowed values by code.

Iterations are repeated until equation (2) is satisfied as follows:

Strains ε_{s1} и ε_c are calculated by condition (1) using iterative algorithm until $N_{Ed} + N_c + N_{s1} + N_{s2} < \delta$, where δ is the acceptable error.

Then the condition $M_{Ed} + M_c + M_{s1} + M_{s2} < \delta$ is verified and if satisfied, calculations are finished.

If it is not satisfied then values of N_{s1} and N_{s2} are calculated by equations for balance of moments about centers of bottom and top reinforcement, respectively:

$$N_{s1} = (M_{Ed} - M_{c2} + N_{Ed} \cdot (h - y_c - d_2)) / z_s$$

$$N_{s2} = -(M_{Ed} - M_{c1} - N_{Ed} \cdot (y_c - d_1)) / z_s$$

Moments about centers of bottom and top reinforcement due to concrete stress are as follows:

$$M_{c1} = N_c \cdot (h - x - d_1 + z_c)$$

$$M_{c2} = -N_c \cdot (x - z_c)$$

where z_s is the distance between centers of bottom and top reinforcement.

Necessary areas of bottom and top reinforcement are calculated from the respective forces:

$$A_{s1} = N_{s1} / f_{yd} \text{ if } N_s > 0; A_{s1} = -N_{s1} / f_{yd} \text{ if } N_{s1} < 0;$$

In case of bending where $K = M / (b \cdot h_0^2 \cdot f_{ck}) > K' = 0.168$ or in case of compression/ tension combined with bending, area of compression reinforcement is calculated:

$$A_{s2} = N_{s2} / f_{yd} \text{ at } N_s > 0; A_{s2} = -N_{s2} / f_{yd} \text{ at } N_{s2} < 0;$$

Iteration is repeated.

Second order effects are included for members in compression.

Bending moments due to second order effects are calculated by the equation:

$$M_{Ed} = M_{0Ed} / (1 - N/N_B) \quad (\text{Eq. 5.30 from EC2})$$

First order bending moment $M_{0Ed} = M + N \cdot e_i$ includes initial imperfections.

$$e_i = \theta_i \cdot L_{ox} / 2 \quad (\text{Eq. 5.2 from EC2})$$

$$M_{0Ed} \geq N \cdot e_0 \quad e_0 = h / 30 \geq 20 \text{ mm}$$

$$\theta_i = \theta_0 \cdot \alpha_h \cdot \alpha_m; \quad \theta_0 = 1/200; \quad \alpha_h = 2/(L/100)^{1/2}; \quad \alpha_m = 1;$$

$$N_B = \pi^2 \cdot EI / L_{ox}^2 \quad (\text{Eq. 5.17 from EC2})$$

$$EI = K_c \cdot E_{cd} \cdot I_c + K_s \cdot I_s \quad (\text{Eq. 5.21 from EC2})$$

$$K_s = 1; \quad K_c = k_1 \cdot k_2 / (1 + \varphi_{ef}); \quad k_1 = (f_{ck}/20)^{1/2}; \quad k_2 = n \cdot \lambda / 170;$$

$$n = N_{ed} / (A_c \cdot f_{cd}); \quad \lambda = L_{ox} / i; \quad i = (I_c / A_c)^{1/2}$$

Effective creep factor is calculated by the formula: $\varphi_{ef} = \varphi(\infty, t_0) \cdot M_{0Eqp} / M_{0Ed}$. Ratio M_{0Eqp} / M_{0Ed} is entered by the user as „Long term load factor“. Creep factor $\varphi(\infty, t_0)$ should be also defined by user according to Figure 3.1 in EC2 .

Buckling force N_B depends on second moment of inertia of reinforcement I_s and the reinforcement is unknown at this stage. Several iterations are required in order to obtain I_s for the final reinforcement that is designed. Calculations are performed by clicking the „**Results**“ button. Following values are calculated:

A_{s1}, A_{s2} – areas of bottom and top reinforcement;

μ_1, μ_2 – respective reinforcement ratios;

σ_{s1}, σ_{s2} – stresses at centers of bottom and top reinforcement;

x – height of compression zone.

The program provides M-M capacity curve for the section with the calculated reinforcement. You can set initial reinforcement and obtain the capacity curve for it. Diagram is calculated by changing strains ε_{s1} and ε_c within specified limits. Ultimate section resistance is calculated for each position and is plotted in **M-N** coordinate system. Diagram is a closed curve. If we plot external moment and axial force as a point in the same system we can compare it to the section capacity. If the point is inside the capacity curve then section is OK for the load. If the point is outside the capacity curve then section will fail. Reinforcement is calculated so that capacity curve goes through the point of external loads.

Shear

Shear design is performed for elements with vertical or inclined shear links and straight main bars (no inclined bars). The following additional data is required:

n_w – number of shear link cuts;

d – shear link diameter;

c – critical crack projection.

θ – angle of compression strut;

α – angle between links and a vertical line;

A_s – existing tension reinforcement (cm^2) with sufficient anchorage behind the section of interest.

The following values are calculated to Eurocode 2:

$V_{Rd,c} = (C_{Rd,c} \cdot k \cdot (100 \cdot \rho \cdot f_{ck})^{0.3333} + k_1 \cdot \sigma_{cp}) \cdot b \cdot h_0$ – concrete capacity without shear reinforcement (Eq. 6.2.a)

$V_{Rd,c} \geq V_{Rd,c,min} = (v_{min} + k_1 \cdot \sigma_{cp}) \cdot b \cdot h_0$ (Eq. 6.2.b)

$$k = 1 + (200/h_0)^{1/2}; \quad \sigma_{cp} = N_{Ed}/A_c < 0,2 f_{cd};$$

$$C_{Rd,c} = 0,18/\gamma_c; \quad k_1 = 0.15;$$

$$v_{min} = 0,035 \cdot k^{3/2} \cdot f_{ck}^{1/2}; \quad \rho = A_s/(b \cdot h_0) \leq 0.002;$$

$V_{Rd,max} = \alpha_c \cdot b \cdot z \cdot v_1 \cdot f_{cd} \cdot (\cot\theta + \cot\alpha)/(1 + \cot^2\theta)$ – ultimate concrete capacity in the compression strut (Eq. 6.14 from EC2). If $V_{Ed} > V_{Rd,max}$, section dimensions or concrete grade should be increased.

$z = 0.9 \cdot h_0$ is lever arm of internal forces;

$$v_1 = 0.6 \cdot (1 - f_{ck}/250) - \text{(Eq. 6.6N of EC2)}.$$

Load, carried by shear reinforcement (kN/m): $q_{sw} = V_{Ed} / (z \cdot (\cot\theta + \cot\alpha) \cdot \sin\alpha)$

Area of shear reinforcement (cm^2/m): $A_{sw} = q_{sw}/(n_w \cdot f_{yw})$

Additional tension force in main reinforcement: $F_{td} = 0.5 \cdot V_{Ed} \cdot (\cot\theta - \cot\alpha)$

Additional main reinforcement to take this force: $A_{slH} = F_{td}/f_{yd}$

$V_{Ed} = V$ is the shear load entered by the user.

If angle θ is entered to be $\theta \neq 0$, the specified value is used in calculations. If angle is $\theta = 0$, it is calculated by the condition $V_{Rd,max} = V_{Ed}$, providing that $21.8^\circ \leq \theta \leq 45^\circ$ ($1 \leq \cot\theta \leq 2.5$).

Link spacing is calculated by the formula:

$$s = A_{sw}/(\pi d^2/4) < s_{max} = 0.75 \cdot h_0 \cdot (1 + \cot\alpha).$$

Torsion

All section parts are included into calculations for I and T sections. Total torsional moment is distributed among separate parts proportionate to their torsional stiffness. Additional main and shear reinforcements are calculated to those by other analysis. Design of each rectangular part of the section is described below.

Concrete cover a_w is defined to the center of main reinforcement.

The following checks are performed for combined torsion with shear force:

$$\text{Concrete capacity without shear reinforcement: } T_{Ed}/T_{Rd,c} + V_{Ed}/V_{Rd,c} > 1 \quad (6.29)$$

$$\text{Ultimate concrete capacity in compression struts: } T_{Ed}/T_{Rd,max} + V_{Ed}/V_{Rd,max} < 1 \quad (6.31)$$

$$\text{Ultimate torsion without shear reinforcement: } T_{Rd,c} = 2 \cdot A_k \cdot t_{ef} \cdot f_{ctd}$$

$$\text{Ultimate torsion for the concrete section: } T_{Rd,max} = v \cdot \alpha_c \cdot f_{cd} \cdot A_k \cdot t_{ef} \cdot \sin(2 \cdot \theta) \quad (6.30)$$

$T_{Ed} = T$ is the torsional moment entered by the user.


Values for V_{Ed} , $V_{Rd,c}$, $V_{Rd,max}$ are calculated as described in chapter "Shear" above.

Reinforcement is calculated as follows:

Shear reinforcement:	$A_{sw} = P / (f_{yw} \cdot \cot \theta)$	
Main reinforcement:	$A_{stot} = P \cdot U_k \cdot \cot \theta / f_{yd}$	(6.28)
Effective thickness:	$t_{ef} = b \cdot h / (2 \cdot b + 2 \cdot h)$	
t_{ef} is taken not less than $2 \cdot a_w$		
Effective cross section area:	$A_k = (b - t_{ef}) \cdot (h - t_{ef})$	
Perimeter of effective area:	$U_k = 2 \cdot (b + h - 2 \cdot t_{ef})$	
	$P = T_{Ed} / (2 \cdot A_k)$	

Results are provided separately for each part of the section.

Calculation report

Professional html report can be generated for each problem by clicking the  "Results" button. Report is displayed in Internet Explorer by default but other web browsers can be used. Most office programs like MS Word can edit **html** files. Report filename is **data_file_name.html**. It comes together with a folder **data_file_name.html_files**. Always keep together report file with the folder. Otherwise pictures and formatting will be lost.

Examples to Bulgarian code NPBStBK

Example 1. Design of reinforced concrete beam

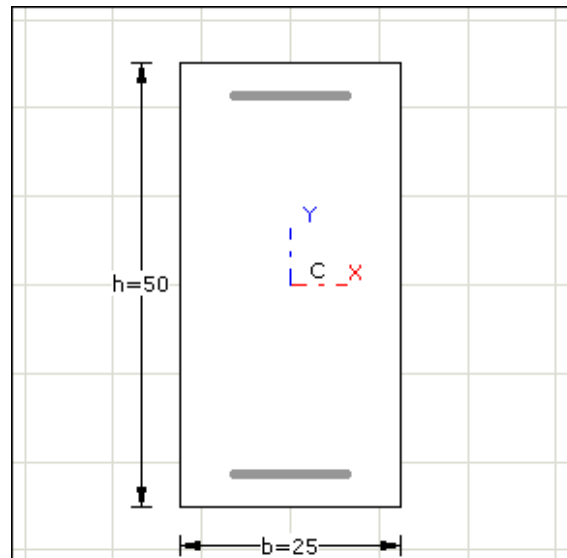
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 25,0 \text{ cm} & h &= 50,0 \text{ cm} \\
 b_f &= 0,0 \text{ cm} & h_f &= 0,0 \text{ cm} \\
 b'_f &= 0,0 \text{ cm} & h'_f &= 0,0 \text{ cm} \\
 a &= 3,5 \text{ cm} & a' &= 3,5 \text{ cm}
 \end{aligned}$$

Section Loads

$$\begin{aligned}
 \text{Bending moment -} & & M &= 162,0 \text{ kN.m} \\
 \text{Axial force-} & & N &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & Q &= 108,0 \text{ kN} \\
 \text{Torsional moment -} & & T &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & KG &= 90,0 \%
 \end{aligned}$$



Materials			
Concrete grade B20	$E_b = 27,5 \text{ MPa}$	$R_b = 11,5 \text{ MPa}$	$R_{bt} = 0,9 \text{ MPa}$
Main reinforcement grade AIII	$E_s = 200,0 \text{ MPa}$	$R_s = 375,0 \text{ MPa}$	$R_{sc} = 375,0 \text{ MPa}$
Shear reinforcement grade AI	$E_{sw} = 200,0 \text{ MPa}$	$R_{sw} = 180,0 \text{ MPa}$	

Bending And Axial Force Design

Strength Reduction Factors		Existing Reinforcement	
Concrete	$\gamma_b = 1,0$	Bottom	$A_{s,ini} = 0,0 \text{ cm}^2$
Reinforcement	$\gamma_s = 1,0$	Top	$A'_{s,ini} = 0,0 \text{ cm}^2$

Shear Force Design

$$\begin{aligned}
 \text{Shear links cuts -} & & n_w &= 2 \\
 \text{Shear links diameter -} & & d &= 8,0 \text{ mm} \\
 \text{Compression strut angle -} & & c &= 0,0 \text{ cm}
 \end{aligned}$$

Deflection And Crack Widths

Beam type - simply supported, beam length $L = 600,0 \text{ cm}$

Distributed load	Bending moment	Axial force
$q_n = 30,0 \text{ kN/m}$	$M_n = 135,0 \text{ kN.m}$	$N_n = 0,0 \text{ kN}$

Existing Reinforcement		
Tensile	4N20,	$A_s = 12,57 \text{ cm}^2$
Compressive	2N12,	$A'_s = 2,26 \text{ cm}^2$

Environment conditions - constant air moisture $< 70\%$ - $\varphi_{b2} = 2,00$, $\nu = 0,15$

Results

Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 10,9 \text{ cm}^2$	$\mu = 0,9 \%$	$\sigma_s = 375,0 \text{ MPa}$
Top	$A'_s = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_s = -375,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 14,0 \text{ cm}^2$	

Bending with axial force design completed successfully!



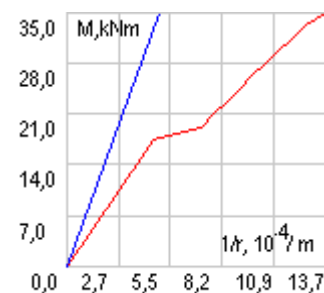
Shear Force Design

- Concrete only resistance - $Q_{b,min} = 62,8 \text{ kN}$
 - Concrete ultimate resistance - $Q_{max} = 374,3 \text{ kN}$
 - Shear reinforcement area - $A_{sw} = 1,9 \text{ cm}^2/\text{m}$
 - Required shear reinforcement - $\Phi 8/25,0 \text{ cm}$
 - Shear reinforcement ratio - $\mu_w = 0,2 \%$
- Shear force design completed successfully!

Deflection And Crack Widths

- Crack opening moment - $M_{crc} = 18,43 \text{ kN.m}$
- Crack width - $a_{crc} = 0,23 \text{ mm}$
- Deflection - $D_{max} = 2,68 \text{ cm} < 3 \text{ cm}$
- Curvature for moment M_n - $1/r = 72,94 \cdot 10^{-4}/\text{m}$
- Stiffness for moment M_n - $B/EI = 0,26$

Deflection and crack widths design completed successfully!



Example 2. Design of reinforced concrete column

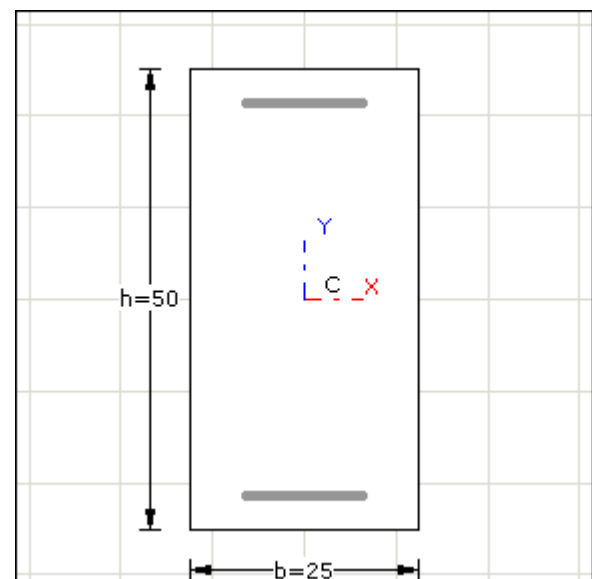
Design with RCExpert

Cross section

- $b = 25,0 \text{ cm}$ $h = 50,0 \text{ cm}$
- $b_f = 0,0 \text{ cm}$ $h_f = 0,0 \text{ cm}$
- $b'_f = 0,0 \text{ cm}$ $h'_f = 0,0 \text{ cm}$
- $a = 3,5 \text{ cm}$ $a' = 3,5 \text{ cm}$

Section Loads

- Bending moment - $M = 400,0 \text{ kN.m}$
- Axial force - $N = -1000,0 \text{ kN}$
- Shear Force - $Q = 0,0 \text{ kN}$
- Torsional moment - $T = 0,0 \text{ kN.m}$
- Long term load factor - $KG = 75,0 \%$



Materials			
Concrete grade B35	$E_b = 33,0 \text{ MPa}$	$R_b = 19,5 \text{ MPa}$	$R_{bt} = 1,3 \text{ MPa}$
Main reinforcement grade AIII	$E_s = 200,0 \text{ MPa}$	$R_s = 375,0 \text{ MPa}$	$R_{sc} = 375,0 \text{ MPa}$
Shear reinforcement grade AI	$E_{sw} = 200,0 \text{ MPa}$	$R_{sw} = 180,0 \text{ MPa}$	

Bending And Axial Force Design сила

Strength Reduction Factors		Existing Reinforcement	
Concrete	$\gamma_b = 1,0$	Bottom	$A_{s,ini} = 0,0 \text{ cm}^2$
Reinforcement	$\gamma_s = 1,0$	Top	$A'_{s,ini} = 0,0 \text{ cm}^2$

Column	Length	Effective lengths
Symmetrical reinforcement	$L = 600,0 \text{ cm}$	In plane of bending - $L_{ox} = 1,0 * L$
		Out plane - $L_{oy} = 1,0 * L$

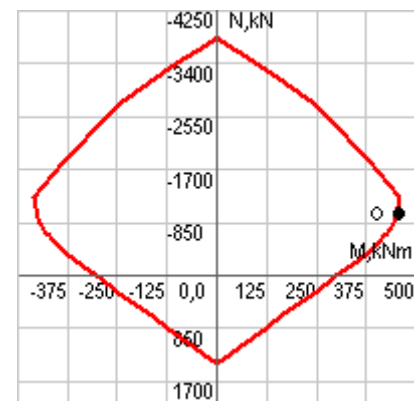
Results

Bending With Axial Force Design

$M_I + M_{II} = 456,5 \text{ kN.m}$

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 18,7 \text{ cm}^2$	$\mu = 1,6 \%$	$\sigma_s = 375,0 \text{ MPa}$
Top	$A'_s = 18,7 \text{ cm}^2$	$\mu' = 1,6 \%$	$\sigma'_s = -375,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 5,0 \text{ cm}^2$	Compr. zone height $x = 21,1 \text{ cm}^2$	

Bending with axial force design completed successfully!



Examples to Eurocode 2

Example 3. Shear force design

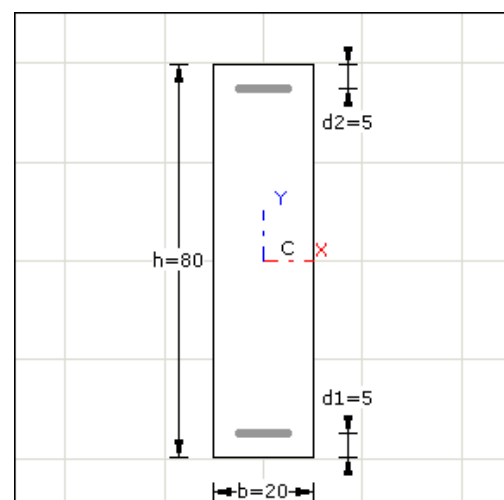
Design with RC Expert

Cross section

$b = 20,0 \text{ cm}$ $h = 80,0 \text{ cm}$
 $b_{f1} = 0,0 \text{ cm}$ $h_{f1} = 0,0 \text{ cm}$
 $b_{f2} = 0,0 \text{ cm}$ $h_{f2} = 0,0 \text{ cm}$
 $d_1 = 5,0 \text{ cm}$ $d_2 = 5,0 \text{ cm}$

Section Loads

Bending moment - $M_{Ed} = 0,0 \text{ kN.m}$
 Axial force- $N_{Ed} = 0,0 \text{ kN}$
 Shear Force - $V_{Ed} = 600,0 \text{ kN}$
 Torsional moment - $T_{Ed} = 0,0 \text{ kN.m}$
 Long term load factor - $K_G = 75,0 \%$





Materials		$\gamma_C = 1,50$	$\gamma_S = 1,15$
Concrete grade C30/37	$E_c = 32,0 \text{ MPa}$	$f_{ck} = 30,0 \text{ MPa}$	$f_{ctk,0.05} = 2,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S450	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 450,0 \text{ MPa}$	$f_{ywd} = 391,0 \text{ MPa}$

Shear Force Design

Shear links cuts - $n_w = 2$
 Shear links diameter - $d = 12 \text{ mm}$
 Compression strut angle - $\theta = 28,7 \text{ deg}$
 Shear links angle - $\alpha = 90,0 \text{ deg}$
 Tensile reinforcement - $A_{sl} = 0,0 \text{ cm}^2$

Results - Shear Force Design

Concrete only resistance - $V_{Rd,c} = 80,0 \text{ kN}$
 Concrete ultimate resistance - $V_{Rd,max} = 600,0 \text{ kN}$
 Shear reinforcement area - $A_{sw} = 6,2 \text{ cm}^2/\text{m}$
 Required shear reinforcement - $\Phi 12/17,5 \text{ cm}$
 Shear reinforcement ratio - $\mu_w = 0,6 \%$
 Additional tensile reinforcement - $A_{slH} = 12,6 \text{ cm}^2 > A_{sl}$

Manual verification

$V_{Ed} = 600 \text{ kN}; \quad f_{ck} = 30 \text{ MPa}; \quad f_{cd} = 20 \text{ MPa}; \quad f_{ywd} = 391 \text{ MPa}$

$h_0 = h - a = 750 \text{ mm}; \quad z = 0.9 \cdot h_0 = 0.9 \cdot 750 = 675 \text{ mm}$

$v = v_1 = 0.6 \cdot (1 - f_{ck}/250) = 0.528$

Calculation of compressive strut angle θ for $V_{Rd,max} = V_{Ed}$:

$$\theta = \frac{1}{2} \arcsin \frac{2 \cdot V_{Ed}}{\alpha_{cw} \cdot v \cdot f_{cd} \cdot b_w \cdot z} = \frac{1}{2} \arcsin \frac{2 \cdot 600000}{1 \cdot 0.528 \cdot 20 \cdot 200 \cdot 675} = 28.7^\circ > 21.8^\circ; \cot \theta = 1.82^\circ$$

Calculation of required shear reinforcement:

$$\frac{A_{sw}}{s} = \frac{V_{Ed}}{z \cdot f_{ywd} \cdot \cot \theta} = \frac{600000}{675 \cdot 391 \cdot 1.82} = 1.249 \text{ m}^2/\text{m}$$

For one cut: $\frac{A_{sw}}{s \cdot n_w} = \frac{12.49}{2} = 6.24 \text{ cm}^2/\text{m}$; Required links are $\Phi 12/175 \text{ mm}$

Additional tensile force: $\Delta F_{td} = 0.5 \cdot V_{Ed} \cdot \cot \theta = 0.5 \cdot 600 \cdot 1.82 = 546 \text{ kN}$

Additional tensile reinforcement for that force: $A_{slH} = \Delta F_{td} / f_{yd} = 546 / 43.5 = 12,6 \text{ cm}^2$

Example 4. Design of rectangular section for bending

Examples 4 to 10 are developed using the book "Reinforced concrete design to Eurocode 2" - Bill Mosley, John Bungey, Ray Hulse, 2007 (Examples 4.1 - 4.10). Formulas are obtained assuming $\alpha_{cc} = 0.85$. Concrete design resistance is $f_{cd} = \alpha_{cc} \cdot f_{ck} / \gamma_c$. Calculations by the program are performed with parabolic-linear stress-strain relationship. Manual verification is performed with rectangular stress distribution and height of compression zone equal to $s = 0.8 \cdot x$.

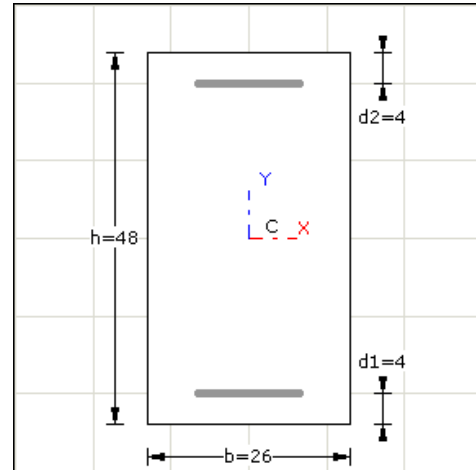
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 26,0 \text{ cm} & h &= 48,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 0,0 \text{ cm} & h_{f2} &= 0,0 \text{ cm} \\
 d_1 &= 4,0 \text{ cm} & d_2 &= 4,0 \text{ cm}
 \end{aligned}$$

Section Loads

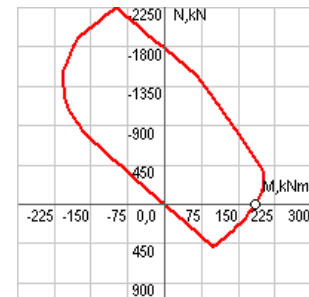
$$\begin{aligned}
 \text{Bending moment -} & & M_{Ed} &= 185,0 \text{ kN.m} \\
 \text{Axial force-} & & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment -} & & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & K_G &= 75,0 \%
 \end{aligned}$$



Materials		$\gamma_c = 1,50; \alpha_{cc} = 0,85$	$\gamma_s = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 434,8 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,3 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 0,0 \text{ cm}^2$
Top	$A'_{s,ini} = 0,0 \text{ cm}^2$



Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 11,3 \text{ cm}^2$	$\mu = 1,0 \%$	$\sigma_s = 434,8 \text{ MPa}$
Top	$A'_s = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_s = -434,8 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 16,3 \text{ cm}^2$	

Manual verification (Example 4.1)

Ultimate bending moment is given $M_{Ed} = 185 \text{ kN.m}$. Find required reinforcement area A_s .

$$K = \frac{M}{b \cdot d^2 \cdot f_{ck}} = \frac{185 \cdot 10^6}{260 \cdot 440^2 \cdot 25} = 0.147 < 0.167 - \text{Compressive reinforcement is not required}$$

$$z = d \cdot \left\{ 0.5 + \sqrt{\left(0.25 - \frac{K}{1.134} \right)} \right\} = 440 \cdot \left\{ 0.5 + \sqrt{\left(0.25 - \frac{0.147}{1.134} \right)} \right\} = 373 \text{ mm}$$

$$A_s = \frac{M}{0.87 \cdot f_{yk} \cdot z} = \frac{185 \cdot 10^6}{0.87 \cdot 500 \cdot 373} = 1140 \text{ mm}^2$$

Example 5. Ultimate bending capacity of rectangular section

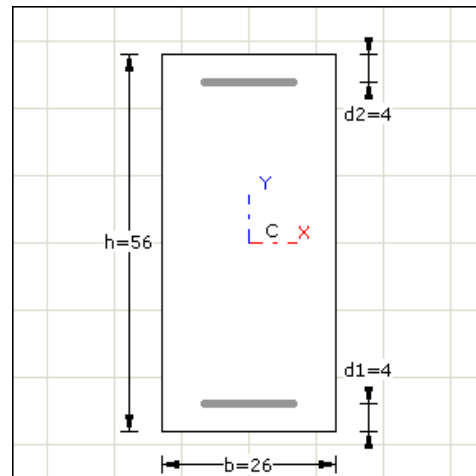
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 26,0 \text{ cm} & h &= 56,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 0,0 \text{ cm} & h_{f2} &= 0,0 \text{ cm} \\
 d_1 &= 4,0 \text{ cm} & d_2 &= 4,0 \text{ cm}
 \end{aligned}$$

Section Loads

$$\begin{aligned}
 \text{Bending moment -} & & M_{Ed} &= 284,0 \text{ kN.m} \\
 \text{Axial force-} & & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment -} & & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & K_G &= 75,0 \%
 \end{aligned}$$



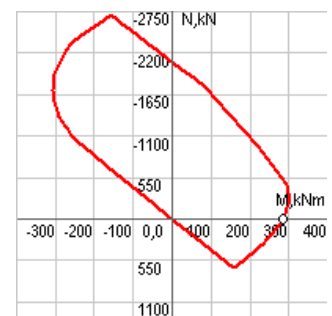
Materials		$\gamma_C = 1,50; \alpha_{cc} = 0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 16,7 \text{ MPa}$	$f_{ctd} = 1,2 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S250	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 250,0 \text{ MPa}$	$f_{ywd} = 217,0 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 14,7 \text{ cm}^2$
Top	$A'_{s,ini} = 0,0 \text{ cm}^2$

Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 15,0 \text{ cm}^2$	$\mu = 1,1 \%$	$\sigma_s = 435,0 \text{ MPa}$
Top	$A'_s = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_s = -435,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 17,7 \text{ cm}^2$	



Manual verification (Example 4.2)

Reinforcement area is given $A_s = 1470 \text{ mm}^2$. Find ultimate bending resistance M_{Rd} .

$$F_{cc} = F_{st} \quad 0.567 \cdot f_{ck} \cdot b \cdot s = 0.87 \cdot f_{yk} \cdot A_s \quad 0.567 \cdot 25 \cdot 300 \cdot s = 0.87 \cdot 500 \cdot 1470$$

$$s = 150 \text{ mm} \quad x = \frac{s}{0.8} = \frac{150}{0.8} = 188 \text{ mm}$$

$$M = F_{st} \cdot z = 0.87 \cdot f_{yk} \cdot A_s \left(d - \frac{s}{2} \right) = 0.87 \cdot 500 \cdot 1470 \cdot \left(520 - \frac{150}{2} \right) \cdot 10^{-6} = 284 \text{ kN/m}$$

Example 6. Bending design of doubly reinforced section

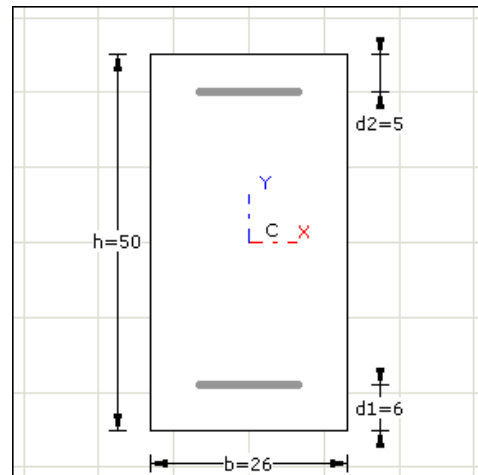
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 26,0 \text{ cm} & h &= 50,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 0,0 \text{ cm} & h_{f2} &= 0,0 \text{ cm} \\
 d_1 &= 6,0 \text{ cm} & d_2 &= 5,0 \text{ cm}
 \end{aligned}$$

Section Loads

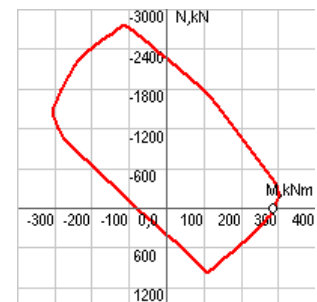
$$\begin{aligned}
 \text{Bending moment} &- & M_{Ed} &= 285,0 \text{ kN.m} \\
 \text{Axial force} &- & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force} &- & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment} &- & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor} &- & K_G &= 75,0 \%
 \end{aligned}$$



Materials		$\gamma_C = 1,50; \alpha_{cc} = 0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,0 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 0,0 \text{ cm}^2$
Top	$A'_{s,ini} = 0,0 \text{ cm}^2$



Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 18,0 \text{ cm}^2$	$\mu = 1,6 \%$	$\sigma_s = 435,0 \text{ MPa}$
Top	$A'_s = 4,3 \text{ cm}^2$	$\mu' = 0,4 \%$	$\sigma'_s = -435,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 20,4 \text{ cm}^2$	

Manual verification (Example 4.3)

Design bending moment is given $M_{Ed} = 285 \text{ kN.m}$. Find required reinforcement A_s and A'_s .

$$K = \frac{M}{b \cdot d^2 \cdot f_{ck}} = \frac{285 \cdot 10^6}{260 \cdot 440^2 \cdot 25} = 0.226 > 0.167 - \text{Compressive reinforcement is required.}$$

$$\frac{d'}{d} = \frac{50}{440} = 0.11 < 0.171$$

$$A'_s = \frac{(K - K_{bal}) \cdot f_{ck} \cdot b \cdot d^2}{0.87 \cdot f_{yk} \cdot (d - d')} = \frac{(0.226 - 0.167) \cdot 25 \cdot 260 \cdot 440^2}{0.87 \cdot 500 \cdot (440 - 50)} = 438 \text{ mm}^2$$

$$A_s = \frac{K_{bal} \cdot f_{ck} \cdot b \cdot d^2}{0.87 \cdot f_{yk} \cdot z_{bal}} + A'_s = \frac{0.167 \cdot 25 \cdot 260 \cdot 440^2}{0.87 \cdot 500 \cdot (0.82 \cdot 440)} + 438 = 1339 + 438 = 1777 \text{ mm}^2$$

Example 7. Ultimate bending capacity of doubly reinforced section

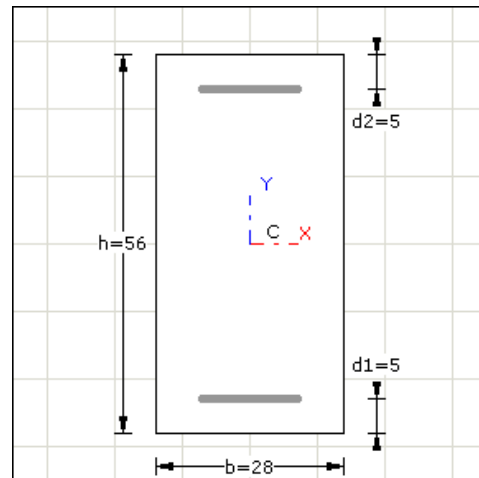
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 28,0 \text{ cm} & h &= 56,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 0,0 \text{ cm} & h_{f2} &= 0,0 \text{ cm} \\
 d_1 &= 5,0 \text{ cm} & d_2 &= 5,0 \text{ cm}
 \end{aligned}$$

Section Loads

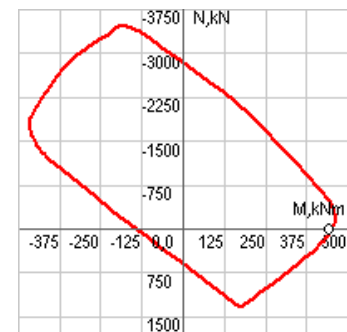
$$\begin{aligned}
 \text{Bending moment -} & & M_{Ed} &= 443,0 \text{ kN.m} \\
 \text{Axial force-} & & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment -} & & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & K_G &= 75,0 \%
 \end{aligned}$$



Materials		$\gamma_C = 1,50; \alpha_{cc} = 0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,0 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 24,1 \text{ cm}^2$
Top	$A'_{s,ini} = 6,3 \text{ cm}^2$



Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 24,1 \text{ cm}^2$	$\mu = 1,7 \%$	$\sigma_s = 435,0 \text{ MPa}$
Top	$A'_s = 6,9 \text{ cm}^2$	$\mu' = 0,5 \%$	$\sigma'_s = -435,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 24,4 \text{ cm}^2$	

Manual verification (Example 4.4)

Reinforcement values are given $A_s = 628 \text{ mm}^2$ and $A'_s = 2410 \text{ mm}^2$. Find section capacity moment M_{Rd} .

$$F_{st} = F_{cc} + F_{sc} \quad 0.87 \cdot f_{yk} \cdot A_s = 0.567 \cdot f_{ck} \cdot b \cdot s + 0.87 \cdot f_{yk} \cdot A'_s$$

$$\frac{0.87 \cdot f_{yk} \cdot (A_s - A'_s)}{0.567 \cdot f_{ck} \cdot b} = \frac{0.87 \cdot 500 \cdot (2410 - 628)}{0.567 \cdot 25 \cdot 280} = 195 \text{ mm} \quad x = \frac{s}{0.8} = 244 \text{ mm}$$

$$\frac{x}{d} = \frac{244}{510} = 0.48 < 0.617 \quad \frac{d'}{x} = \frac{50}{225} = 0.22 < 0.38$$

$$M = F_{cc} \cdot \left(d - \frac{s}{2}\right) + F_{sc} \cdot (d - d') = 0.567 \cdot f_{ck} \cdot b \cdot s \cdot \left(d - \frac{s}{2}\right) + 0.87 \cdot f_{yk} \cdot A'_s \cdot (d - d')$$

$$= \left[0.567 \cdot 25 \cdot 280 \cdot 195 \left(510 - \frac{195}{2}\right) + 0.87 \cdot 500 \cdot 620 (510 - 50) \right] \cdot 10^{-6} = 319 + 124 = 443 \text{ kN/m}$$

Example 8. Ultimate bending capacity of section with flanges

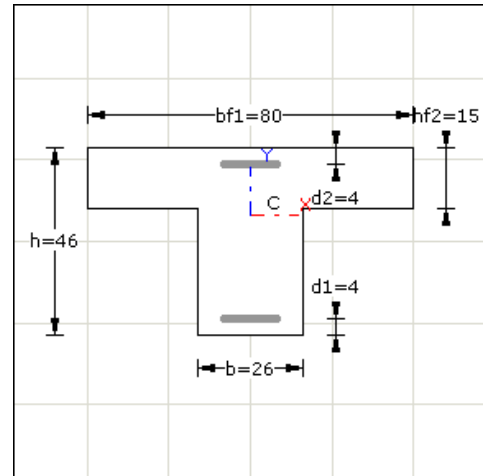
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 26,0 \text{ cm} & h &= 46,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 80,0 \text{ cm} & h_{f2} &= 15,0 \text{ cm} \\
 d_1 &= 4,0 \text{ cm} & d_2 &= 4,0 \text{ cm}
 \end{aligned}$$

Section Loads

$$\begin{aligned}
 \text{Bending moment -} & & M_{Ed} &= 249,0 \text{ kN.m} \\
 \text{Axial force-} & & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment -} & & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & K_G &= 75,0 \%
 \end{aligned}$$



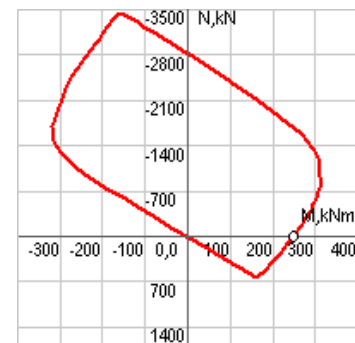
Materials		$\gamma_C = 1,50; \alpha_{cc}=0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,0 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 14,7 \text{ cm}^2$
Top	$A'_{s,ini} = 0,0 \text{ cm}^2$

Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 14,7 \text{ cm}^2$	$\mu = 1,4 \%$	$\sigma_s = 435,0 \text{ MPa}$
Top	$A'_s = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_s = -234,3 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 8,0 \text{ cm}^2$	



Manual verification (Example 4.5)

Reinforcement area is given $A_s = 1470 \text{ mm}^2$. Find section bending capacity M_{Rd} .

$$F_{cc} = F_{st} \quad 0.567 \cdot f_{ck} \cdot b_f \cdot s = 0.87 \cdot f_{yk} \cdot A_s$$

$$s = \frac{0.87 \cdot 500 \cdot 1470}{0.567 \cdot 25 \cdot 800} = 56 \text{ mm} < h_f = 150 \text{ mm}$$

$$x = \frac{s}{8} = 70 \text{ mm} \quad z = d - \frac{s}{2} = 420 - \frac{56}{2} = 392 \text{ mm}$$

$$M = F_{cc} \cdot z = 0.567 \cdot f_{ck} \cdot b_f \cdot s \cdot z = 0.567 \cdot 25 \cdot 800 \cdot 56 \cdot 392 \cdot 10^{-6} = 249 \text{ kN/m}$$

Example 9. Bending design of section with flanges

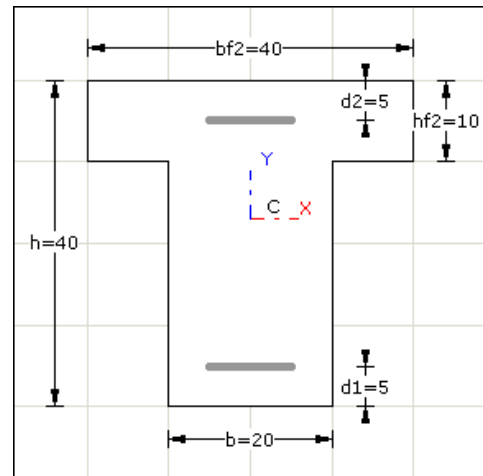
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 20,0 \text{ cm} & h &= 40,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 40,0 \text{ cm} & h_{f2} &= 10,0 \text{ cm} \\
 d_1 &= 5,0 \text{ cm} & d_2 &= 5,0 \text{ cm}
 \end{aligned}$$

Section Loads

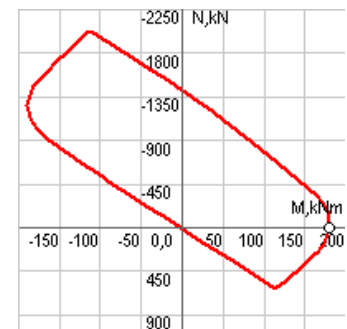
$$\begin{aligned}
 \text{Bending moment -} & \quad M_{Ed} = 180,0 \text{ kN.m} \\
 \text{Axial force-} & \quad N_{Ed} = 0,0 \text{ kN} \\
 \text{Shear Force -} & \quad V_{Ed} = 0,0 \text{ kN} \\
 \text{Torsional moment -} & \quad T_{Ed} = 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & \quad K_G = 75,0 \%
 \end{aligned}$$



Materials		$\gamma_C = 1,50; \alpha_{cc} = 0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 434,8 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,3 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement	
Bottom	$A_{s,ini} = 0,0 \text{ cm}^2$
Top	$A'_{s,ini} = 0,0 \text{ cm}^2$



Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 14,5 \text{ cm}^2$	$\mu = 2,1 \%$	$\sigma_s = 434,8 \text{ MPa}$
Top	$A'_{s} = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_{s} = -434,8 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 13,4 \text{ cm}^2$	

Manual verification (Example 4.6)

Design moment is given $M_{Ed} = 180 \text{ kN.m}$. Find required reinforcement area A_s .

$$M_f = F_{cf} z_1 \quad M_f = 0.567 f_{tk} b_f h_f \left(d - \frac{h_f}{2} \right) = 0.567 \cdot 25 \cdot 400 \cdot 100 \left(350 - \frac{100}{2} \right) \cdot 10^{-6} = 170 \text{ kN.m} < 180 \text{ kN.m}$$

$$\begin{aligned}
 s_w = s - h_f \quad 180 = M_f + F_{cw} z_2 &= 170 + 0.567 f_{tk} b_w s_w z_2 = 170 + 0.567 \cdot 25 \cdot 200 \cdot s_w \left(250 - \frac{s_w}{2} \right) \cdot 10^{-6} = \\
 &= 170 + 2835 \cdot s_w \left(250 - \frac{s_w}{2} \right) \cdot 10^{-6} \quad s_w^2 - 500 s_w + 7.05 \cdot 10^3 = 0 \quad s_w = 15 \text{ mm}
 \end{aligned}$$

$$x = \frac{(h_f + s_w)}{0.8} = \frac{(100 + 15)}{0.8} = 144 \text{ mm} = 0.41 d$$

$$F_{st} = F_{cf} + F_{cw} \quad 0.87 f_{yk} A_s = 0.567 f_{tk} b_f h_f + 0.567 f_{tk} b_w s_w$$

$$0.87 \cdot 500 \cdot A_s = 0.567 \cdot 25 (400 \cdot 100 + 200 \cdot 15) = 610 \cdot 10^3 \quad A_s = \frac{610 \cdot 10^3}{0.87 \cdot 500} = 1402 \text{ mm}^2$$

Example 10. Ultimate bending capacity of section with flanges

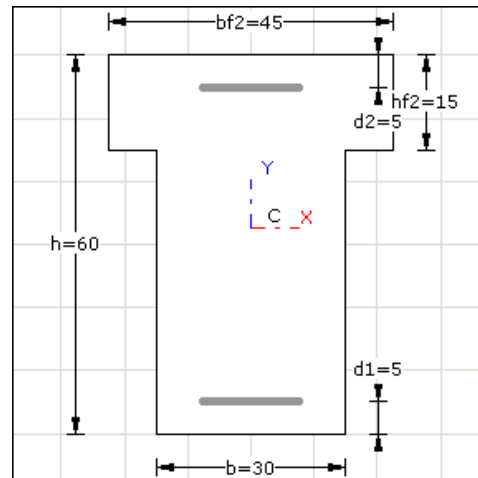
Design with RC Expert

Cross section

$$\begin{aligned}
 b &= 30,0 \text{ cm} & h &= 60,0 \text{ cm} \\
 b_{f1} &= 0,0 \text{ cm} & h_{f1} &= 0,0 \text{ cm} \\
 b_{f2} &= 45,0 \text{ cm} & h_{f2} &= 15,0 \text{ cm} \\
 d_1 &= 5,0 \text{ cm} & d_2 &= 5,0 \text{ cm}
 \end{aligned}$$

Section Loads

$$\begin{aligned}
 \text{Bending moment -} & & M_{Ed} &= 519,0 \text{ kN.m} \\
 \text{Axial force-} & & N_{Ed} &= 0,0 \text{ kN} \\
 \text{Shear Force -} & & V_{Ed} &= 0,0 \text{ kN} \\
 \text{Torsional moment -} & & T_{Ed} &= 0,0 \text{ kN.m} \\
 \text{Long term load factor -} & & K_G &= 75,0 \%
 \end{aligned}$$



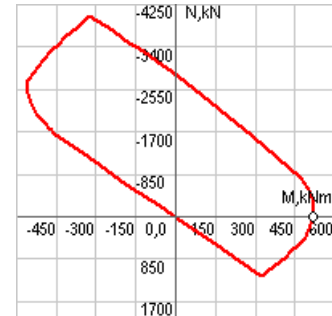
Materials		$\gamma_C = 1,50; \alpha_{cc}=0,85$	$\gamma_S = 1,15$
Concrete grade C25/30	$E_c = 31,5 \text{ MPa}$	$f_{ck} = 25,0 \text{ MPa}$	$f_{ctk,0.05} = 1,8 \text{ MPa}$
		$f_{cd} = 14,1 \text{ MPa}$	$f_{ctd} = 1,0 \text{ MPa}$
Main reinforcement grade S500	$E_y = 200,0 \text{ MPa}$	$f_{yk} = 500,0 \text{ MPa}$	$f_{yd} = 435,0 \text{ MPa}$
Shear reinforcement grade S220	$E_{yw} = 200,0 \text{ MPa}$	$f_{ywk} = 220,0 \text{ MPa}$	$f_{ywd} = 191,0 \text{ MPa}$

Input Data for Bending And Axial Force Design

Existing Reinforcement			
Bottom	$A_{s,ini} = 25,9 \text{ cm}^2$	Top	$A'_{s,ini} = 0,0 \text{ cm}^2$

Results for Bending With Axial Force Design

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_s = 27,1 \text{ cm}^2$	$\mu = 1,6 \%$	$\sigma_s = 435,0 \text{ MPa}$
Top	$A'_s = 0,0 \text{ cm}^2$	$\mu' = 0,0 \%$	$\sigma'_s = -435,0 \text{ MPa}$
Out of plane	$A_{s,tot} = 0,0 \text{ cm}^2$	Compr. zone height $x = 21,1 \text{ cm}^2$	



Manual verification (Example 4.7)

Reinforcement area is given $A_s = 2592 \text{ mm}^2$. Find section bending capacity M_{Rd} .

$$F_{cf} = 0.567 f_{tk} b_f h_f = 0.567 \cdot 25 \cdot 450 \cdot 150 \cdot 10^{-3} = 957 \text{ kN}$$

$$F_{st} = 0.87 f_{yk} A_s = 0.87 \cdot 500 \cdot 2592 \cdot 10^{-3} = 1128 \text{ kN}$$

$$F_{cw} = 0.567 f_{tk} b_w (s - h_f) = 0.567 \cdot 25 \cdot 300 \cdot (s - 150) \cdot 10^{-3} = 4.25 (s - 150)$$

$$F_{cw} = F_{st} - F_{cf} \quad 4.25 \cdot (s - 150) = 1128 - 957 \quad s = 190$$

$$x = \frac{s}{0.8} = 2.38 \text{ mm} = 0.43d \quad F_{cw} = 4.25 \cdot (190 - 150) = 170 \text{ kN}$$

$$M = F_{cf} \left(d - \frac{h_f}{2} \right) + F_{cw} \left(d - \frac{s}{2} - \frac{h_f}{2} \right) = \left[957 \cdot \left(550 - \frac{150}{2} \right) + 170 \cdot \left(550 - \frac{190}{2} - \frac{150}{2} \right) \right] \cdot 10^{-3} = 519 \text{ kN/m}$$

Example 11. Capacity curves for bending and axial force

Draw capacity curves for bending and axial force for the given section using RC Expert. Reinforcement is symmetrical $A_{s1}=A_{s2}$ and $d_1/h=0.1$.

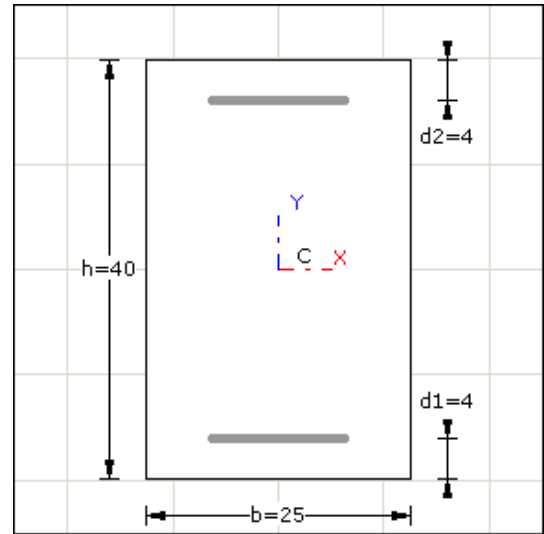
Cross section - rectangular

$$b = 25,0 \text{ cm} \quad h = 40,0 \text{ cm}$$

$$d_1 = 4,0 \text{ cm} \quad d_2 = 4,0 \text{ cm}$$

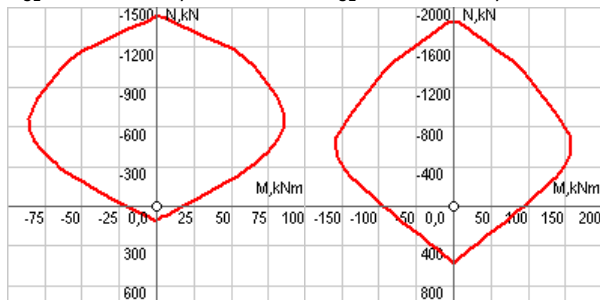
$$\gamma_c = 1,50 \quad \gamma_s = 1,15$$

Materials	
Concrete grade C20/25	$f_{ck} = 20,0 \text{ MPa}$
$E_c = 30,0 \text{ MPa}$	$f_{cd} = 13,3 \text{ MPa}$
Main reinforcement grade S500	$f_{yk} = 500 \text{ MPa}$
$E_y = 200 \text{ MPa}$	$f_{yd} = 435 \text{ MPa}$
Shear reinforcement grade S220	$f_{ywk} = 220 \text{ MPa}$
$E_{yw} = 200 \text{ MPa}$	$f_{ywd} = 191 \text{ MPa}$

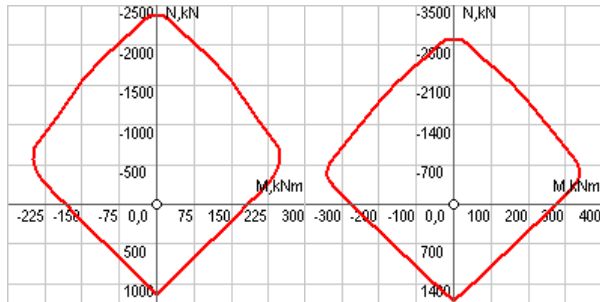


Absolute coordinates M-N

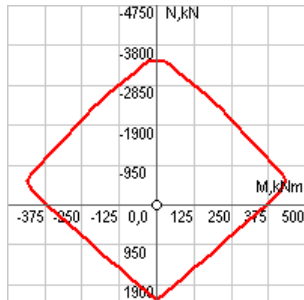
$$A_{s1} = 0.00 \text{ cm}^2, \omega = 0.0 \quad A_{s1} = 6.55 \text{ cm}^2, \omega = 0.5$$



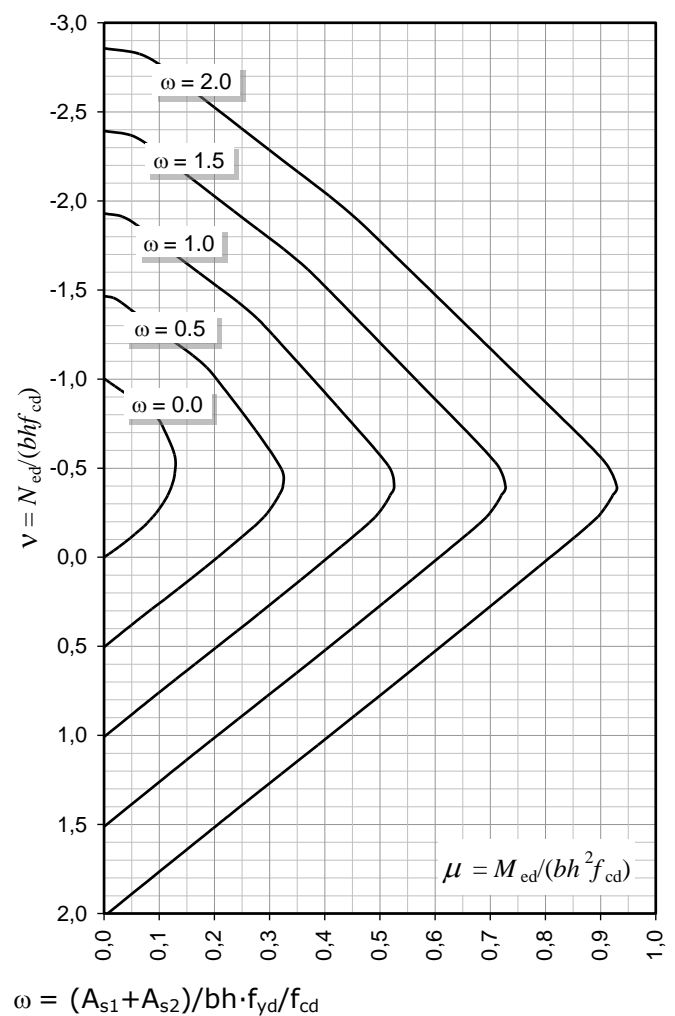
$$A_{s1} = 13.1 \text{ cm}^2, \omega = 1.0 \quad A_{s1} = 19.6 \text{ cm}^2, \omega = 1.5$$



$$A_{s1} = 26.2 \text{ cm}^2, \omega = 2.0$$



Relative coordinates $\mu-v$



Diagrams are calculated for $\epsilon_{yu} = 10\text{‰}$, $\epsilon_{cu2} = 3.5\text{‰}$, $\epsilon_{c2} = 2.0\text{‰}$. Same diagrams calculated for $\epsilon_{yu} = 25\text{‰}$ and $\epsilon_{c2} = 2.2\text{‰}$ are given on fig. 5.54 In the book "Reinforced concrete NPBSK-EC2", K. Roussev, 2008.