ПРОЕКТСОФТ

Software Package

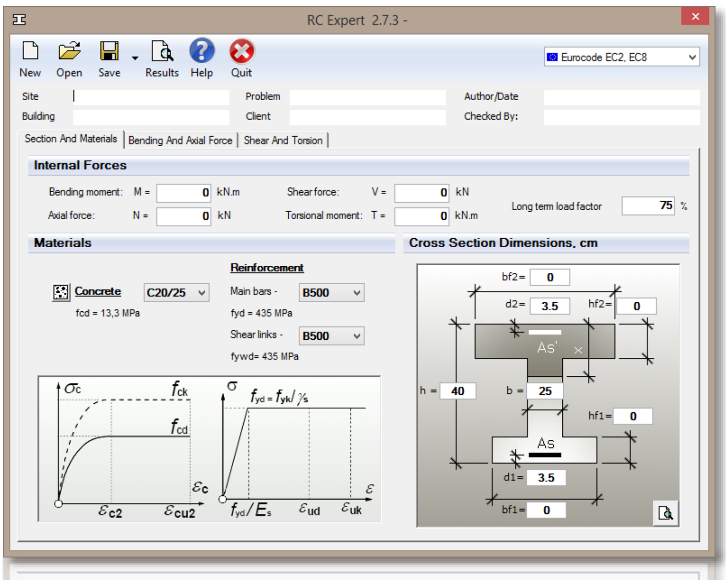
Design Expert version 2.7

Structural Design and Detailing to Eurocode

RC Expert

Design of reinforced concrete members to EN 1992-1-1

User Manual



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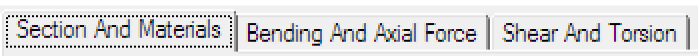
About the program

RC Expert is a software for design of reinforced concrete members with rectangular, "T" and "I" cross sections to Eurocode (EC2). Bending with axial force, shear and torsion design are performed. Initial imperfections, nominal eccentricity and second order effects are taken into account for bending with axial force design. Effective lengths are entered by the user. The program is quick and easy to use, with rich capabilities and friendly graphical user interface. Input data and results are presented in professional looking **HTML** report for viewing and printing.

Data input

Input data is divided into several pages:



You can browse among pages consequently by clicking the respective tabs. When you finish entering the input data, click the "**Results**" button. If current file is not saved, you will be prompted to save.

Input data is entered in tables and text fields on each page. You can move to the next field using the Tab key. Moving back to the previous field is performed by the **Shift+Tab** key combination.

Files

RC Expert has its own file format and the data for each problem can be saved to a file on the disk. Input files have *.rce extension, while the design results are recorded in *.rce.html files.

New file

Click the button to save the current data to a new file. A standard new file dialog appears. Select or write down file path and name and click "**Save**".

Open a file

Click the button. A standard file selection dialog appears. Select or write down file path and name and click "**Open**".

Save a file

Click the button. A standard save file dialog appears. Select or write down file path and name. If file already exists, you can overwrite it or select a different name.

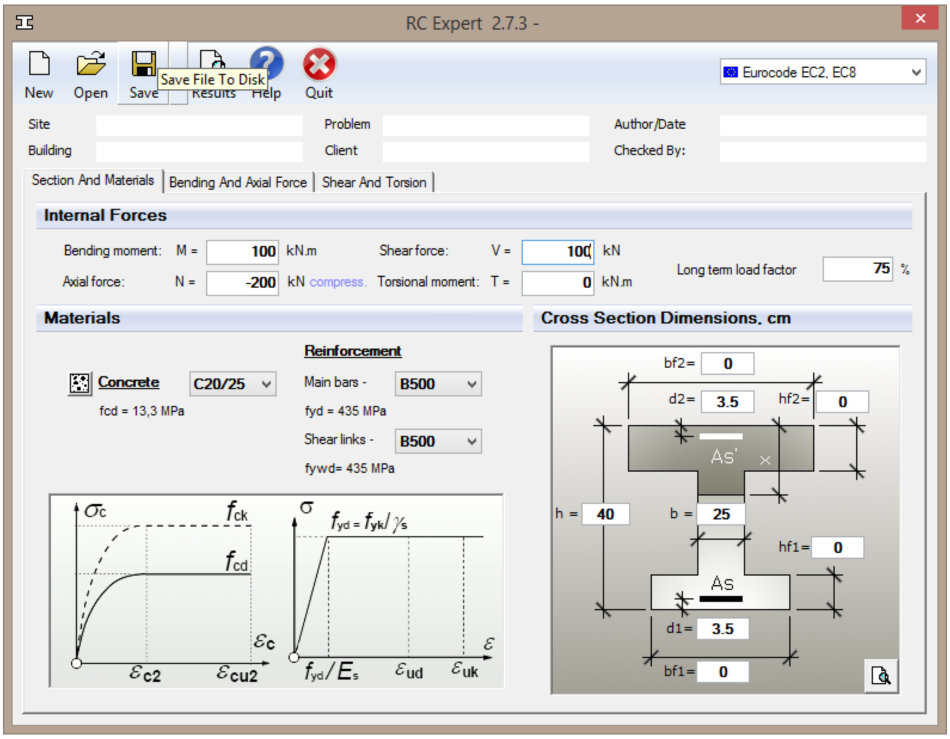
Design code

Design Expert is compatible to Eurocodes, mainly EN 1992-1-1 and EN 1998-1-1. It is applicable to most countries as far as you can define your own material properties, partial safety factors, loads and some other important parameters. Detailed description of all design methods and formulas used in this program is provided further in this manual.

Internal forces

Design values of internal forces are entered – bending moment M_{Ed}, axial force N_{Ed}, shear force V_{Ed} and torsional force T_{Ed}. Negative axial force is compressive and positive is tensile.

Sections and Materials



The input data described below is common for all design checks. Additional data, that is specific for each kind of check is entered separately in the respective page.

Cross section

Cross section dimensions are entered in the respective text fields in the picture. Press the button to see a scaled preview of the section. Shape can be rectangular, T or I. To obtain a rectangular section, enter flange dimensions to be zeroes. Concrete cover is defined as the distance from the edge of concrete to the center of reinforcement.

Materials

Select concrete grade C20/25 and steel grades for main B500 and shear B500 reinforcement. Characteristic and design values for material properties are predefined in tables. Concrete compressive and tensile strengths are additionally multiplied by the sustained loading factors α_{cc} and α_{ct}. They should be defined separately in the respective fields since they are not included in the table values.

Material tables

You can open material tables by clicking the button. A dialog containing both concrete and reinforcement tables appears on screen. You can modify values, add new rows by clicking „+" the button and remove rows using the „-" button. Finally you should press "**Save**" to save changes and close the dialog. If you want to discard changes, just press "**Exit**" and you will return to the main window.

Material tables are common for the whole computer. Any changes you make will reflect all Design Expert modules and input files.

Materials according to Eurocode

Concrete

Design Expert includes the following concrete grades according to EN 1992-1-1, Table 3.1:

Name	E_{cm} GPa	$f_{ck,cube}$ MPa	f_{cd} MPa	f_{ctd} MPa	f_{ck} MPa	$f_{ctk,0.05}$ MPa	ε_{c2}	ε_{cu2}
C12/15	27.0	15.00	8.00	0.73	12.00	1.10	0.002	0.0035
C16/20	29.0	20.00	10.67	0.87	16.00	1.30	0.002	0.0035
C20/25	30.0	25.00	13.33	1.00	20.00	1.50	0.002	0.0035
C25/30	31.5	30.00	16.67	1.20	25.00	1.80	0.002	0.0035
C30/37	33.0	37.00	20.33	1.33	30.50	2.00	0.002	0.0035
C35/45	34.0	45.00	23.33	1.47	35.00	2.20	0.002	0.0035
C40/50	35.0	50.00	26.67	1.67	40.00	2.50	0.002	0.0035
C45/55	36.0	55.00	30.00	1.80	45.00	2.70	0.002	0.0035
C50/60	37.0	60.00	33.67	1.93	50.50	2.90	0.002	0.0035

The following symbols are used in the table above:

E_{cm} – concrete secant modulus of elasticity;

$f_{ck,cube}$ – characteristic cube strength;

f_{ck} – characteristic cylinder strength;

$f_{ctk,0.05}$ – characteristic tensile strength with 5% probability of failure;

$f_{cd} = \alpha_{cc} f_{ck}/\gamma_c$ – design compressive strength;

$f_{ctd} = \alpha_{ct} f_{ctk,0.05}/\gamma_c$ – design tensile strength;

ε_{c2} – compressive strain at maximum stress for parabolic-linear stress-strain;

ε_{cu2} – ultimate compressive strain at concrete edge.

Design values for compressive and tensile strengths in the table are determined for partial safety factor γ_c = 1.5. They still do not include α_{cc} and α_{ct} factors which should be defined additionally. Some countries use α_{cc} = 0.85 and α_{ct} is usually equal to 1.0. You should look for these values in your national annex document.

Reinforcement steel grades

Design Expert include the following steel grades:

Name	E_s GPa	f_{yd} MPa	f_{yk} MPa	ε_{yd}
B220	200	191	220	0.01
B250	200	217	250	0.01
B420	200	365	420	0.01

The following symbols are used in the table:

E_s – design modulus of elasticity;

f_{yd} – design yield strength;

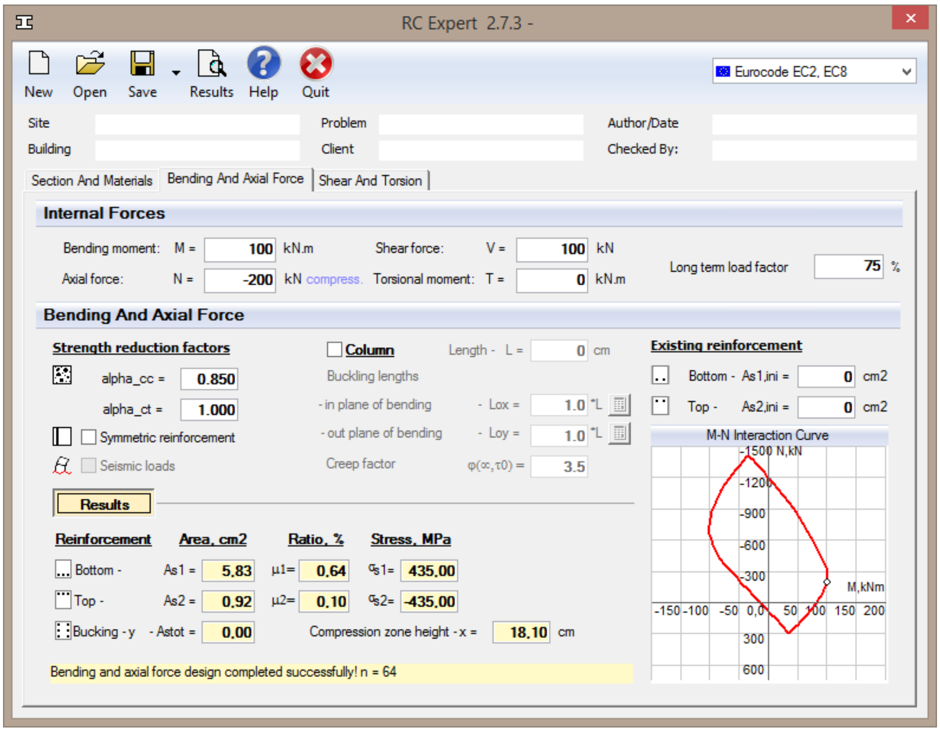
f_{yk} – characteristic yield strength;

B460	200	400	460	0.01
B500	200	435	500	0.01

ε_{yd} – design ultimate strain.

Design to Eurocode 2

Bending with axial force design



The design procedure can handle all kinds of bending and axial force with symmetric and non-symmetric reinforcement. Axial force can be tensile "**+**" or compressive "**–**".

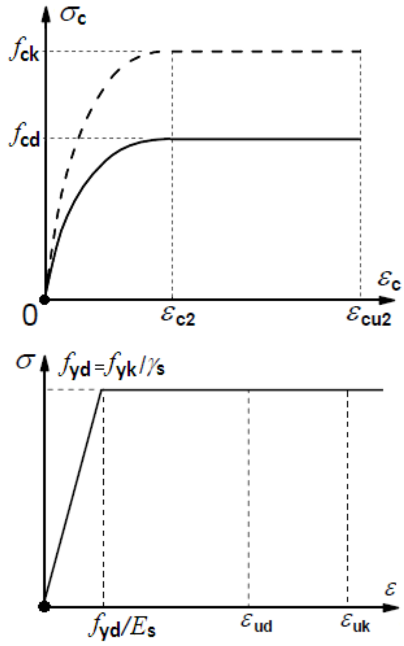
Factors α_{cc} and α_{ct} should be defined additionally by user. Nominal eccentricity, initial imperfections and second order effects can be taken into account. Select the "**Column**" checkbox and enter member length L and effective length factors for in-plane L_{ox} and out-of-plane L_{oy} bending.

In case of non-symmetric reinforcement you can perform additional reinforcement optimization using the "Existing reinforcement" option. You can enter the value of $A_{s2,ini}$ equal to A_{s1} from previous combination with opposite direction of bending and take its favorable influence upon A_{s1}.

Press the "**Results**" button in order to start the calculations. The following results are provided:

A_{s1}, A_{s2} – areas of top and bottom reinforcement;
μ_1, μ_2 – reinforcement ratios;
σ_{s1}, σ_{s2} – stresses in bottom and top reinforcement;
x – compression zone height;

Theoretical background



- Concrete tension stress is excluded and all tension is taken by reinforcement;
- Parabolic-linear stress-strain relationship with maximum value of f_{cd} is used for calculation of concrete design stress;
- Linear-plastic stress-strain relationship with maximum value of f_{yd} is used for calculation of steel design stress;
- Bond exists between steel and concrete;
- Bernoulli hypothesis for planarity of sections is assumed – strain diagram is linear along section height;
- Section capacity is reached when tensile strain in reinforcement and/or compressive strain in concrete reach their ultimate values;
- Section forces due to external loads are in equilibrium with internal forces resulting from concrete and reinforcement stresses.

Initial imperfections, nominal eccentricity and second order effects.

When the "**Column**" checkbox is selected, initial imperfections as included as defined in equation (5.2) to EN 1992-1-1. They are accounted as for single element in the form of additional eccentricity:

$$e_i = \theta_i \cdot L_o/2, \text{ where}$$

L_o – effective member length;

$\theta_i = \theta_o \cdot \alpha_h \cdot \alpha_m$ – member inclination;

$\theta_o = 1/200$ – basic value of inclination;

$\alpha_h = 2/\sqrt{L}$ – height reduction factor. L is the geometrical height of the member in meters;

$\alpha_m = 1$ – reduction factor for number of members.

In case of compression, second order effects are included using nominal stiffness method. The design value of the bending moment is determined by equation (5.30):

$$M_{Ed} = \frac{M_{0Ed}}{1 - N/N_B}$$

$M_{0Ed} = M + N \cdot e_i$ is the first order bending moment including initial imperfections. The value of eccentricity e_i must be not be less than $e_0 = h/30 \geq 20$ mm, according to EN 1992-1-1, section 6.1 (4);

h – cross section height;

N – design axial force due to external load;

N_B – critical compressive force. It is calculated to eq. (5.17):

$$N_B = \pi^2 \cdot EI/L_o^2$$

$EI = K_c \cdot E_{cd} \cdot I_c + K_s \cdot E_s \cdot I_s$ – nominal stiffness, obtained by eq. (5.21);

$K_s = 1$ – factor that accounts for the contribution of the reinforcement;

$K_c = k_1 \cdot k_2/(1 + \varphi_{ef})$ – factor that accounts for effects of cracking, creep, shrinkage etc.;

$\varphi_{ef} = \varphi(\infty,t_0) \cdot M_{0Eqp}/M_{0Ed}$ – effective creep factor;

$k_1 = \sqrt{f_{ck}/20}$ – factor that depends on concrete grade;

$k_2 = n \cdot \lambda/170 \le 0.20$ – factor that depends on axial force and slenderness;

$n = N/(A_c \cdot f_{cd})$ – normalized axial force;

$\lambda = L_o/i$ – slenderness ratio;

$i = \sqrt{I_c/A_c}$ – radius of gyration;

f_{cd} – design value of concrete compressive strength;

f_{ck} – characteristic compressive cylinder strength of concrete at 28 days;

A_c – area of cross section;

I_c – second moment of area of concrete section;

I_s – second moment of area of reinforcement about the center of area of the cross section;

$E_{cd} = E_{cm}/\gamma_{cE}$ – design value of the modulus of elasticity of concrete;

$\gamma_{cE} = 1{,}3$ – partial safety factor for concrete;

E_s – design value of the modulus of elasticity of reinforcement.

Calculation of reinforcement

The design procedure is developed for sections with arbitrary shapes. An iterative algorithm is applied for calculation of reinforcement. The unknown parameters in this procedure are listed below:

A_{s1} – area of tensile reinforcement;

A_{s2} – area of compressive reinforcement;

ε_{s1} – strain at bottom reinforcement;

ε_c – strain at the most compressed edge of the concrete or

ε_{s2} – strain at top reinforcement for sections entirely in tension.

The unknown parameters are obtained by the equilibrium of the internal forces:

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

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

M_{Ed} and N_{Ed} are the design values of internal forces due to external loads. The resultant forces in concrete and reinforcement and the respective moments about the center of area are calculated as follows:

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

$$N_{s1} = A_{s1} \cdot \sigma_{s1} \qquad M_{s1} = N_{s1} \cdot z_1 \qquad z_1 = y_c - d_1$$

$N_{s2} = A_{s2} \cdot \sigma_{s2}$ $\quad M_{s2} = N_{s2} \cdot z_2$ $\quad z_2 = y_c - h - y_c - d_2$

The compression zone height is obtained by the equation:

$x = d \cdot \varepsilon_c / (\varepsilon_c + \varepsilon_s)$

Concrete stress is obtained from the section strain diagram using equations (3.17) and (3.18):

$$\sigma_c(z) = f_{cd}\left[1 - \left(1 - \frac{\varepsilon_c(z)}{\varepsilon_{c2}}\right)^n\right] - \text{за } 0 \le \varepsilon_c(z) \le \varepsilon_{c2}$$

$$\sigma_c(z) = f_{cd} \; - \text{за } \varepsilon_{c2} \le \varepsilon_c(z) \le \varepsilon_{cu2}, where$$

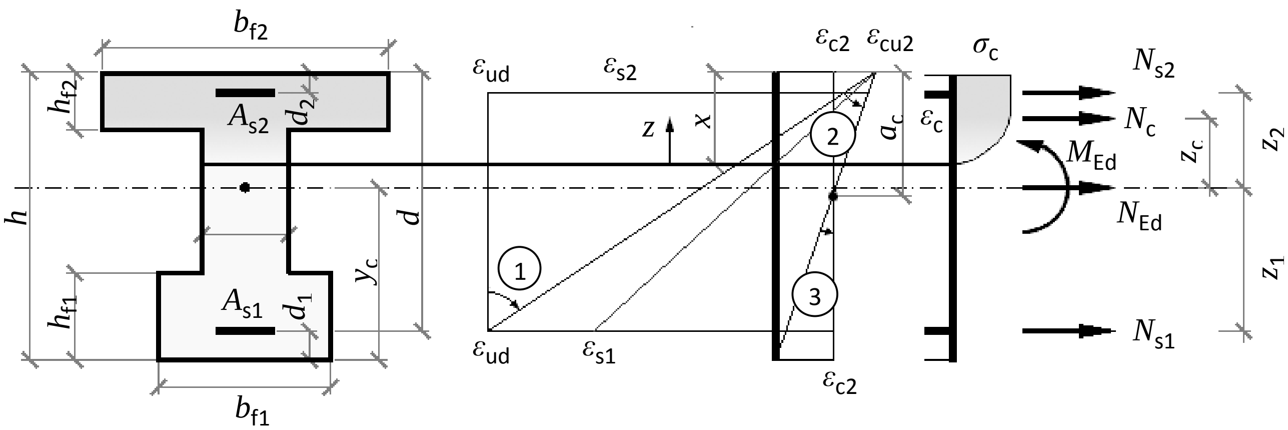
f_{cd} – design value of concrete compressive strength;

n = 2; ε_{c2} = 2.0 ‰; ε_{cu2} = 3.5 ‰ – for concrete grade lower than C50/60;

Reinforcement stress is determined by:

$-f_{yd} \le \sigma_{si} = E_s . \varepsilon_{si} \le f_{yd}$ $(i = 1{,}2)$, where

f_{yd} – design yield strength of the reinforcement steel;
E_s – is the design value of the modulus of elasticity of reinforcement.



Iterations are performed by variation of strain in tensile reinforcement ε_{s1} and compressed concrete edge ε_c so that the section always remains in limit state. The procedure is different depending on the case where strain diagram is located:

Case (1): Tensile reinforcement strain remains constant $\varepsilon_{s1} = \varepsilon_{ud}$ while strain at top edge ε_c varies from ε_{ud} (in top reinforcement) to -ε_{cu2} (at concrete edge);

Case (2): Concrete strain at top edge remains constant ε_c = - ε_{cu2} while tensile reinforcement strain varies from ε_{ud} to -$\varepsilon_{cu2}.d_1/h$. At that moment, concrete strain at bottom edge reaches zero.

Case (3): The section is entirely in compression so the strain diagram rotates around point **C** where the strain always remain -ε_{c2}. The location of point **C** from the top edge is determined by the distance $a_c = h \cdot (1 - \varepsilon_{c2}/\varepsilon_{cu2})$.

That is how the number of unknown parameters is reduced due to the condition that the section always should remain in limit state. We have to search either for ε_{s1} or ε_c and obtain the other from the strain diagram. If we know ε_{s1} and ε_c we can calculate the areas of top and bottom reinforcement directly. For each reinforcement we can use the moment equilibrium around the center of the opposite reinforcement to get the equations:

$$A_{s1} = (N_{Ed} \cdot z_2 + M_{Ed} + N_c \cdot (z_2 - z_c)) / (\sigma_{s1} z_s) \quad (3)$$

$$A_{s2} = (N_{Ed} \cdot z_1 - M_{Ed} + N_c \cdot (z_1 + z_c)) / (\sigma_{s2} z_s) \quad (4)$$

The distance between centers of top and bottom reinforcement is assumed to be $z_s = z_1 + z_2$. If the section is entirely in tension, the above equations give the final values of both reinforcement areas having $N_c = 0$ and $\sigma_{s1} = \sigma_{s2} = f_{yd}$.

In case of bending with axial force and non-symmetric reinforcement, we have 2 equations and 3 unknown parameters. There are unlimited number of solutions that satisfy equations (1) and (2). Then, the values of A_{s1} and A_{s2} are obtained by solving the optimization problem for minimizing the total reinforcement: $|A_{s1}| + |A_{s2}| = \min$. The solution is found by a special iterative algorithm.

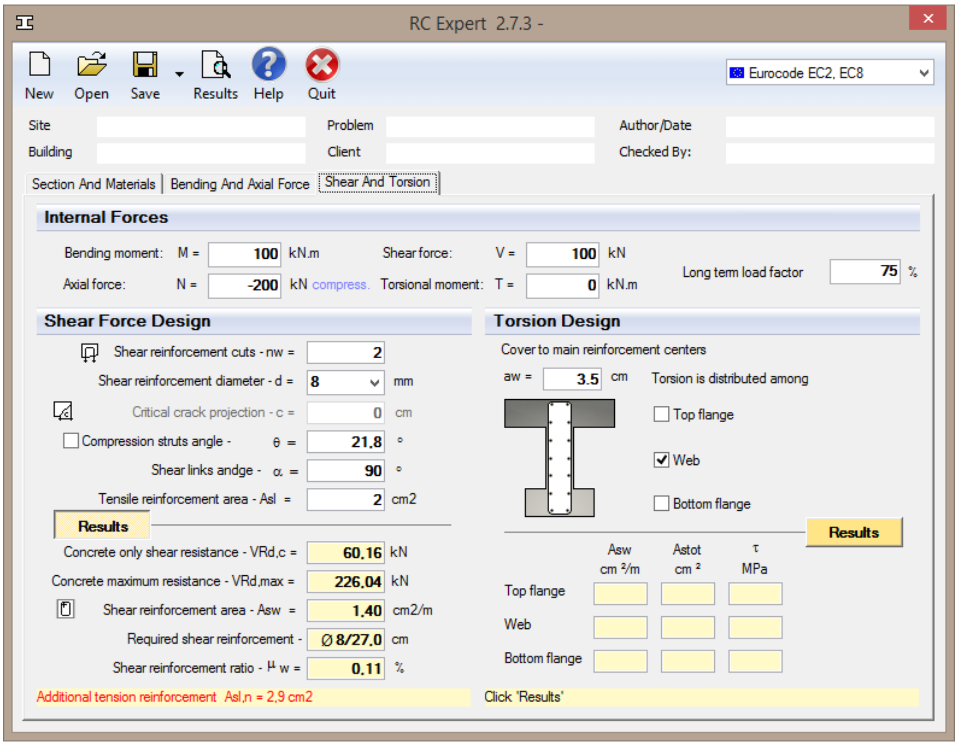
In case of symmetric reinforcement, a unique solution exists. At each iteration, the area of either top or bottom reinforcement is obtained by formulas (3) or (4) while the other is taken to be equal. For arbitrary strain, that usually violates the respective equilibrium equation, so the iterations continue until we find that value of $A_{s1} = A_{s2}$ that satisfy both (3) and (4). Then we say that we have a convergence.

In case of bending, we have only tension reinforcement until we reach the condition for sufficient ductility $x/d = 0.45$. Then we provide compressive reinforcement that allows moment re-distribution in statically indeterminate systems to occur before reaching the ultimate limit state. The solution is performed in the following sequence: First, we assume $x/d = 0.45$ and determine the reinforcement by equations (3) and (4). If $A_{s2} > 0$ then the compressive reinforcement is actually needed and this is the final solution. Otherwise, we take $A_{s2} = 0$, and iteratively search the value of A_{s1} necessary to satisfy the equation (3).

Interaction diagrams

M-N interaction diagrams can be generated for the calculated or the initial reinforcement if the latest is defined by user. The diagram is obtained by variation of the strain diagram defined by ε_{s1} and ε_c. For each iteration, the resulting axial force and moment are calculated representing a point in the **M-N** coordinate system. By connecting all points consequentially, a closed curve is obtained. We can put external moments and axial forces as points in the same coordinate system. If a point falls outside the interaction curve, then section capacity is not sufficient for the applied loads. If all points are located inside, then the section has sufficient capacity. The reinforcement is determined so that the point of the external load forces is located right on the contour of the diagram.

Shear force design



Design check can performed with vertical or inclined shear links (no bended bars). Additional input data is required:

n_{w} – number of shear link legs;

d_{w} – shear links diameter;

θ – angle of compressed concrete strut;

α – angle of shear links;

A_{sl} – area of tensile reinforcement (cm^2) with sufficient anchoring after the section of interest.

Calculations are performed according to the procedure defined in EN 1992-1-1:

Shear capacity without shear reinforcement is calculated:

$$V_{\mathrm{Rd,c}} = (C_{\mathrm{Rd,c}} \cdot k \cdot (100 \cdot \rho_{\mathrm{l}} \cdot f_{\mathrm{ck}})^{1/3} + k_1 \cdot \sigma_{\mathrm{cp}}) \cdot b_{\mathrm{w}} \cdot d$$

$$V_{\mathrm{Rd,c}} \geq V_{\mathrm{Rd,c,min}} = (v_{\mathrm{min}} + k_1 \cdot \sigma_{\mathrm{cp}}) \cdot b_{\mathrm{w}} \cdot d$$

$k = 1 + \sqrt{200/d} \leq 2;$ $\sigma_{\mathrm{cp}} = N_{\mathrm{Ed}}/A_{\mathrm{c}} < 0.2\, f_{\mathrm{cd}};$

$C_{\mathrm{Rd,c}} = 0.18/\gamma_{\mathrm{c}};$ $k_1 = 0.15;$

$v_{min} = 0{,}035\, k^{3/2}\sqrt{f_{ck}};$ $\rho_{\mathrm{l}} = A_{\mathrm{sl}}/(b_{\mathrm{w}} \cdot d) \leq 0.02;$

Maximum shear capacity of compressed concrete strut:

$$V_{\mathrm{Rd,max}} = \alpha_{\mathrm{cw}} \cdot b_{\mathrm{w}} \cdot z \cdot v_1 \cdot f_{\mathrm{cd}} \cdot (\cot\theta + \cot\alpha)/(1 + \cot^2\theta)$$ (eq. 6.14 in EN 1992-1-1)

If $V_{\mathrm{Ed}} > V_{\mathrm{Rd,max}}$ then concrete capacity is not sufficient for the external shear force and must be increased.

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

d is the effective section depth;

$\nu_1 = 0.6 \cdot (1 - f_{ck}/250)$ (eq. 6.6N in EN 1992-1-1)

$\alpha_{cw} =$	1	if	$\sigma_{cp} = 0$
	$1 + \sigma_{cp}/f_{cd}$	if	$0 < \sigma_{cp} < 0.25 f_{cd}$
	1.25	if	$0.25 f_{cd} < \sigma_{cp} < 0.5 f_{cd}$
	$2.5(1 - \sigma_{cp}/f_{cd})$	if	$0.5 f_{cd} < \sigma_{cp} < f_{cd}$

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

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

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

V_{Ed} is the design value of the shear force in the section.

Additional main reinforcement is provided for the additional tensile force. In most programs, it is accepted to cover the diagram of the required reinforcement instead of the diagram of the tension force. This is the case with Design Expert as well. Then, the additional area of main reinforcement is calculated as follows:

$A_{sl,n} = F_{td}/f_{yd}$

It should be added to the main reinforcement determined by bending design. The quantity of the calculated shear reinforcement depends on the angle θ of the compressive strut. The value of θ can be defined by user within the limits of $21.8° \le \theta \le 45°$ $(1 \le \cot\theta \le 2.5)$. If you select the respective checkbox, the custom defined value is used in the calculations. Otherwise, the program will calculate the angle from the condition $V_{Rd,max} = V_{Ed}$. Link spacing is determined according to the selected diameter by the equation: $s = \pi d_w^2/(4A_{sw}) < s_{max} = 0.75d \cdot (1 + \cot\alpha)$.

Torsion design

For I and T sections, all section parts (web and flanges) can be considered in torsion design as rectangular segments. Total torsional moment is distributed among the different parts proportionate to their torsional stiffness. Main and shear reinforcement is calculated additional to the reinforcement obtained from bending and shear design. Calculations for each rectangular part are performed as described further.

Concrete cover for torsion a_w should be specified from the concrete edge to the center of main reinforcement.

Shear force is included in calculation of torsional stresses. The following checks are performed:

Requirement for shear reinforcement: $T_{Ed} / T_{Rd,c} + V_{Ed} / V_{Rd,c} > 1$ (6.29)

Capacity of concrete compressive struts: $T_{Rd,max} = \nu \cdot \alpha_c \cdot f_{cd} \cdot A_k \cdot t_{ef} \cdot \sin(2 \cdot \theta)$ (6.30)

$T_{Ed} = T$ is the design torsion force.

Values for V_{Ed}, $V_{Rd,c}$ and $V_{Rd,max}$ are according to the "Shear force design" chapter above in this manual.

The calculation of the reinforcement is performed as follows:

Shear reinforcement: $A_{sw} = P / (f_{ywd} \cdot \cot\theta)$

Main reinforcement: $A_{stot} = P \cdot U_k \cdot \cot\theta / f_{yd}$ (6.28)

Effective section width for torsion: $t_{ef} = b \cdot h / (2 \cdot b + 2 \cdot h)$

$t_{ef} \leq 2 \cdot a_w$

Effective section area: $A_k = (b - t_{ef}) \cdot (h - t_{ef})$

Perimeter of the 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 section part.

Report

You can generate a detailed report in **HTML** format for each problem by clicking the "**Results**" button. The report is opened in Internet Explorer by default, but you can use other web browsers as well. Most office programs like MS Word can also edit **html** files. The report is saved in a file named **data_file_name.html**.

The file always comes together with a folder named **data_file_name.html_files**. Always keep the file and the folder together, otherwise all pictures and formatting will be lost.

Examples

A lot of examples have been solved for verification of the software but only a few are presented in this manual. The examples are elaborated according to „RC Design Manual. Eurocode 2“, KIIP, Sofia 2011, Prof. Konstantin Rusev at al.

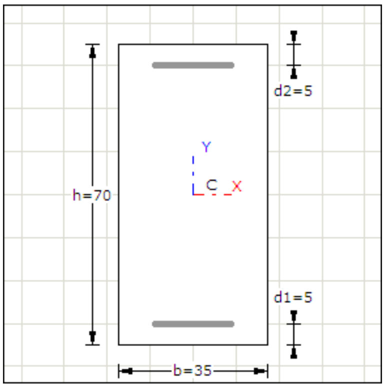
Example 1. Shear force design

Solution with RC Expert

Cross section

b = 35,0 cm h = 70,0 cm

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



Internal forces

Shear force - V_{Ed} = 770,0 kN

Materials			
Concrete grade C25/30	E_{cm} = 31,5 GPa	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 B500	E_s = 200,0 GPa	f_{yk} = 500,0 MPa	f_{yd} = 435,0 MPa
Shear reinforcement B500	E_{yw}= 200,0 GPa	f_{ywk}= 500,0 MPa	f_{ywd}= 435,0 MPa

Input data

Number of shear link legs - n_w = 2

Diameter of shear links - d_w = 12,0 mm

Angle of inclination of shear links - a = 90,0 deg

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

Shear design results

Compression strut angle- θ= 28,3 deg

Concrete only resistance- $V_{Rd,c}$ = 77,2 kN

Concrete maximum resistance- $V_{Rd,max}$ = 770,0 kN

Shear reinforcement area - A_{sw} = 8,2 cm^2/m

Required shear reinforcement- Φ12/13,5

Shear reinforcement ratio - m_w = 0,5 %

Required main reinforcement - Asl,n = 16,4 cm2

Manual check

$$z = 0.9d = 0.9 \cdot 65 = 58.5\ cm$$

$$\theta = 0.5 \sin^{-1}\left(\frac{V_{Ed}}{0.20(1 - f_{ck}/250) f_{ck} bz}\right) = 0.5 \sin^{-1}\left(\frac{770 \cdot 10^3}{0.20(1 - 25/250)25 \cdot 350 \cdot 585}\right) = 28.3°$$

$$v_1 = 0.6 \cdot (1 - f_{ck}/250) = 0.6 \cdot (1 - 25/250) = 0.54$$

$$V_{Rd,max} = \alpha_{cw}\, b_w\, z\, v_1 f_{cd} \cot\theta/(1 + \cot^2\theta) = 1 \cdot 35 \cdot 58.5 \cdot 0.54 \cdot 1.67 \cdot \cot 28.3°/(1 + \cot^2 28.3°) = 770\text{ kN}$$

$$A_{sw} = \frac{V_{Ed}}{n_w\, z \cot\theta\, f_{yd}} = \frac{770 \cdot 100}{2 \cdot 58.5 \cdot \cot 28.3° \cdot 43.5} = 8.15 \frac{cm^2}{m}$$

Selected Ø12 at spacing $s = \frac{\pi d_w^2}{4A_{sw}} = \frac{\pi 12^2}{4 \cdot 8.15} = 13.9\ cm < 0.75d = 48.75\ cm$

Example 2. Bending design of rectangular cross section

Solution with RC Expert

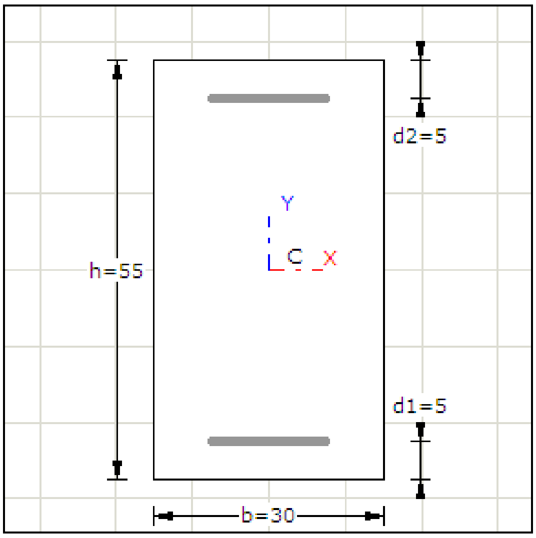
Cross section

$b = 30{,}0$ cm $h = 55{,}0$ 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



Internal forces

Bending moment - $M_{Ed} = 200{,}0$ 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 - KG = 75,0 %

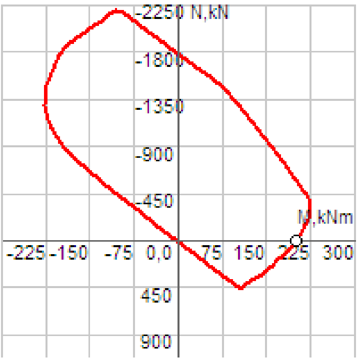
Materials			
Concrete grade C16/20	$E_c = 29{,}0$ GPa	$f_{ck} = 16{,}0$ MPa	$f_{ctk,0.05} = 1{,}3$ MPa
		$f_{cd} = 10{,}7$ MPa	$f_{ctd} = 0{,}9$ MPa
Main reinforcement grade B500	$E_y = 200{,}0$ GPa	$f_{yk} = 500{,}0$ MPa	$f_{yd} = 435{,}0$ MPa

Input data

Strength Reduction Factors	Existing Reinforcement	
alpha_cc = 1,00	Bottom	$A_{s1,ini} = 0{,}0$ cm^2
alpha_ct = 1,00	Top	$A_{s2,ini} = 0{,}0$ cm^2

Bending with axial force design results

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_{s1} = 10.7$ cm^2	$\mu_1 = 0{,}7\%$	$\sigma_{s2} = 435{,}0$ MPa
Top	$A_{s2} = 0.0$ cm^2	$\mu_2 = 0{,}0\%$	$\sigma_{s1} = -435{,}0$ MPa
Total	$A_{s,tot} = 0.0$ cm^2	Compr. zone height x = 17,7cm^2	



Manual verification

$$m_{Ed} = \frac{M_{Ed}}{bd^2\eta f_{cd}} = \frac{20000}{30 \cdot 50^2 \cdot 1 \cdot 1.33} = 0.2$$

$$\xi = 0.2817;\ \varsigma = 0.8872;\ \varepsilon_{c2d} = -3.5‰;\ \varepsilon_{s1d} = 8.92‰;\ \sigma_{s1} = 43.5\,kN/cm^2$$

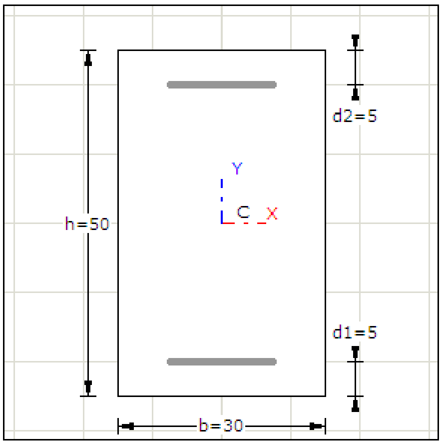
$$A_{s1} = \frac{M_{Ed}}{\varsigma d \sigma_{s1}} = \frac{20000}{0.8872 \cdot 50 \cdot 43.5} = 10.37\ cm^2$$

Example 3. Bending with axial force design of symmetrically reinforced section

Solution with RC Expert

Cross section

$b = 30{,}0$ 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
$d_1 = 5{,}0$ cm	$d_2 = 5{,}0$ cm



Internal forces

Moment - $M_{Ed} = 119{,}7$ kN.m

Axial force - $N_{Ed} = -199{,}5$ kN

Long term load factor - KG = 75,0 %

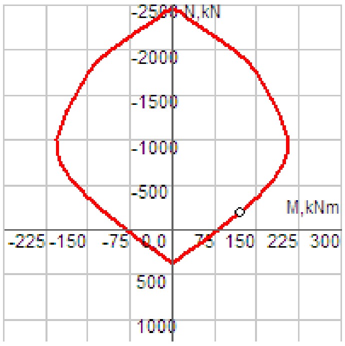
Materials			
Concrete grade C25/30	$E_c = 31{,}5$ GPa	$f_{ck} = 25{,}0$ MPa	$f_{ctk,0.05} = 1{,}8$ MPa
		$f_{cd} = 16{,}7$ MPa	$f_{ctd} = 1{,}2$ MPa
Main reinforcement grade B500	$E_s = 200{,}0$ GPa	$f_{yk} = 500{,}0$ MPa	$f_{yd} = 435{,}0$ MPa
Shear reinforcement grade B500	$E_{yw} = 200{,}0$ GPa	$f_{ywk} = 500{,}0$ MPa	$f_{ywd} = 435{,}0$ MPa

Input data

Strength Reduction Factors	Existing Reinforcement	
alpha_cc =0,85	Bottom	$A_{s1,ini} = 0{,}0$ cm^2
alpha_ct =1,00	Top	$A_{s2,ini} = 0{,}0$ cm^2

Bending with axial force design results

Reinforcement	Area	Reinf. ratio	Reinf. stress
Bottom	$A_{s1} = 4{,}4$ cm^2	$\mu_1 = 0{,}3\%$	$\sigma_{s1} = 435{,}0$ MPa
Top	$A_{s2} = 4{,}4$ cm^2	$\mu_2 = 0{,}3\%$	$\sigma_{s2} = -233{,}5$ MPa
Total	$A_{s,tot} = 8{,}8$ cm^2	Compr. zone height x = 9,2 cm^2	



Manual verification

$$m_{Ed} = \frac{M_{Ed}}{bh^2\eta f_{cd}} = \frac{119.7 \cdot 10^6}{300 \cdot 500^2 \cdot 11.33} = 0.141$$

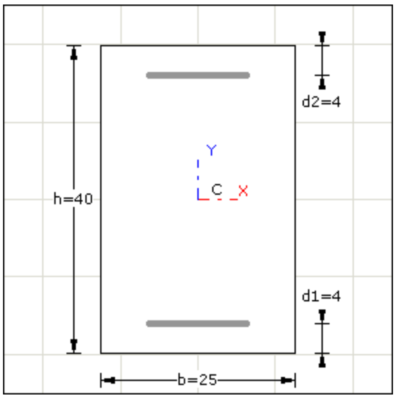
$$n_{Ed} = \frac{N_{Ed}}{bh\eta f_{cd}} = \frac{-199.5 \cdot 10^3}{300 \cdot 500 \cdot 11.33} = -0.117$$

Read from fig. 15.5 the value of $\omega_{tot} = 0.225$

$$A_{s,tot} = \omega_{tot}\frac{bh\eta f_{cd}}{f_{yd}} = 0.225\frac{300 \cdot 500 \cdot 11.33}{435} = 879\ mm^2 = 8.8\ cm^2$$

Example 4. Interaction curves for bending with axial force.

Interaction curves for bending with axial force are generated using RC Expert. The section is rectangular with symmetric reinforcement $A_{s1,ini} = A_{s2,ini}$ and $d_1/h = 0.1$. The curves are compared with those provided in the manual on figure 15.5.



Rectangular cross section

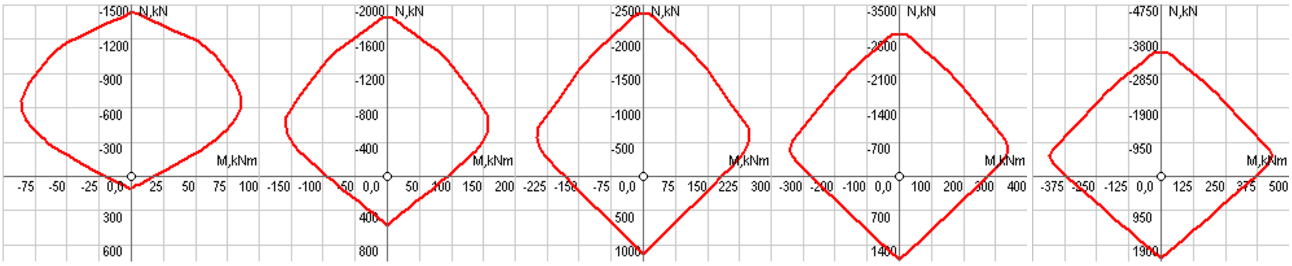
$b = 25{,}0$ cm $h = 40{,}0$ cm

$d_1 = 4{,}0$ cm $d_2 = 4{,}0$ cm

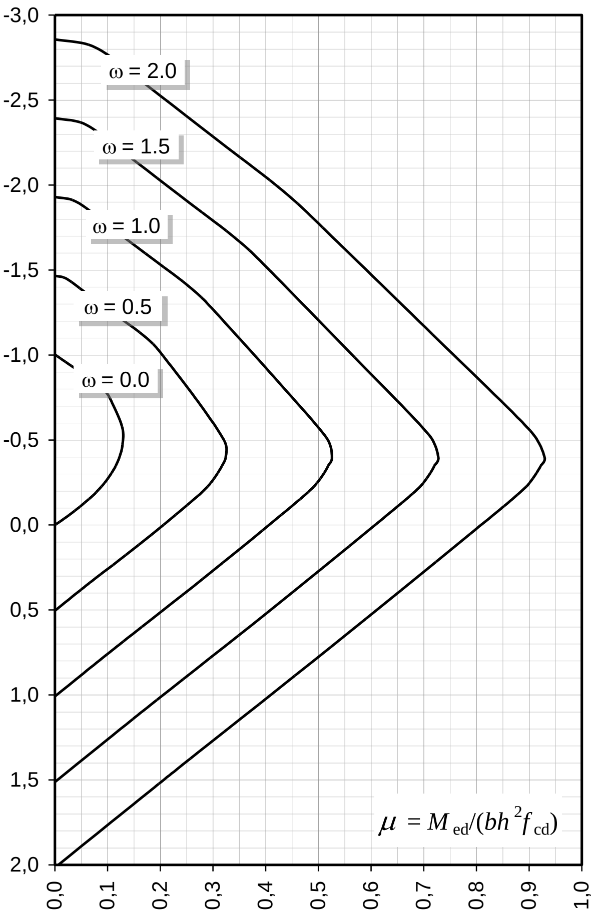
Materials			
Concrete grade C20/25	f_{ck} = 20,0 MPa	f_{cd} = 13,3 MPa	E_{cm} = 30 GPa
Steel grade B500	f_{yk} = 500 MPa	f_{yd} = 435 MPa	E_s = 200 GPa

Results in 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



Results from RC Expert in related coordinates



Results in the manual