Q3 – Thin-walled Cross Section

Contents

Basic Documentation – Overview

In addition to the individual program manuals, you will find basic explanations on the operation of the programs on our homepage www.frilo.com in the Campus-download-section.

Tip: Go back - e.g. after a link to another chapter / document - in the PDF with the key combination "ALT" + "left arrow key".

Application options

The software allows you to calculate the properties listed below on any composite thin-walled steel shape typically used in steel engineering:

Cross-sectional properties of the general structural system

Cross-sectional area

Location of the centre of gravity

Second moments of area

Angle of the main axes

Second moments of area referenced to the main axes

Section moduli

Radii of inertia

Core area

Dimensions of the enveloping rectangle

→ see cross-sectional properties of the general structural system

Enhanced cross-sectional properties for the equivalent member system

Location of the shear centre

Shear areas for shear deformation

Shear areas for the stress calculation

Torsional moment of inertia

Torsional section modulus

Warping section modulus

Kindem lengths

First moments of area

Stresses in the general structural system

Axial bending stress caused by axial force and My and Mz in the corner points of each section (max. and min. value, all other internal forces are disregarded).

The software assumes that the individual shapes of the assembled section are joined in a shear-transmitting connection,

→ see stresses in the corner points

Stresses on the equivalent member system

Axial bending stress caused by axial force and My and Mz

Axial stress caused by warping torsion

Resulting axial stress

Shear stress due to shear force

Shear stress due to St. Venant's torsion on the closed cross section

Shear stress due to St. Venant's torsion on the open cross section

Shear stress due to warping torsion

Resulting shear stress

Comparison stress

Normalized warping on the equivalent member system

Normalized warping function relating to the shear centre

Normalized warping function relating to the centre of gravity

Results obtained on the general structural system

Core area

Load arrangement of the general system - only axial force and bending moments

Cross section properties (main axes etc.) on the general system

Stresses due to N, My, Mz only

Shape selection

Standard steel shapes (DIN, ARBED) are available in a database.
The definition of single-symmetrical double-T-shapes, metal plates and round steel is done by specifying their dimensions.
In addition to this, you can define (select) user-defined U-channel, angled, hollow and thin-walled open shapes (Q20 cross section).
These shapes can be combined to any kind of cross section. You can define the cross section via a table or with the help of graphical functions.

Equivalent member system

The enhanced cross-sectional properties (warping section modulus, etc.) are calculated on an equivalent member system that must be self-contained.

The cross section entered by the user is decomposed in such a member system.

Each member has a constant thickness. If the system is multi-piece (normally with more than one profile), connections must be defined between the individual profiles. These connections can be defined graphically or via a table.

Each member has a number and is identified by a node number at its front end and its rear end. Connections are created between either two nodes or a node and a member. In the latter case, a perpendicular is dropped from the selected node to the member to be connected. A new node is generated at the point of intersection and the selected member is split into two members.

In practice, these connections are realized with weld seams, for instance.

The software does not verify the weld seams, however. The connections are treated like members and nodes of the equivalent member system.

Entering internal forces via tables

N, My, Mz

The following internal forces are only taken into account in the equivalent member system:

Vz, Vy, Mtp, Mts, B

→ See also the chapter Internal forces

Basis of calculation

Equivalent member system

The shear centre is calculated on the equivalent member system. It is the point in the cross section, in which the shear force applies a resultant of all shear force stresses.

If the resulting shear force applies outside of the shear centre, a torsional moment is generated that produces additional shear stress and deformation. These shear stresses must be superimposed with shear force stresses.

Torsion can be either St. Venant's torsion (primary torsion) or warping torsion (secondary torsion).

Warping torsion - secondary shear stress and axial stress

Warping of a cross section means that the cross section does not remain in the plane. The cross section points are displaced in the direction of the member axis. This property depends on the type of cross section:

- Warping-resistant cross sections: pipes, L-shapes, T-shapes, cross shapes
- Quasi warping-resistant cross sections: multi-cell hollow sections
- Cross sections prone to warping: open thin-walled cross sections

If warping of the cross section is impeded, shear stress (due to the secondary torsion moment) and axial stress (due to the bi-moment and/or warping moment) are generated.

When warping is impeded, the cross-section becomes stiffer. This property is defined by the warping resistance CM. Since this property only occurs on cross sections that can warp, the resistance to warping of those cross sections is high in contrast to cross sections not affected by warping.

The member has the lowest resistance to warping in a rotation around the shear centre.

St. Venant's torsion

If the above mentioned warping effect is neglected, we talk about primary (pure) torsion. A closed shear flow is generated inside the individual thin-walled cross-section parts. The highest shear stress applies at the edges and is equal to zero along the central axis of the individual cross section parts (equivalent members).

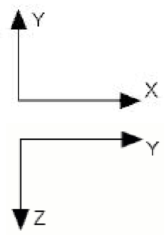
The portions of primary and secondary torsion depend on the type of cross section, the structural system and the loading.

Definition of the structural system

You can define the system via tables or the graphical user interface. Corresponding options (graphical/via tables) are available in the main menu.

Graphical definition

! Some functions of the graphical user interface are only available via the "context-sensitive menu." Right click on the graphic screen to display the context-sensitive menu. See the example in the chapter "Metal plates".



All graphical user specifications refer to the x/y coordinate axes.

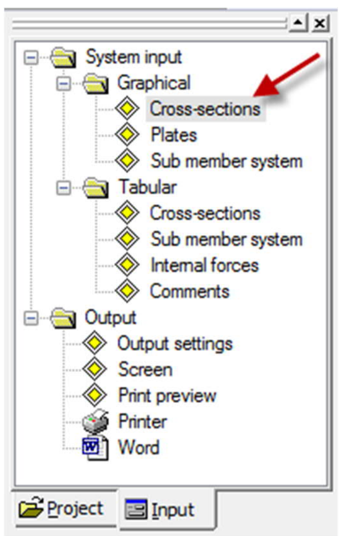
Optionally, output data can also refer to the y/z coordinate axes.

Two toolbars are available for the control of the graphical definition.

System	displays the buttons for the definition of shapes and metal plates as well as for the functions displace, copy, caption, delete ....
Equivalent member system	displays the buttons for the definition and deletion of connections. Tooltips are available for the different functions.

The definition on the graphical screen is always based on the x/y system of coordinates.

Steel shapes



The user can access the shape selection via the corresponding menu item.

Alternatively, you can launch the shape selection via the button.

You can select a standard shape from the displayed list or define a shape by entering the dimensions.
→ See the chapter "Cross sections and shape selection“.

After having selected the desired steel shape, the dialog for setting the corresponding parameters is displayed.

Reference point

The reference points are shown on the steel shape displayed on the graphical screen - see graphical representation on the next page.

Clicking on a reference point enables/selects this point and it changes its colour.

The selected point is used as a reference for the subsequent positioning of the shape.

Distance to the marked reference point

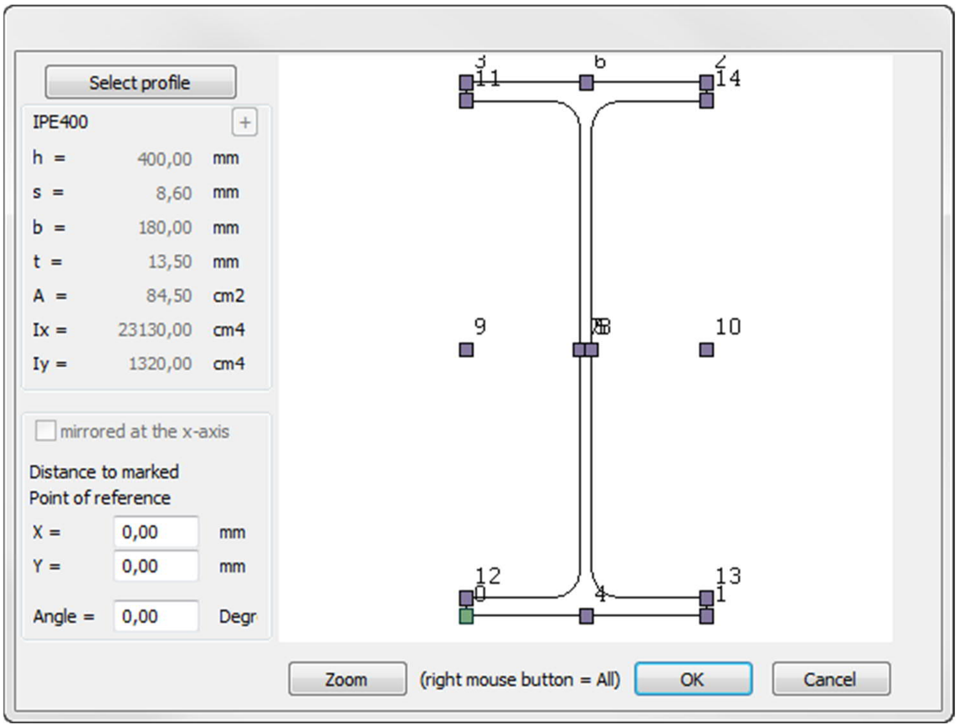
You can move the reference point by changing its x and/or y coordinate.

Angle

The definition of an angle (positive, rotating anti-clockwise) provides for the rotation of the shape.

Mirrored along the x-axis

You can mirror Z and L shapes along the x-axis by activating the corresponding option.



Zoom

Zooms the steel shape on the graphic screen in or out.

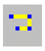
Shape selection

Activating this option displays the selection of shapes once more and you can select another steel shape.

Positioning of the selected shape

After setting the parameters described above and confirming them with OK, you can position the shape (reference point) on the graphic screen with the help of the mouse.

Metal plates

Symbol: 

The cursor is shown as cross hairs and you can draw a polygonal chain to define a plate with the help of the mouse or specify the relevant coordinates in the numerical definition section. You can exit the definition of the polygonal chain by activating the corresponding option in the context menu (right mouse button, see the following paragraph).

Note: *Use the background grit for orientation and the snap mode.*

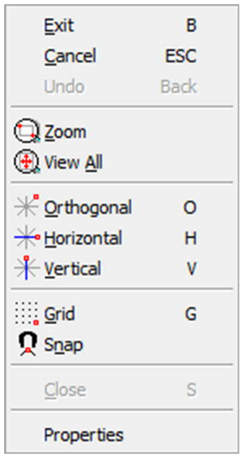
Ill.: Numerical specification of coordinates, buttons for the snap mode, background grit etc.

! The fundamentals of the graphical definition are described in the document "Graphical input".

Context-sensitive function menu

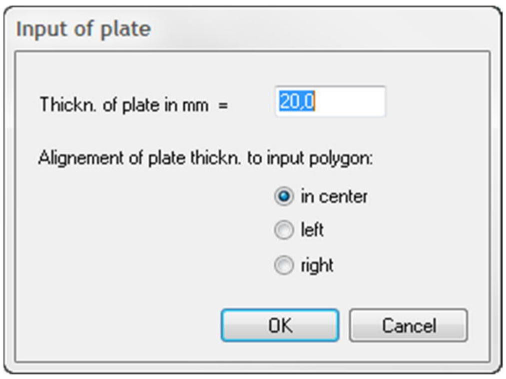
To close a polygonal chain or abort the definition, right-click on the graphic screen to display the context-sensitive menu with the corresponding functions (see the illustration).

Close	the most recently set point of the polygon is connected to the first point (closed profile).
Exit	quits the definition of the shape.
Cancel	cancels the definition of the shape.
Undo	the most recent polygonal point is deleted.
Orthogonal ...Snap	general functions for the definition via the graphical user interface.
Properties	representation options - dimensions, rotation, background grit.



After activating either the "Close" or "Exit" function, the dialog for the definition of the metal plate is displayed. You can enter the plate thickness in mm and the desired "direction of extension" in relation to the defined polygonal chain.

Note: *The alignment left or right refers to the direction (cw or ccw) in which the polygonal chain was defined.*



Equivalent bar system

The mouse cursor is shown as a rectangle and the capture function is active. Select a node and subsequently the next node or a bar. After the successful selection, the connection is displayed on the graphic screen.

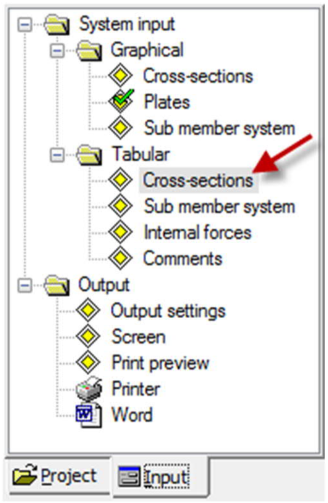
Read the chapter Definition of the equivalent member system via tables for more information.

See also

Equivalent member system toolbar

Basis of calculation of the equivalent member system

Definition via tables



Shapes displays the shape selection list. Position the cursor in the shape column and press the F5 key.

Equivalent member system the steel shapes are automatically transformed into an equivalent member system. Such a system can only be calculated if it is contiguous. Therefore, you must define connections if need be.

Internal forces displays tables for the definition of the internal forces (N, My, Mz, Vz, Vy, Mtp, Mts, B).

Shapes

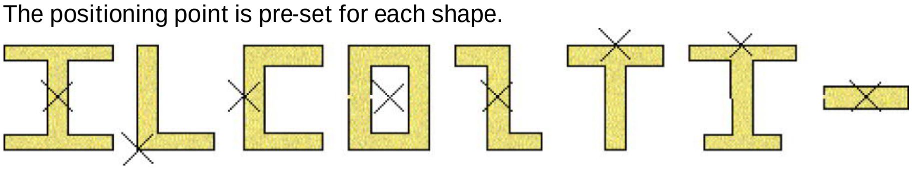
Shape press F5 to start the shape selection. You can select a standard shape from the displayed list or define a shape by specifying its dimensions.

Item specification of an item name. The software proposes "Item + consecutive number" as a default.

Height, Thickness, Width the geometric properties of the selected steel shape are displayed in the corresponding columns.

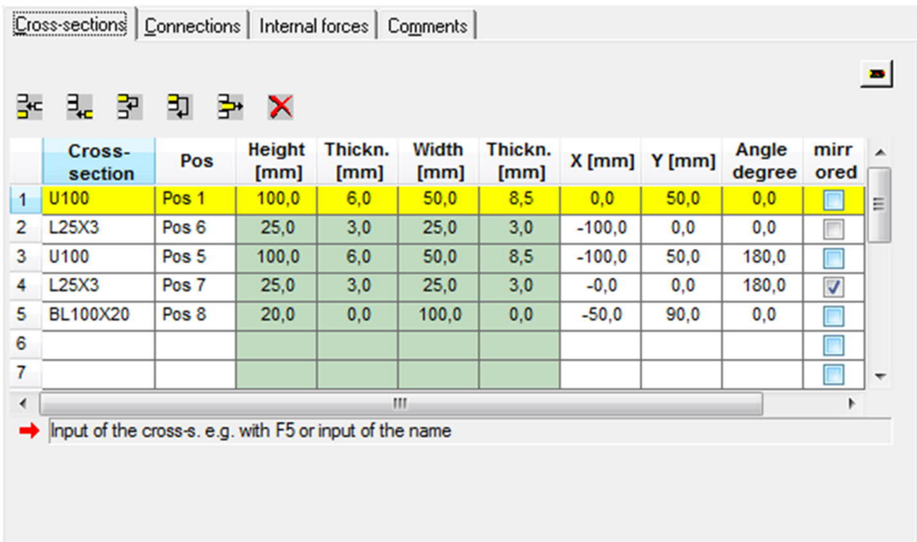
X, Y specification of the positioning point of the shape in the x/y-system (x to the right = positive sign, y to the top = positive sign).

The positioning point is pre-set for each shape.



Angle specification of the angle of rotation of the shape - anti-clockwise is positive.

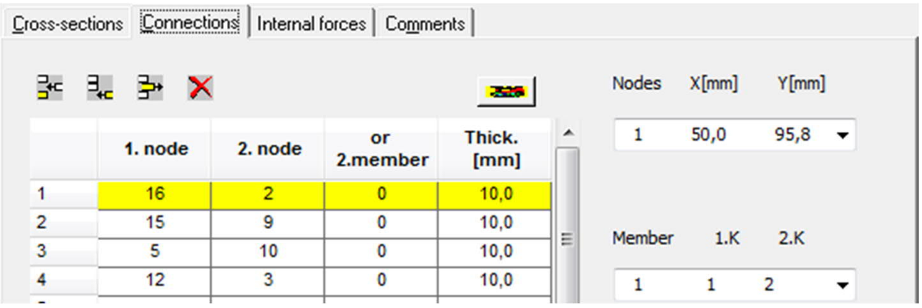
Mirrored you can enable this option for L and Z shapes to mirror the profiles along the x-axis.



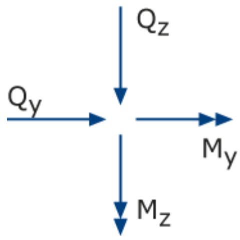
Equivalent member system

The defined steel shapes are automatically transformed into an equivalent member system. Such a system can only be calculated if it is contiguous. Therefore, you must define connections if need be. You can do this by specifying either two node numbers or a node and a member number. If the second number is a member number, a perpendicular is dropped from the previously defined node to the specified member to establish the connection. The member is divided into two sections in this process.

All nodes and members of the system are displayed in the selection list adjacent to the table.



Internal forces



Sign definition: see the illustration

N axial force (compression) in the centre of gravity in kN → axial stress

My moment around the y-axis in [kNm] → axial bending stress. It is positive, if the moment vector points in the positive direction of the axis.

My moment around the z-axis in [kNm] → axial bending stress. It is positive, if the moment vector points in the positive direction of the axis.

The following internal forces are only taken into account in the equivalent member system:

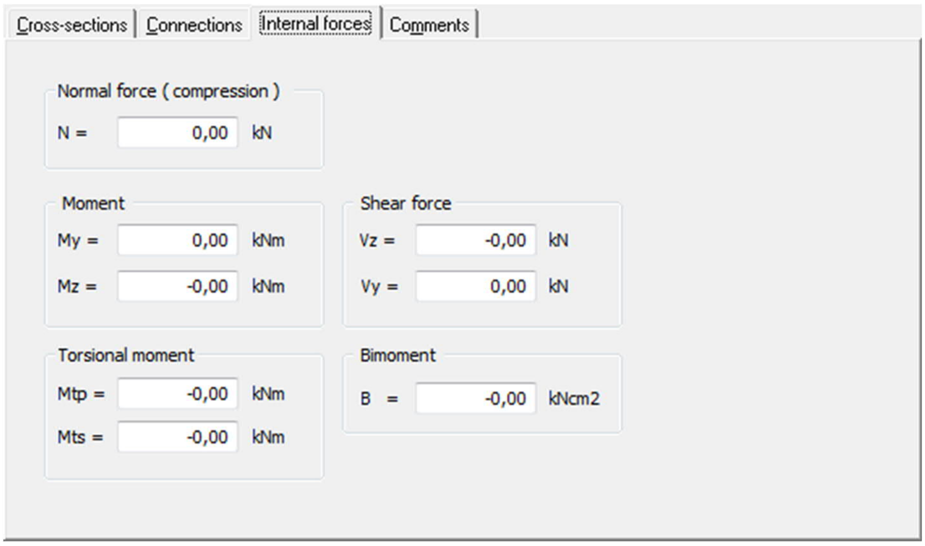
Vz shear force in the z-direction in kN → shear stress

Vy shear force in the y-direction in kN → shear stress

Mtp primary torsional moment (St. Venant) in kNm → shear stress

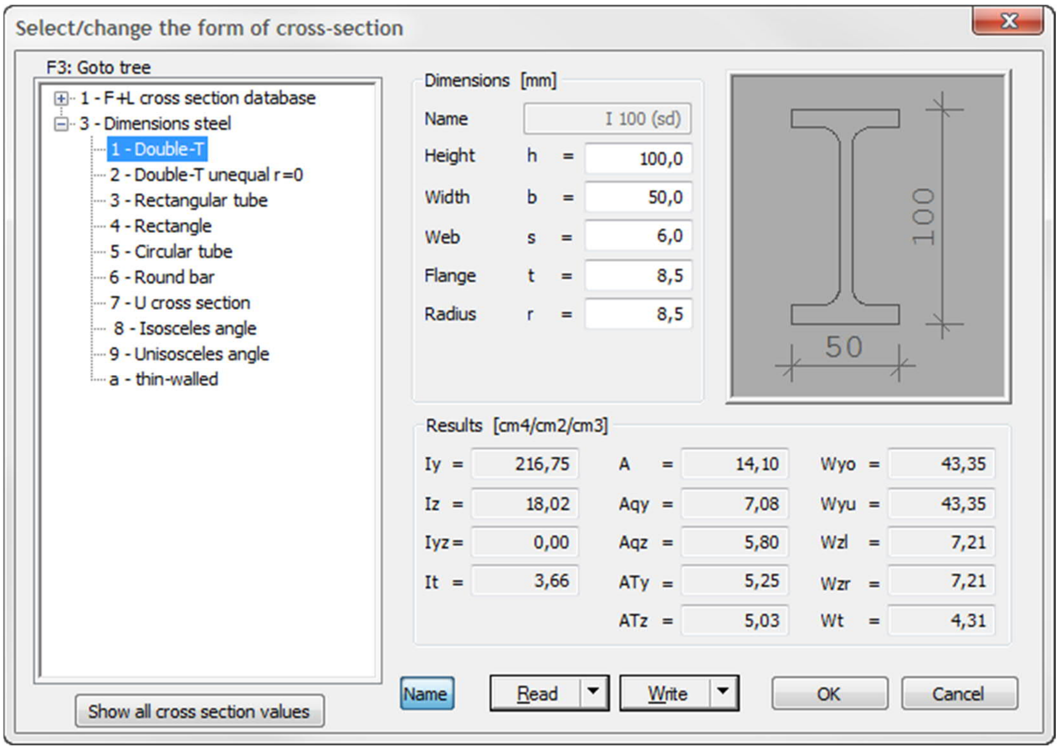
Mts secondary torsional moment (warping torsion) in kNm → shear stress

B bimoment (warping moment) in kNcm² → axial stress



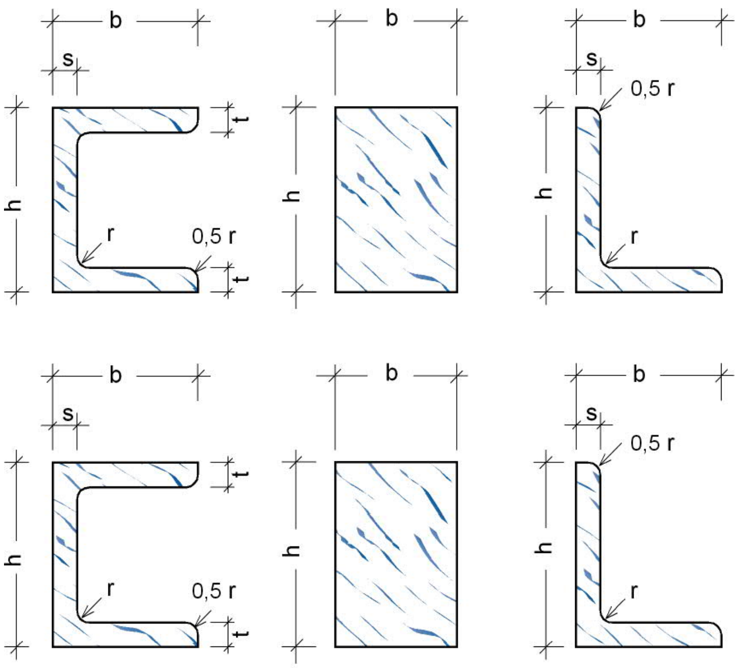
Cross sections and steel shape selection

The profile selection window is displayed when you define a new cross section or edit an existing one.



See also the document Select - edit cross section

Designation of dimensions



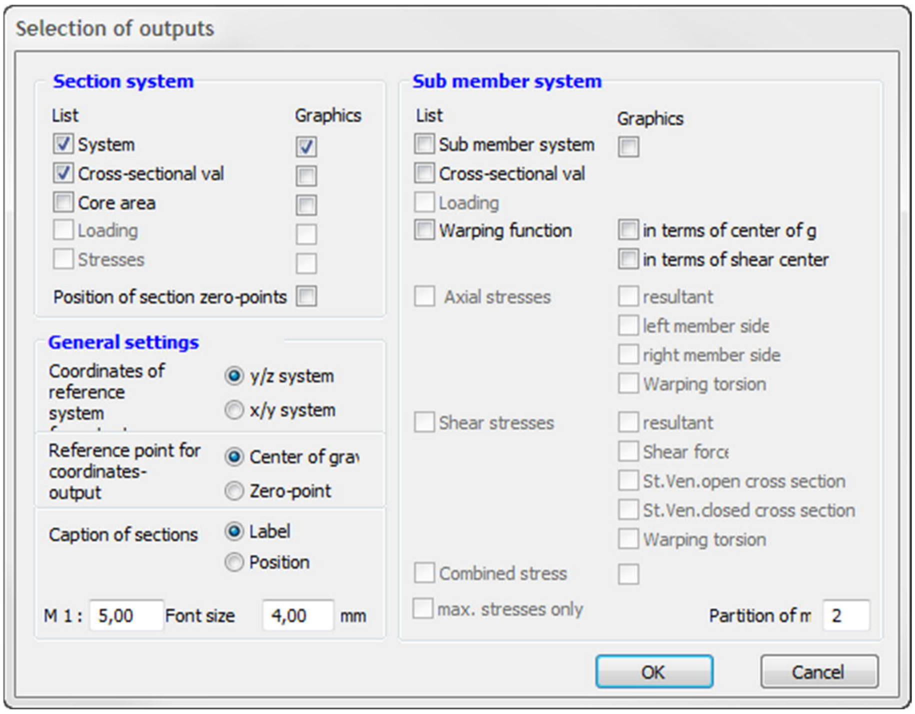
Results and output

Output of the system data, results and graphics on the screen or printer.

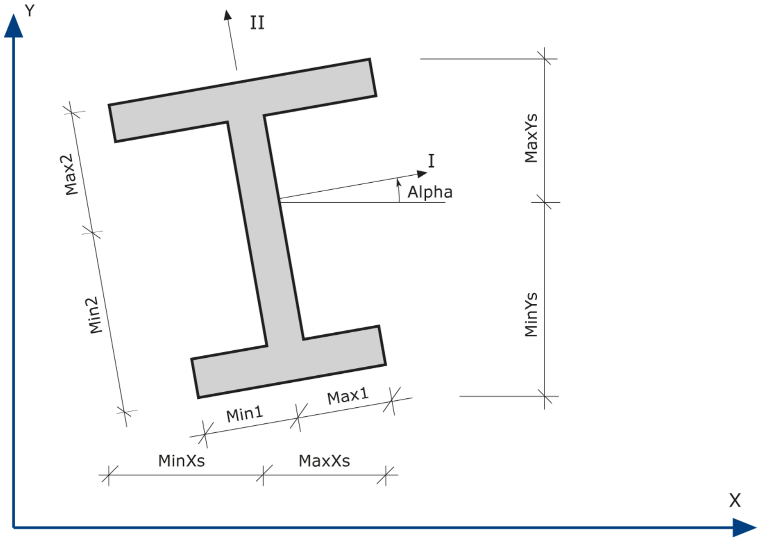
Output profile	allows you to define the scope of data to be put out be checking the corresponding options.
Screen	displays the value tables on the screen.
Page view	displays a page view of the PDF file.
Printer	starts the output on the printer
Word	if installed on your computer, the text editor MS Word is launched and the output data are transferred. You can edit the data in Word as required.

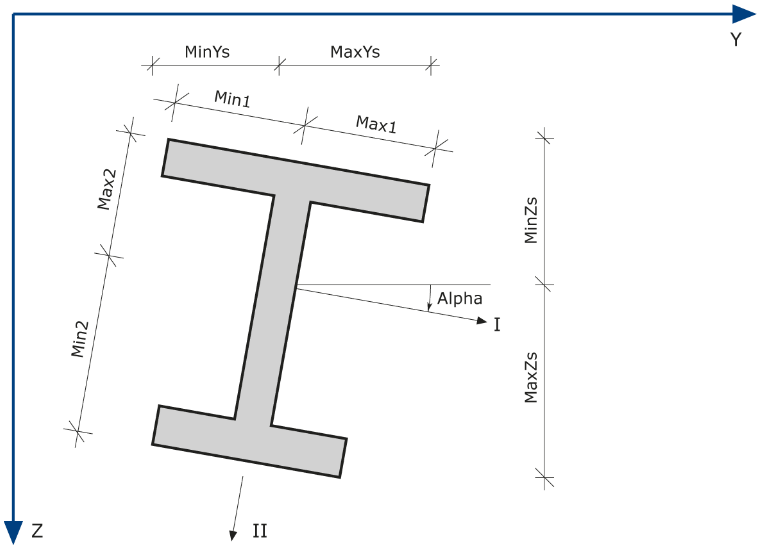
Output profile

You can define the values and graphics to be put out, the reference system of coordinates for the output and the reference point for the output of the coordinates. In addition, you can select whether the steel shape caption should be a name or the item. The scale and font size (in mm) are also selectable.



Systems of coordinates for the output





Cross-sectional properties of the general structural system

The following properties are determined for the assembled profile:

- Cross sectional area
- Position of the centre of gravity in the global system of coordinates
- Moment of inertia Iy, Iz and Iyz (or Ix, Iy and Ixy)
- Angle alpha of the main axes
- Moments of inertia I1 (max I) and I2 (min I) relating to the main axes
- Maximum distance of the edges to the centre of gravity in the direction of the global axes as well as the main axes
- Maximum section moduli
- Weight

The coordinates of the centre of gravity refer to the origin of the global system of coordinates.

Alpha designates the angle between the horizontal axis and the main axis (strong axis) and ranges between -90° and +90°.

In the x/y system of coordinates, angles are positive if they rotate anti-clockwise; in the y/z system of coordinate, they are positive if the rotate clockwise.

The positive direction of the second main axis (weak axis) is determined by adding 90° to alpha (must be specified with a sign).

MinYs (MaxYs) is the greatest distance of an edge point to the centre of gravity of the assembled steel shape in the negative (positive) direction of the y axis. This applies analogously to MinZs and MaxZs as well as MinXs and MaxXs.

Min1 (Max1) is the greatest distance of an edge point to the centre of gravity in the negative (positive) direction of main axis I. This applies analogously to Min2 and Max2.

The following relations exist between the resistance moments and the main axes:

W1t	=	I1 / Max2	for the x/y system coordinates
W1b	=	I1 / Min2	
W1t	=	I1 / Min2	for the y/z system coordinates
W1b	=	I1 / Max2	
W2l	=	I2 / Min1	for both systems of coordinates
W2r	=	I2 / Max1	

W1 = resistance moment around main axis I

W2 = resistance moment around main axis II

t = top, b = bottom, l = left, r = right

If you imagine the steel shape rotated in such a manner that the positive end of main axis I points to the right, the index of the resistance moment indicates its location; i.e. the point above main axis I with the greatest distance to it has the resistance moment W1t.

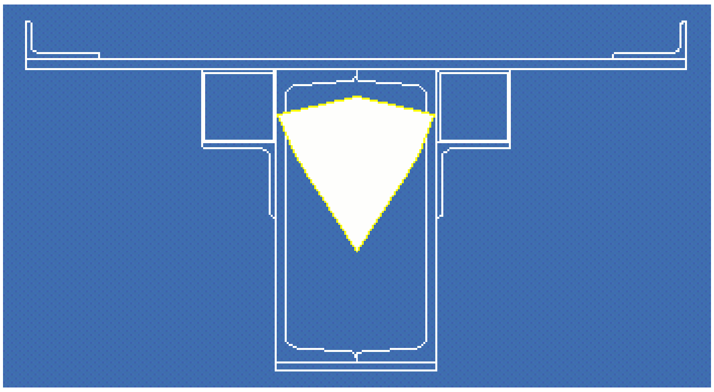
Core area

The core area of the assembled cross section is calculated for a general structural system.

If an axial force applies within the core area it generates only longitudinal stresses of the same sign in the cross section.

If the point of application of axial force lies on the border of the core area, the associated neutral axis is tangent to the edge of the cross section.

The position of the neutral axes tangent to the assembled cross section is calculated. The results can be used to determine the corner points of the core cross section.



Stresses in the corner points

The Q3 application allows you to calculate axial stress due to double bending with axial force for a general system.

The maximum and minimum stress values are indicated for each individual steel shape and for the assembled shape together with the associated coordinates.

You can optionally select whether the coordinates that are put out should refer to the global zero point of the system of coordinates or to the centre of gravity of the assembled steel shape.

The software assumes that the individual steel shapes are joined in a shear-transmitting connection.

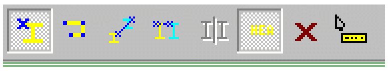
Equivalent member system

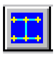
See also:
Application options, equivalent member system
Basis of calculation, equivalent member system

Toolbars in Q3

Definition of the structural system

Definition of the system

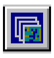
The following buttons are displayed: 



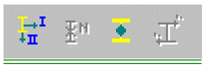
Definition of the equivalent member system

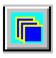
The following buttons are displayed: 

Results



System results

The following buttons are displayed: 



Equivalent member system results

The following buttons are displayed:

Note: *You can move the toolbars per drag and drop (e.g. from below the menu bar into a vertical position at the right border of the screen).*

System definition toolbar

The following buttons are displayed when you click on the button (definition of the general system).

Define steel shapes

Define metal plates

Move: after selection of a shape, click on a reference point. The geometric assignment is preserved during the displacement process. The reference point is particularly helpful if the orientation in the horizontal or vertical source and target positions is the same. You can use the cross hairs of the cursor as an auxiliary line.

A second mouse click fixes the target point of the displacement.

The graphical auxiliary functions facilitate your work.

Copy: similar proceeding as with move with the exception that the source position is preserved and you set up a new steel shape in the target position identified by the caption Item (n+1).

Mirror steel shapes: the line along which the shape shall be mirrored is freely selectable. (Observe the information in the status line). The shape is copied and mirrored.

Enable/disable profile caption

Move caption

Delete steel shapes: click on the steel shapes that should be deleted, the selected shapes are shown in a different colour. Exit the selecting process via the context-sensitive menu (right mouse button). Activate the "Exit" option to delete the selected profiles.

Enable/disable the steel shape tooltips. Steel shape tooltips = indicating the name, dimensions, position and structural values of the steel shape when hovered with the mouse cursor.

Select the steel shapes to be edited

You can select several elements simultaneously. Depending on the currently active selection mode, the steel shapes are either selected per mouse click or by zooming out an area with the mouse.

When you have selected the desired elements exit the selecting process by activating the corresponding option in the context-sensitive menu.

System results toolbar

Display of the following values/graphics

Cross sectional properties

Load arrangement of the system

Core area

Stress due to M, N

Equivalent member system toolbar

Definition

Definition of the equivalent member system. Clicking on this button displays the following buttons:

Define connections

Delete connections

Output

Output of the equivalent member system Clicking on this button displays the following buttons:

Results obtained in the calculation of the equivalent member system

Stress due to bending and axial force, left side of the member

Stress due to bending and axial force, right side of the member

Axial stress due to warping torsion

Resulting axial stress

Shear stress due to shear force

Shear stress due to St. Venant's torsion on the open cross section

Shear stress due to St. Venant's torsion on the closed cross section

Shear stress due to warping torsion

Resulting shear stress

Comparison stress

Normalized warping relating to the centre of gravity

Normalized warping relating to the shear centre

Hide/display dimension lines

Hide/display member outline

Hide/display node numbers

Hide/display member numbers

Hide/display hollow cross sections

Hide/display cross sectional properties

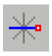
Toolbar for general graphical functions

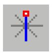
The functions and basic operation of the graphical user interface are described in detail in the document "Graphical User Interface".

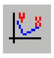
 Enable/disable the object snapping function.

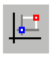
 Enable/disable the background grit.

 Orthogonal. Polygonal lines can only be defined orthogonal to each other. Steel shapes can only be moved vertically or horizontally.

 Horizontal. You can enter only horizontal polygon lines for metal plates.

 Vertical. You can enter only vertical polygon lines for metal plates.

 Local system of coordinates.

 Enable/disable the relative system of coordinates. If the relative system of coordinates is active, the coordinates specified for individual polygon points are set to zero, so that the next coordinate can be specified in relation to the previous.

Selection modes

 Snap small

 Crossing

 Window