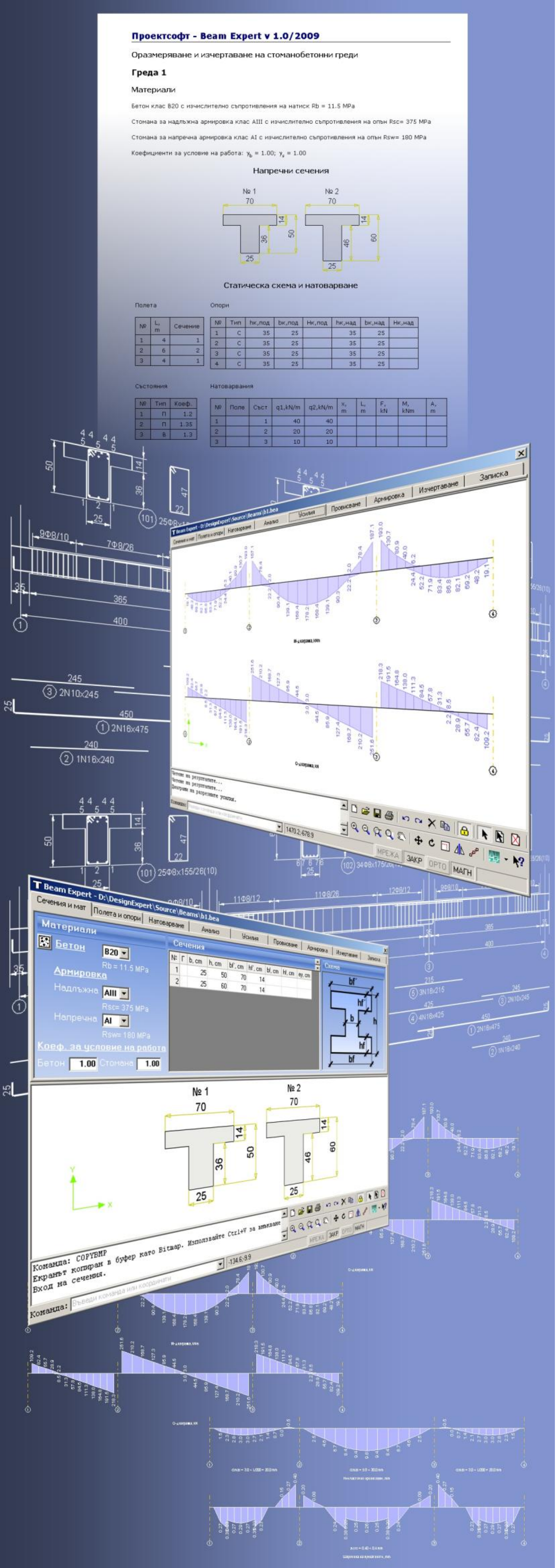


ПРОЕКТСОФТ

Software Package

Design Expert version 2.0

RC Expert

Design of reinforced concrete elements

User Manual

2011

TABLE OF CONTENTS

ABOUT THE PROGRAM 3
ENTERING DATA 3
FILES 3
INPUT DATA 3
Design codes 3
Loads 3
Cross Section 3
Materials 4
DESIGN TO BULGARIAN CODE (NPBSTBK) 4
Bending with axial force 4
Shear 6
Torsion 6
Crack widths and deflection 7
DESIGN TO EUROCODE 2 7
Bending with axial force 7
Shear 9
Torsion 10
CALCULATION REPORT 11
EXAMPLES TO BULGARIAN CODE NPBSTBK 12
Example 1. Design of reinforced concrete beam 12
Example 2. Design of reinforced concrete column 13
EXAMPLES TO EUROCODE 2 14
Example 3. Shear force design 14
Example 4. Design of rectangular section for bending 16
Example 5. Ultimate bending capacity of rectangular section 17
Example 6. Bending design of doubly reinforced seciton 18
Example 7. Ultimate bending capacity of doubly reinforced section 19
Example 8. Ultimate bending capacity of section with flanges 20
Example 9. Bending design of section with flanges 21
Example 10. Ultimate bending capacity of section with flanges 22
Example 11. Capacity curves for bending and axial force 23

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 $\mathbf{M}_{Ed}$, axial force $\mathbf{N}_{Ed}$, shear force **Q** ($\boldsymbol{V}_{Ed}$) and torsion $\mathbf{T}_{Ed}$. 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 d1,d2 (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 $\boldsymbol{L}$ and buckling lengths in plane of bending $\boldsymbol{L}_{ox}$ and out of plane $\boldsymbol{L}_{oy}$. You can enter initial compressive reinforcement $\boldsymbol{A}_{s2,ini}$ 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 $\boldsymbol{N}/(\boldsymbol{A}\cdot\boldsymbol{R}_{bn}) < 0.5$ 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): $\eta = 1/(1 - \boldsymbol{N}/\boldsymbol{N}_{cr})$. Buckling force is calculated by equation (68):

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

Creep factor is determined by the formula $\varphi_l = 1 + \boldsymbol{M}_G/\boldsymbol{M}$. Ratio $\boldsymbol{KG} = \boldsymbol{M}_G/\boldsymbol{M}$ 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".

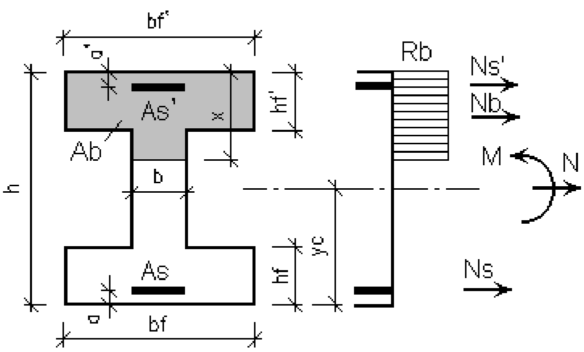
Buckling force $\boldsymbol{N}_{cr}$ depends on second moment of inertia of reinforcement I_{st} and the reinforcement is still unknown. Several iterations are required in order to obtain I_{st} for the final reinforcement that is designed. Calculations are performed by clicking the "**Results**" button.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

$\boldsymbol{A}_s$, $\boldsymbol{A'}_s$	– areas of bottom and top reinforcement;
μ, μ'	– respective reinforcement ratios;
σ_s, σ'_s	– stresses at centers of bottom and top reinforcement;
$\boldsymbol{x}$	– height of compression zone.
$\boldsymbol{A}_{s,tot}$	– 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 $\boldsymbol{R}_b$. Unknown values are: $\boldsymbol{A}_s$ – tensile reinforcement area; $\boldsymbol{A'}_s$ – compressive reinforcement area; $\boldsymbol{x}$ – compression zone height. They are determined from the condition for balance of internal forces:

$N + N_b + N_s + N_s' = 0$ (1)

$M + M_b + M_s + M_s' = 0$ (2)



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

$N_b = A_b \cdot R_b$; $M_b = N_b \cdot (h - y_c - x/2)$;

$N_s = A_s \cdot \sigma_s$; $M_s = N_s \cdot (y_c - a)$

$N_s' = A_s' \cdot \sigma_s'$; $M_s' = N_s' \cdot (h - y_c - a')$;

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

$$R_{sc} \le \sigma_{si} = -\frac{1 - \omega \cdot y_{si} / x}{1 - \omega/1.1} \cdot \sigma_{sc,u} \le R_{sc}$$

$y_{si} = h_0$ – за σ_s
$y_{si} = a'$ – за σ_s'

Formulas for stresses are based on equation (77), $\omega = 0.85 - 0.008 \cdot R_b$.

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

$N + N_b + N_s + N_s' < \delta$, where δ is the acceptable error.

Then the condition $M + M_b + M_s + M_s' < \delta$ is verified and if satisfied, calculations are finished.

If it is not satisfied then values of N_s and N_s' are calculated by equations for balance of moments about centers of bottom and top reinforcement, respectively:

$N_s = (M - M_b' + N \cdot (h - y_c - a'))/z_s$ $N_s' = -(M - M_b - N \cdot (y_c - a))/z_s$

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

$M_b = N_b \cdot z_b$

$M_b' = -N_b \cdot (z_s - z_b)$

where z_b is the distance between the center of compression zone and the bottom reinforcement

and 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:

$A_s = N_s / R_s$ при $N_s > 0$; $A_s = -N_s / R_{sc}$ при $N_s < 0$;

In case of bending where $\xi = x/h_0 < \xi_R := \frac{\omega}{1 + \frac{\sigma_{sR}}{\sigma_{scu}} \cdot \left(1 - \frac{\omega}{1.1}\right)}$ or in case of compression/ tension combined with bending, area of compression reinforcement is calculated:

$A_s' = N_s' / R_s$ if $N_s > 0$; $A_s' = -N_s' / R_{sc}$ if $N_s' < 0$;

Iteration is repeated.

Additional checks are performed for out of plane buckling due to axial force $N < m \cdot \varphi \cdot (R_b \cdot A + R_{sc} \cdot A_{s,tot})$. Buckling factor φ is determined from Table 33 in Bulgarian code NPBStBK using effective length L_{oy}. Total reinforcement area $A_{s,tot}$ 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 (cm^2/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:

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

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

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

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

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:

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

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

Concrete capacity check: $\tau < 0.3 \cdot R_b$

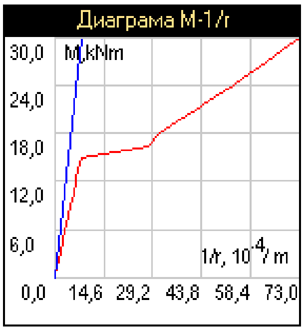
Shear reinforcement: $A_{sw,t} = p \cdot 100 / (0.9 \cdot R_{sw})$

Main reinforcement: $\boldsymbol{A}_{s,tot} = p \cdot \boldsymbol{U}_{ef} / (0.9 \cdot \boldsymbol{R}_s)$;

$\boldsymbol{p} = \boldsymbol{T}/(2 \cdot \boldsymbol{A}_{ef})$; $\boldsymbol{b}_{ef} = \boldsymbol{b} - 2 \cdot (\boldsymbol{a}_w$; $\boldsymbol{h}_{ef} = \boldsymbol{h} - 2 \cdot \boldsymbol{a}_w$; $\boldsymbol{U}_{ef} = 2 \cdot (\boldsymbol{b}_{ef} + \boldsymbol{h}_{ef})$; $\boldsymbol{A}_{ef} = \boldsymbol{b}_{ef} \cdot \boldsymbol{h}_{ef}$

Concrete cover $\boldsymbol{a}_w$ is defined to the center of main reinforcement.

Crack widths and deflection



The program calculates moment of cracking $\boldsymbol{M}_{crc}$, crack widths $\boldsymbol{a}_{crc}$ 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 $\boldsymbol{L}$, nominal distributed load $\boldsymbol{q}_n$ or maximal moment $\boldsymbol{M}_n$. 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.

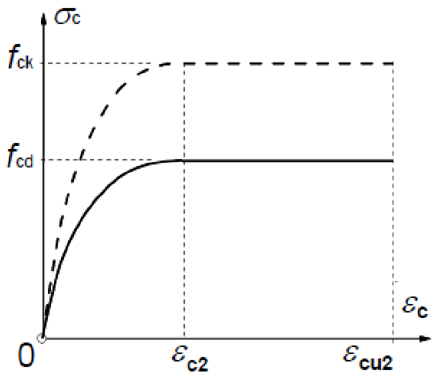
Design to Eurocode 2

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:

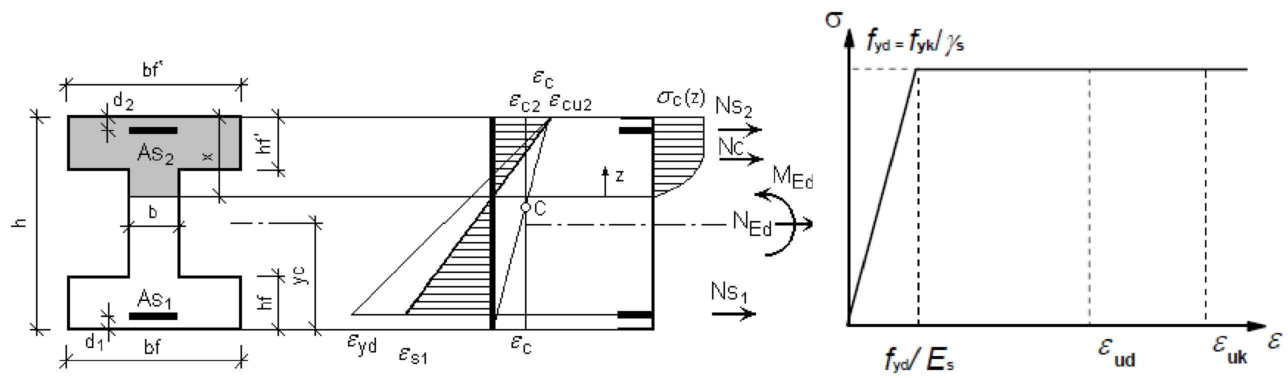
- concrete tensile stress is ignored and all tension is carried by the reinforcement;
- stress-strain relationship for concrete is parabolic-linear with maximum value of $\boldsymbol{f}_{cd}$;
- stress-strain relationship for steel is linear-plastic with maximum value of $\boldsymbol{f}_{yd}$;
- there 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 $0 \le \varepsilon_c \le \varepsilon_{c2}$ -

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

for $\varepsilon_{c2} \le \varepsilon_c \le \varepsilon_{cu2}$ - $\sigma_c = \boldsymbol{f}_{cd}$



$-f_{yd} \le \sigma_s = E_s \cdot \varepsilon_y \le f_{yd}$

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: $\varepsilon_{cu2} \le \varepsilon_c \le 0$ – for concrete and $\varepsilon_{c2} \le \varepsilon_s \le \varepsilon_{yd}$ – 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:

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

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

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

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 enforcement are calculated from the respective forces:

$\boldsymbol{A}_{s1} = \boldsymbol{N}_{s1} / \boldsymbol{f}_{yd}$ if $\boldsymbol{N}_s > 0$; $\boldsymbol{A}_{s1} = -\boldsymbol{N}_{s1} / \boldsymbol{f}_{yd}$ if $\boldsymbol{N}_{s1} < 0$;

In case of bending where $\boldsymbol{K} = \boldsymbol{M} / (\boldsymbol{b} \cdot \boldsymbol{h}_0^2 \cdot \boldsymbol{f}_{ck}) > \boldsymbol{K}' = 0.168$ or in case of compression/ tension combined with bending, area of compression reinforcement is calculated:

$\boldsymbol{A}_{s2} = \boldsymbol{N}_{s2} / \boldsymbol{f}_{yd}$ at $\boldsymbol{N}_s > 0$; $\boldsymbol{A}_{s2} = -\boldsymbol{N}_{s2} / \boldsymbol{f}_{yd}$ at $\boldsymbol{N}_{s2} < 0$;

Iteration is repeated.

Second order effects are included for members in compression.

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

$\boldsymbol{M}_{Ed} = \boldsymbol{M}_{0Ed} / (1 - \boldsymbol{N}/\boldsymbol{N}_B)$ (Eq. 5.30 from EC2)

First order bending moment $\boldsymbol{M}_{0Ed} = \boldsymbol{M} + \boldsymbol{N} \cdot \boldsymbol{e}_i$ includes initial imperfections.

$\boldsymbol{e}_i = \theta_i \cdot \boldsymbol{L}_{ox}/2$ (Eq. 5.2 from EC2)

$\boldsymbol{M}_{0Ed} \geq \boldsymbol{N} \cdot \boldsymbol{e}_0$ $\boldsymbol{e}_0 = \boldsymbol{h}/30 \geq 20$ mm

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

$\boldsymbol{N}_B = \pi^2 \cdot \boldsymbol{EI}/\boldsymbol{L}_{ox}^2$ (Eq. 5.17 from EC2)

$\boldsymbol{EI} = \boldsymbol{K}_c \cdot \boldsymbol{E}_{cd} \cdot \boldsymbol{I}_c + \boldsymbol{K}_s \cdot \boldsymbol{I}_s$ (Eq. 5.21 from EC2)

$\boldsymbol{K}_s = 1$; $\boldsymbol{K}_c = \boldsymbol{k}_1 \cdot \boldsymbol{k}_2 / (1 + \varphi_{ef})$; $\boldsymbol{k}_1 = (\boldsymbol{f}_{ck}/20)^{1/2}$; $\boldsymbol{k}_2 = \boldsymbol{n} \cdot \lambda / 170$;

$\boldsymbol{n} = \boldsymbol{N}_{ed} / (\boldsymbol{A}_c \cdot \boldsymbol{f}_{cd})$; $\lambda = \boldsymbol{L}_{ox}/\boldsymbol{i}$; $\boldsymbol{i} = (\boldsymbol{I}_c/\boldsymbol{A}_c)^{1/2}$

Effective creep factor is calculated by the formula: $\varphi_{ef} = \varphi(\infty, t0) \cdot \boldsymbol{M}_{0Eqp}/\boldsymbol{M}_{0Ed}$. Ratio $\boldsymbol{M}_{0Eqp}/\boldsymbol{M}_{0Ed}$ 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 $\boldsymbol{N}_B$ 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:

$\boldsymbol{A}_{s1}$, $\boldsymbol{A}_{s2}$ – 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;

$\boldsymbol{x}$ – 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:

$\boldsymbol{n}_w$ – number of shear link cuts;

$\boldsymbol{d}$ – shear link diameter;

$\boldsymbol{c}$ – critical crack projection.

θ – angle of compression strut;

α – angle between links and a vertical line;

$\boldsymbol{A}_s$ – existing tension reinforcement (cm^2) with sufficient anchorage behind the section of interest.

The following values are calculated to Eurocode 2:

$\boldsymbol{V}_{Rd,c} = (\boldsymbol{C}_{Rd,c} \cdot \boldsymbol{k} \cdot (100 \cdot \rho_l \cdot \boldsymbol{f}_{ck})^{0.3333} + \boldsymbol{k}_1 \cdot \sigma_{cp}) \cdot \boldsymbol{b} \cdot \boldsymbol{h}_0$ – concrete capacity without shear reinforcement (Eq. 6.2.a)

$\boldsymbol{V}_{Rd,c} \geq \boldsymbol{V}_{Rd,c,min} = (\boldsymbol{v}_{min} + \boldsymbol{k}_1 \cdot \sigma_{cp}) \cdot \boldsymbol{b} \cdot \boldsymbol{h}_0$ (Eq. 6.2.b)

$\boldsymbol{k} = 1 + (200/\boldsymbol{h}_0)^{1/2}$; $\sigma_{cp} = \boldsymbol{N}_{Ed}/\boldsymbol{A}_c < 0,2\ \boldsymbol{f}_{cd}$;

$\boldsymbol{C}_{Rd,c} = 0,18/\gamma_c$; $\boldsymbol{k}_1 = 0.15$;

$\boldsymbol{v}_{min} = 0,035 \cdot \boldsymbol{k}^{3/2} \cdot \boldsymbol{f}_{ck}^{1/2}$; $\rho_l = \boldsymbol{A}_s/(\boldsymbol{b} \cdot \boldsymbol{h}_0) \leq 0.002$;

$\boldsymbol{V}_{Rd,max} = \alpha_c \cdot \boldsymbol{b} \cdot \boldsymbol{z} \cdot \nu_1 \cdot \boldsymbol{f}_{cd} \cdot (\cot\theta + \cot\alpha)/(1 + \cot^2\theta)$ – ultimate concrete capacity in the compression strut (Eq. 6.14 from EC2). If $\boldsymbol{V}_{Ed} > \boldsymbol{V}_{Rd,max}$, section dimensions or concrete grade should be increased.

$\boldsymbol{z} = 0.9 \cdot \boldsymbol{h}_0$ is lever arm of internal forces;

$\nu_1 = 0.6 \cdot (1 - \boldsymbol{f}_{ck}/250)$ - (Eq. 6.6N от EC2).

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

Area of shear reinforcement (cm^2/m): $\boldsymbol{A}_{sw} = \boldsymbol{q}_{sw}/(\boldsymbol{n}_w \cdot \boldsymbol{f}_{yw})$

Additional tension force in main reinforcement: $\boldsymbol{F}_{td} = 0.5 \cdot \boldsymbol{V}_{Ed} \cdot (\cot\theta - \cot\alpha)$

Additional main reinforcement to take this force: $\boldsymbol{A}_{slн} = \boldsymbol{F}_{td}/\boldsymbol{f}_{yd}$

$\boldsymbol{V}_{Ed} = \boldsymbol{V}$ 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 $\boldsymbol{V}_{Rd,max} = \boldsymbol{V}_{Ed}$, providing that $21.8° \leq \theta \leq 45°$ ($1 \leq \cot\theta \leq 2.5$).
Link spacing is calculated by the formula:

$\boldsymbol{s} = \boldsymbol{A}_{sw}/(\pi \cdot \boldsymbol{d}^2/4) < \boldsymbol{s}_{max} = 0.75 \cdot \boldsymbol{h}_0 \cdot (1 + \cot\alpha)$.

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 $\boldsymbol{a}_w$ is defined to the center of main reinforcement.

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

Concrete capacity without shear reinforcement: $\boldsymbol{T}_{Ed} / \boldsymbol{T}_{Rd,c} + \boldsymbol{V}_{Ed} / \boldsymbol{V}_{Rd,c} > 1$ (6.29)

Ultimate concrete capacity in compression struts: $\boldsymbol{T}_{Ed} / \boldsymbol{T}_{Rd,max} + \boldsymbol{V}_{Ed} / \boldsymbol{V}_{Rd,max} < 1$ (6.31)

Ultimate torsion without shear reinforcement: $\boldsymbol{T}_{Rd,c} = 2 \cdot \boldsymbol{A}_k \cdot \boldsymbol{t}_{ef} \cdot f_{ctd}$

Ultimate torsion for the concrete section: $\boldsymbol{T}_{Rd,max} = \nu \cdot \alpha_c \cdot \boldsymbol{f}_{cd} \cdot \boldsymbol{A}_k \cdot \boldsymbol{t}_{ef} \cdot \sin(2 \cdot \theta)$ (6.30)

$\boldsymbol{T}_{Ed} = \boldsymbol{T}$ is the torsional moment entered by the user.

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

Reinforcement is calculated as follows:

Shear reinforcement: $\boldsymbol{A}_{sw} = \boldsymbol{P} / (\boldsymbol{f}_{yw} \cdot \cot\theta)$

Main reinforcement: $\boldsymbol{A}_{stot} = \boldsymbol{P} \cdot \boldsymbol{U}_k \cdot \cot\theta / \boldsymbol{f}_{yd}$ (6.28)

Effective thickness: $\boldsymbol{t}_{ef} = \boldsymbol{b} \cdot \boldsymbol{h} / (2 \cdot \boldsymbol{b} + 2 \cdot \boldsymbol{h})$

$\boldsymbol{t}_{ef}$ is taken not less than $2 \cdot \boldsymbol{a}_w$

Effective cross section area: $\boldsymbol{A}_k = (\boldsymbol{b} - \boldsymbol{t}_{ef}) \cdot (\boldsymbol{h} - \boldsymbol{t}_{ef})$

Perimeter of effective area: $\boldsymbol{U}_k = 2 \cdot (\boldsymbol{b} + \boldsymbol{h} - 2 \cdot \boldsymbol{t}_{ef})$

$\boldsymbol{P} = \boldsymbol{T}_{Ed} / (2 \cdot \boldsymbol{A}_k)$

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

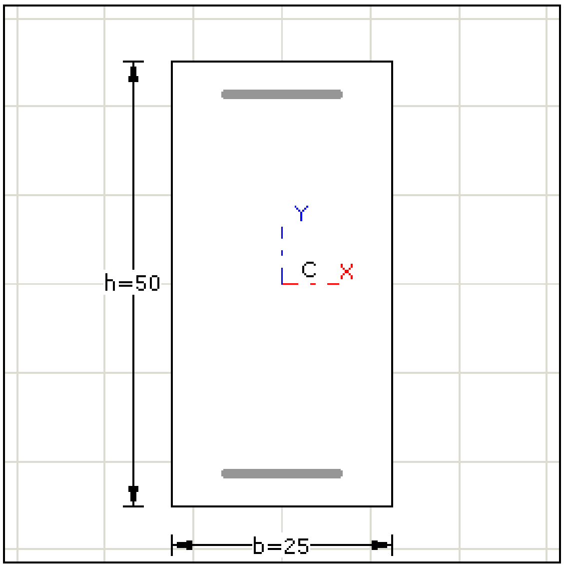
Cross section

b = 25,0 cm h = 50,0 cm

b_f = 0,0 cm h_f = 0,0 cm

$b`_f$ = 0,0 cm    $h`_f$ = 0,0 cm

a = 3,5 cm $a`$ = 3,5 cm



Section Loads

Bending moment -   M = 162,0 kN.m

Axial force-   N = 0,0 kN

Shear Force -   Q = 108,0 kN

Torsional moment -   T = 0,0 kN.m

Long term load factor -   KG = 90,0 %

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

Bending And Axial Force Design

Strength Reduction Factors		**Existing Reinforcement**	
Concrete	γ_b = 1,0	Bottom	$A_{s,ini}$ = 0,0 cm^2
Reinforcement	γ_s = 1,0	Top	$A`_{s,ini}$ = 0,0 cm^2

Shear Force Design

Shear links cuts - n_w = 2

Shear links diameter -   d = 8,0 mm

Compression strut angle -   c = 0,0 cm

Deflection And Crack Widths

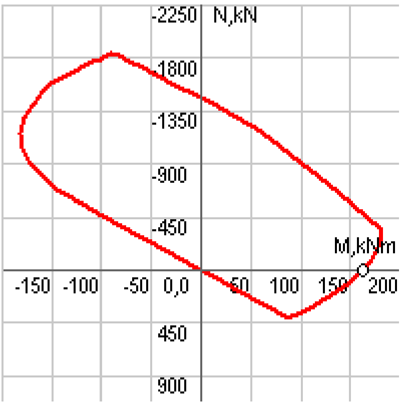
Beam type - simply supported, beam length L = 600,0 cm

Distributed load	**Bending moment**	**Axial force**
q_n = 30,0 kN/m	M_n = 135,0 kN.m	N_n = 0,0 kN

Existing Reinforcement		
Tensile	4N20,	A_s = 12,57 cm^2
Compressive	2N12,	$A`_s$ = 2.26 cm^2

Environment conditions - constant air mositure < 70% - φ_{b2} = 2,00, ν = 0,15

Results



Bending With Axial Force Design

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

Bending with axial force design completed successfully!

Shear Force Design

Concrete only resistance - $Q_{b,min}$ = 62,8 kN

Concrete ultimate resistance - Q_{max} = 374,3 kN

Shear reinforcement area - A_{sw} = 1,9 cm^2/m

Required shear reinforcement - Φ8/25,0 cm

Shear reinforcement ratio - μ_w = 0,2 %

Shear force design completed successfully!

Deflection And Crack Widths

Crack opening moment - M_{crc} = 18,43 kN.m

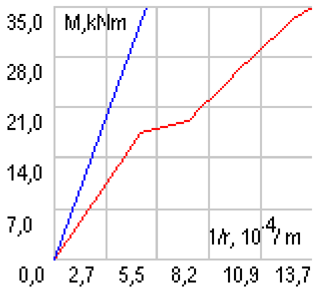
Crack width - a_{crc} = 0,23 mm

Deflection - D_{max} = 2,68 cm< 3 cm

Curvature for moment Mn - 1/r = 72,94 10^{-4}/m

Stiffness for moment Mn- B/EI = 0,26

Deflection and crack widths design completed successfully!



Example 2. Design of reinforced concrete column

Design with RCExpert

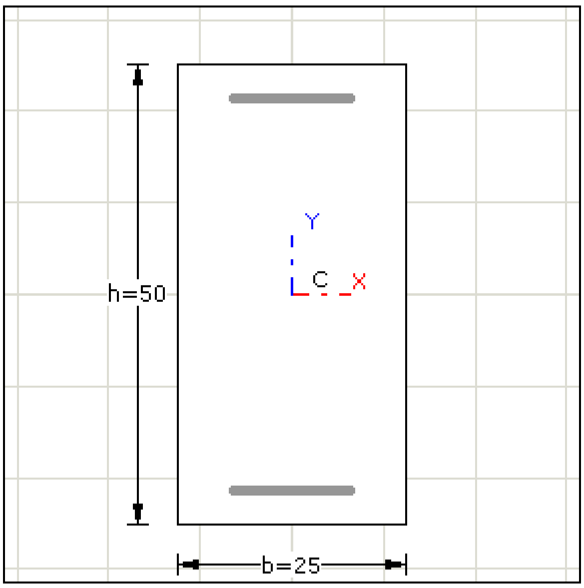
Cross section

b = 25,0 cm h = 50,0 cm

b_f = 0,0 cm h_f = 0,0 cm

$b`_f$ = 0,0 cm  $h`_f$ = 0,0 cm

a = 3,5 cm $a`$ = 3,5 cm



Section Loads

Bending moment - M = 400,0 kN.m

Axial force- N = -1000,0 kN

Shear Force - Q = 0,0 kN

Torsional moment - T = 0,0 kN.m

Long term load factor - KG = 75,0 %

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

Bending And Axial Force Design сила

Strength Reduction Factors		Existing Reinforcement	
Concrete	γ_b = 1,0	Bottom	$A_{s,ini}$ = 0,0 cm^2
Reinforcement	γ_s = 1,0	Top	$A`_{s,ini}$ = 0,0 cm^2

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

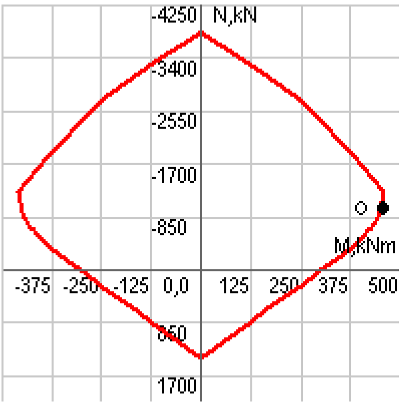
Results

Bending With Axial Force Design

MI + MII = 456,5 kN.m

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

Bending with axial force design completed successfully!



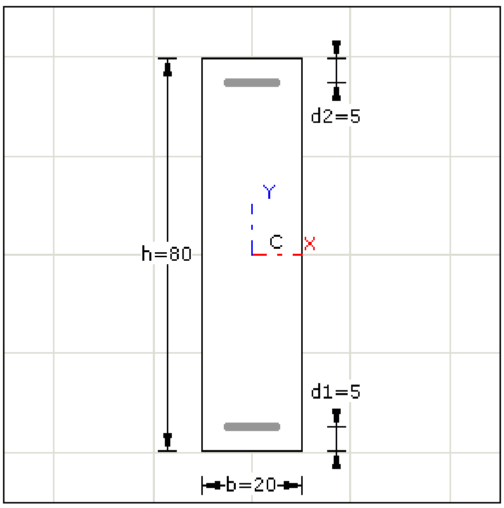
Examples to Eurocode 2

Example 3. Shear force design

Design with RC Expert

Cross section

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



Section Loads

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

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

Shear Force Design

Shear links cuts - n_w = 2

Shear links diameter - d = 12 mm

Compression strut angle - θ = 28,7 deg

Shear links angle - α = 90,0 deg

Tensile reinforcement - A_{sl} = 0,0 cm^2

Results - Shear Force Design

Concrete only resistance - $V_{Rd,c}$ = 80,0 kN

Concrete ultimate resistance - $V_{Rd,max}$ = 600,0 kN

Shear reinforcement area - A_{sw} = 6,2 cm^2/m

Required shear reinforcement - Φ12/17,5 cm

Shear reinforcement ratio - μ_w = 0,6 %

Additional tensile reinforcement - A_{slH} = 12,6 cm^2 > A_{sl}

Manual verification

$\boldsymbol{V}_{Ed}$ = 600 kN; $\boldsymbol{f}_{ck}$ = 30 MPa; $\boldsymbol{f}_{cd}$ = 20 MPa; $\boldsymbol{f}_{ywd}$ = 391 MPa

$\boldsymbol{h}_0 = \boldsymbol{h} - \boldsymbol{a}$ = 750 mm; $\boldsymbol{z} = 0.9\cdot\boldsymbol{h}_0 = 0.9\cdot750 = 675$ mm

$\nu = \nu_1 = 0.6\cdot(1 - \boldsymbol{f}_{ck}/250) = 0.528$

Calculation of compressive strut angle $\boldsymbol{\theta}$ for $\boldsymbol{V}_{Rd,max}$= $\boldsymbol{V}_{Ed}$:

$$\theta = \frac{1}{2}\arcsin\frac{2\cdot V_{Ed}}{\alpha_{cw}\cdot\nu\cdot f_{cd}\cdot b_w\cdot z} = \frac{1}{2}\arcsin\frac{2\cdot600000}{1\cdot0.528\cdot20\cdot200\cdot675} = 28.7° > 21.8°;\ \cot\theta = 1.82°$$

Calculation of required shear reinforcement:

$$\frac{A_{sw}}{s} = \frac{V_{Ed}}{z\cdot f_{ywd}\cdot\cot\theta} = \frac{600000}{675\cdot391\cdot1.82} = 1.249\,mm^2/mm$$

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

Additional tensile force: $\Delta\boldsymbol{F}_{td} = 0.5\cdot\boldsymbol{V}_{Ed}\cdot\cot\boldsymbol{\theta} = 0.5\cdot600\cdot1.82 = 546$ kN

Additional tensile reinforcement for that force: $\boldsymbol{A}_{slH} = \Delta\boldsymbol{F}_{td}/\boldsymbol{f}_{yd}$ =546/43.5 = 12,6 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 α_{cc} = 0.85. Concrete design resistance is $\boldsymbol{f}_{cd} = \alpha_{cc} \cdot \boldsymbol{f}_{ck} / \gamma_C$. 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 $\boldsymbol{s} = 0.8 \cdot \boldsymbol{x}$.

Design with RC Expert

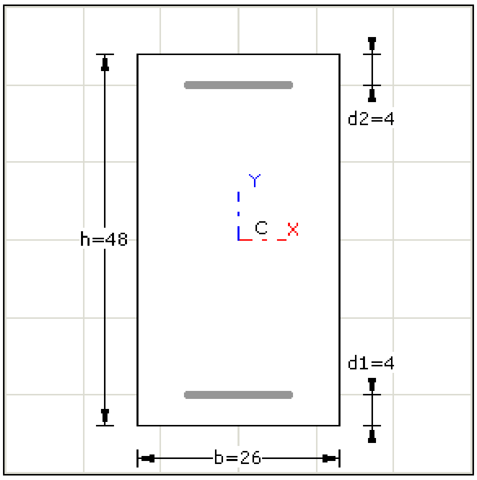
Cross section

b = 26,0 cm h = 48,0 cm

b_{f1} = 0,0 cm h_{f1} = 0,0 cm

b_{f2} = 0,0 cm h_{f2} = 0,0 cm

d_1 = 4,0 cm d_2 = 4,0 cm



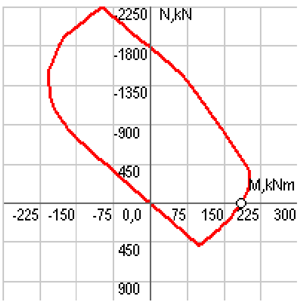
Section Loads

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

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

Input Data for Bending And Axial Force Design

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



Results for Bending With Axial Force Design

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

Manual verification (Example 4.1)

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

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

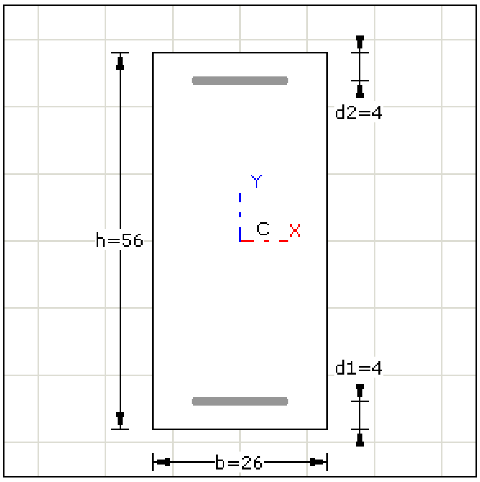
$$z = d \cdot \left\{0.5 + \sqrt{\left(0.25 - \frac{K}{1.134}\right)}\right\} = 440 \cdot \left\{0.5 + \sqrt{\left(0.25 - \frac{0.147}{1.134}\right)}\right\} = 373 mm$$

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

Example 5. Ultimate bending capacity of rectangular section

Design with RC Expert

Cross section



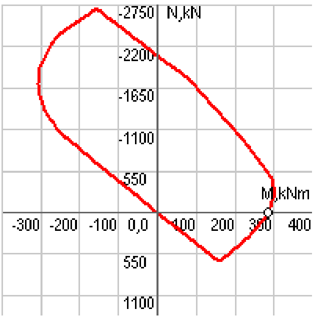
$b = 26,0$ cm $h = 56,0$ cm
$b_{f1} = 0,0$ cm $h_{f1} = 0,0$ cm
$b_{f2} = 0,0$ cm $h_{f2} = 0,0$ cm
$d_1 = 4,0$ cm $d_2 = 4,0$ cm

Section Loads

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

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

Input Data for Bending And Axial Force Design



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

Results for Bending With Axial Force Design

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

Manual verification (Example 4.2)

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

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

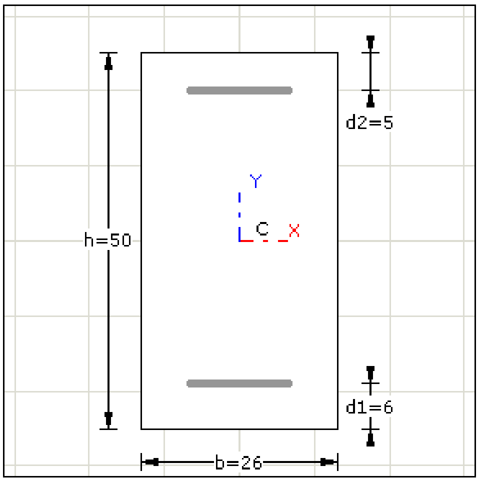
$$s = 150\text{mm} \qquad x = \frac{s}{0.8} = \frac{150}{0.8} = 188\text{mm}$$

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

Example 6. Bending design of doubly reinforced seciton

Design with RC Expert

Cross section



b = 26,0 cm h = 50,0 cm

b_{f1} = 0,0 cm h_{f1} = 0,0 cm

b_{f2} = 0,0 cm h_{f2} = 0,0 cm

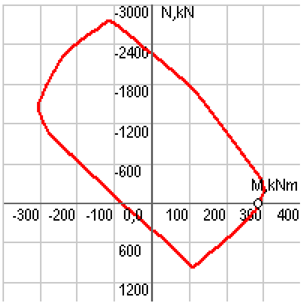
d_1 = 6,0 cm d_2 = 5,0 cm

Section Loads

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

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

Input Data for Bending And Axial Force Design



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

Results for Bending With Axial Force Design

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

Manual verification (Example 4.3)

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

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

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

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

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

Example 7. Ultimate bending capacity of doubly reinforced section

Design with RC Expert

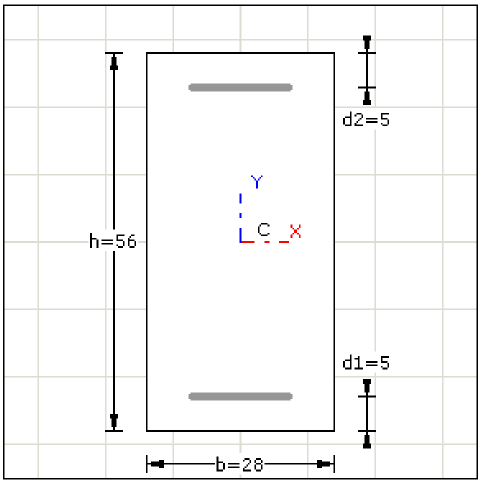
Cross section

b = 28,0 cm h = 56,0 cm

b_{f1} = 0,0 cm h_{f1} = 0,0 cm

b_{f2} = 0,0 cm h_{f2} = 0,0 cm

d_1 = 5,0 cm d_2 = 5,0 cm



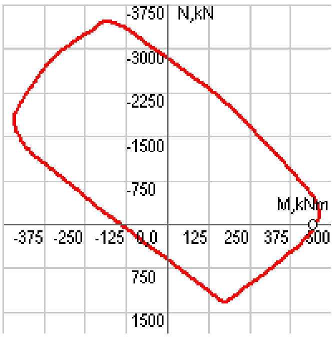
Section Loads

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

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

Input Data for Bending And Axial Force Design

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



Results for Bending With Axial Force Design

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

Manual verification (Example 4.4)

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

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

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

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

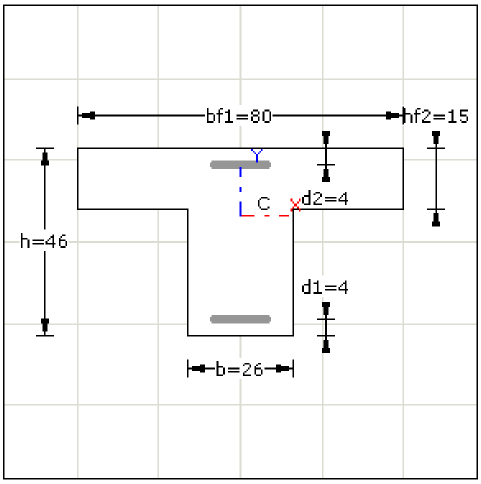
$$M = F_{cc} \cdot \left(d - \frac{s}{2}\right) + F_{sc} \cdot (d - d') = 0.567 \cdot f_{ck} b \cdot s \cdot \left(d - \frac{s}{2}\right) + 0.87 \cdot f_{yk} \cdot A'_s \cdot (d - d') =$$

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

Example 8. Ultimate bending capacity of section with flanges

Design with RC Expert

Cross section



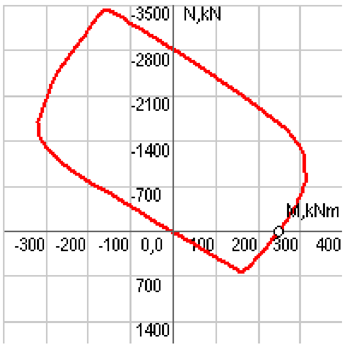
$b = 26{,}0$ cm	$h = 46{,}0$ cm
$b_{f1} = 0{,}0$ cm	$h_{f1} = 0{,}0$ cm
$b_{f2} = 80{,}0$ cm	$h_{f2} = 15{,}0$ cm
$d_1 = 4{,}0$ cm	$d_2 = 4{,}0$ cm

Section Loads

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

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

Input Data for Bending And Axial Force Design



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

Results for Bending With Axial Force Design

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

Manual verification (Example 4.5)

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

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

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

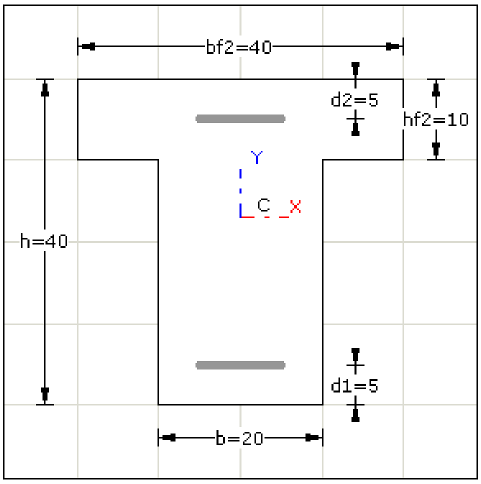
$$x = \frac{s}{8} = 70\,mm \qquad z = d - \frac{s}{2} = 420 - \frac{56}{2} = 392\,mm$$

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

Example 9. Bending design of section with flanges

Design with RC Expert

Cross section



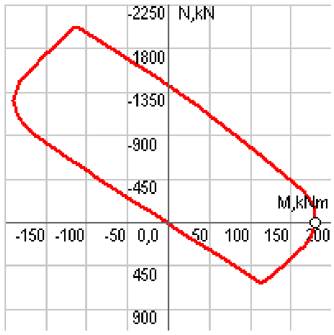
$b = 20{,}0$ cm	$h = 40{,}0$ cm
$b_{f1} = 0{,}0$ cm	$h_{f1} = 0{,}0$ cm
$b_{f2} = 40{,}0$ cm	$h_{f2} = 10{,}0$ cm
$d_1 = 5{,}0$ cm	$d_2 = 5{,}0$ cm

Section Loads

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

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

Input Data for Bending And Axial Force Design



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

Results for Bending With Axial Force Design

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

Manual verification (Example 4.6)

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

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

$$s_w = s - h_f \quad 180 = M_f + F_{cw} z_2 = 170 + 0.567 f_{ck} b_w s_w z_2 = 170 + 0.567 \cdot 25 \cdot 200 \cdot s_w \left(250 - \frac{s_w}{2}\right) \cdot 10^{-6} =$$

$$= 170 + 2835 \cdot s_w \left(250 - \frac{s_w}{2}\right) \cdot 10^{-6} \qquad s_w^2 - 500 s_w + 7.05 \cdot 10^3 = 0 \qquad s_w = 15 mm$$

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

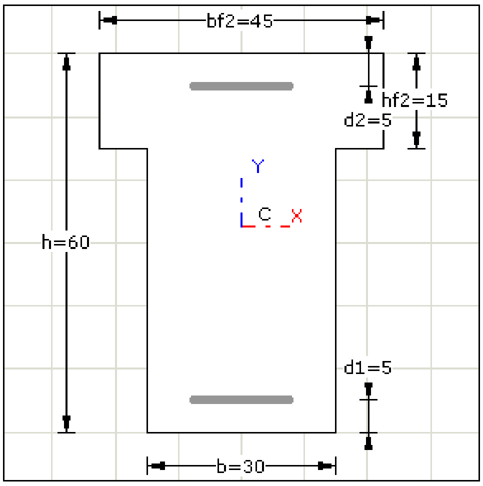
$$F_{st} = F_{cf} + F_{cw} \qquad 0.87 f_{yk} A_s = 0.567 f_{ck} b_f h_f + 0.567 f_{ck} b_w s_w$$

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

Example 10. Ultimate bending capacity of section with flanges

Design with RC Expert

Cross section



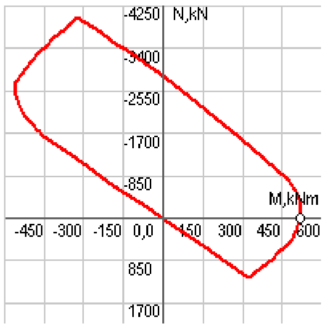
b = 30,0 cm	h = 60,0 cm
b_{f1} = 0,0 cm	h_{f1} = 0,0 cm
b_{f2} = 45,0 cm	h_{f2} = 15,0 cm
d_1 = 5,0 cm	d_2 = 5,0 cm

Section Loads

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

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

Input Data for Bending And Axial Force Design



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

Results for Bending With Axial Force Design

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

Manual verification (Example 4.7)

Reinforcement area is giver A_s = 2592 mm^2. Find section bending capacity M_{Rd}.

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

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

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

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

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

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

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 $d_1/h=0.1$.

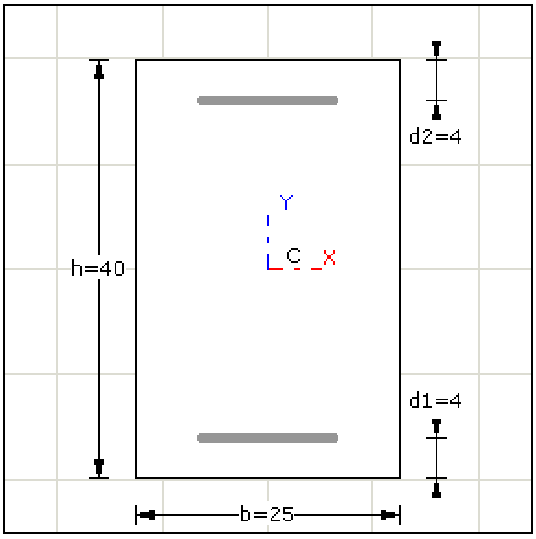
Cross section - rectangular

b = 25,0 cm h = 40,0 cm

d_1 = 4,0 cm d_2 = 4,0 cm

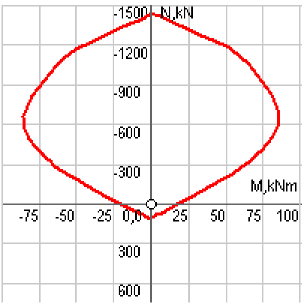
γ_C = 1,50 γ_S = 1,15

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

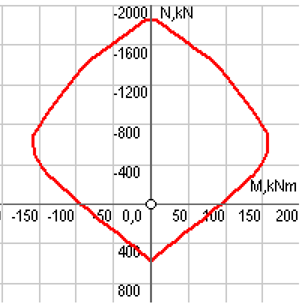


Absolute coordinates M—N

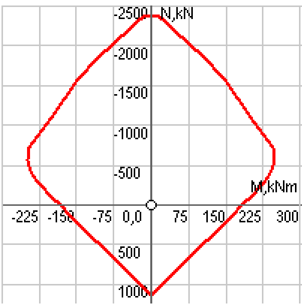
A_{s1}= 0.00 cm², ω=0.0



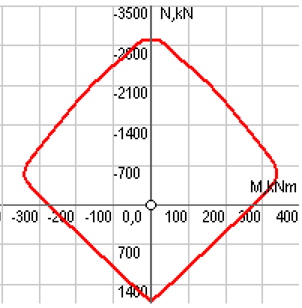
A_{s1}= 6.55 cm², ω=0.5



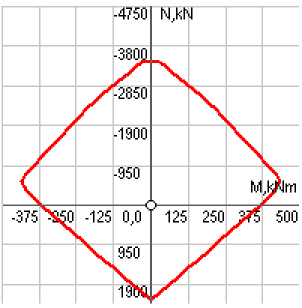
A_{s1}= 13.1 cm², ω=1.0



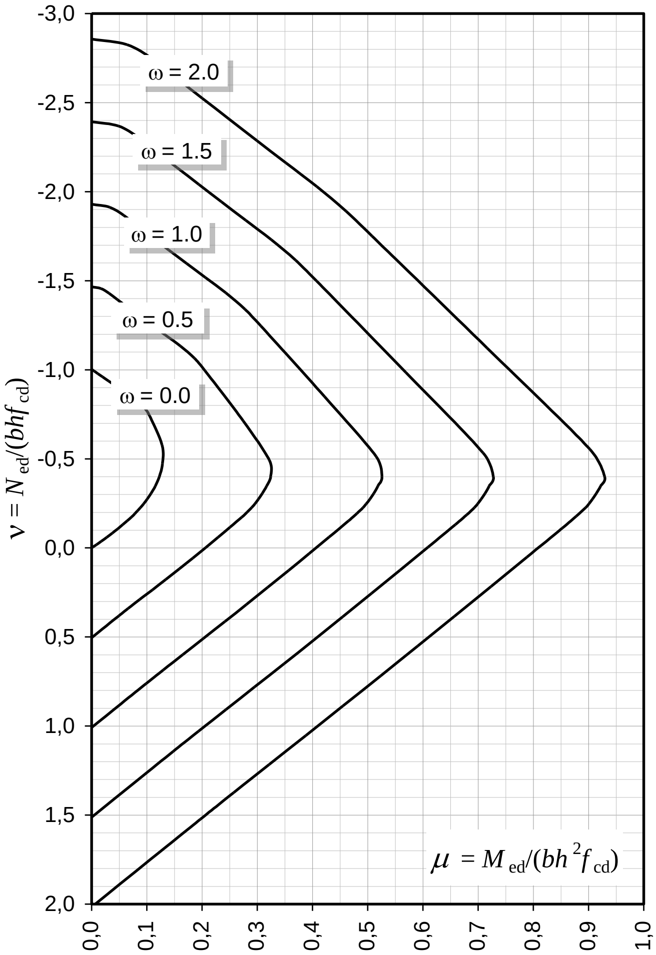
A_{s1}= 19.6 cm², ω=1.5



A_{s1}= 26.2 cm², ω=2.0



Relative coordinates μ—ν



$\omega = (A_{s1}+A_{s2})/bh \cdot f_{yd}/f_{cd}$

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