FRILO Software
A NEMETSCHEK COMPANY
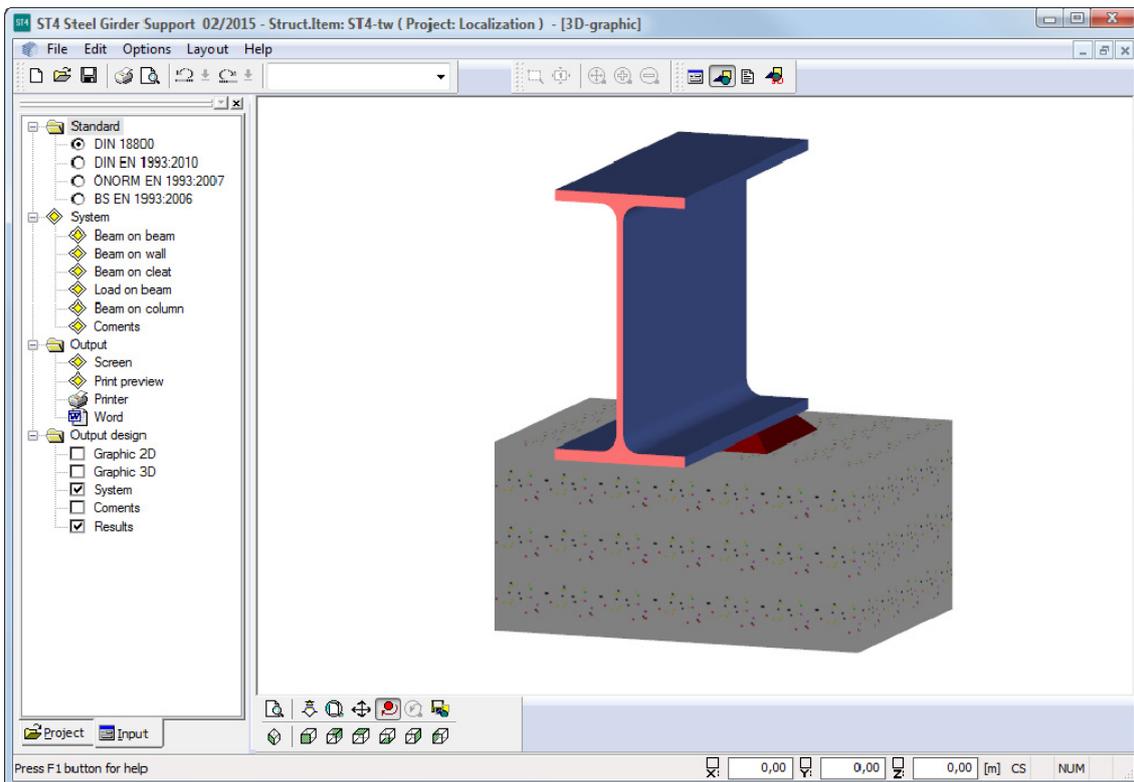
ST4 – Steel Girder Support

FRILO Software GmbH

www.frilo.com

info@frilo.eu

As of 07.12.2015

Version 2/2015

ST4 – Steel Girder Support

Contents

Application options

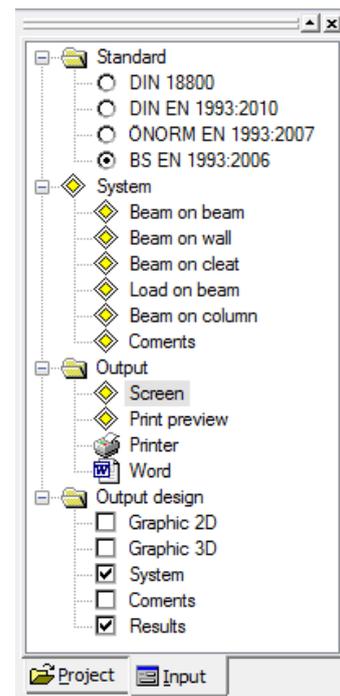The ST4 application allows the calculation of various girder (beam) supports. The forces can be transmitted with the help of stiffeners or without them.
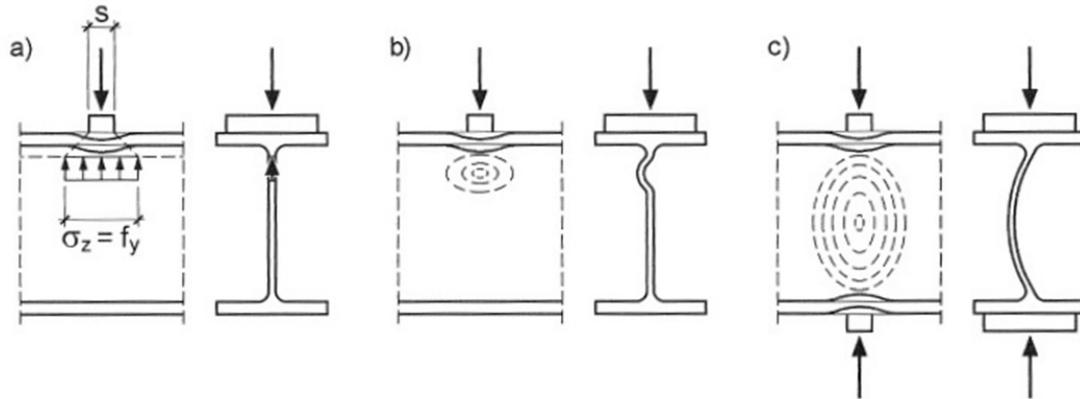
Load introduction options

- Beam on beam
- Beam on wall
- Beam on cleat
- Load on beam
- Beam on column

Basis of calculation

The design is performed in accordance with EN 1993-1-5, para. 6. The design resistance of an unbraced beam is determined by the expression.

$$F_{Rd} = \frac{f_{yw} \cdot L_{eff} \cdot t_w}{\gamma_{M1}}$$

The variables are as follows:

t_w = thickness of web reinforcing metal

f_{yw} = yield strength

L_{eff} = effective load propagation length with consideration to web buckling under transversal loads, depending on the length ss over which a rigid load introduction takes place, see EN 1993-1-5, chap. 6.2 for further details.

γ_{M1} = partial safety factor for stability failure

Rigid load introduction length

The rigid load introduction length is the length over which a load is applied to a flange. It is calculated as specified by EN 1993-1-5, para. 6.3.
The load propagation angle corresponds to an inclination of 1:1 (45°).
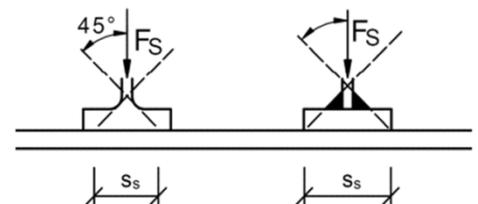
Load introduction with stiffeners

The load introduction via stiffeners is calculated in accordance with Kindmann, Verbindungen im Stahl- und Verbundbau, chap. 3.3.4.

The applying force is distributed to the stiffeners and the web of the steel shape→, see illustration.

The force per stiffener results from
$F_R = F \cdot A_R / (2 \cdot A_R + A_S)$

the force on the web from
$F_S = F - 2 \cdot F_R$

This method allows the dimensioning of full and partial stiffeners.

The thickness of the stiffener should be matched to the dimensions of the web and the flange of the steel shape. For the determination of the stiffener thickness, it is useful to assign the stiffener to an area where local buckling cannot occur. This corresponds to the following relation:

$t_R >= b_R / 11$
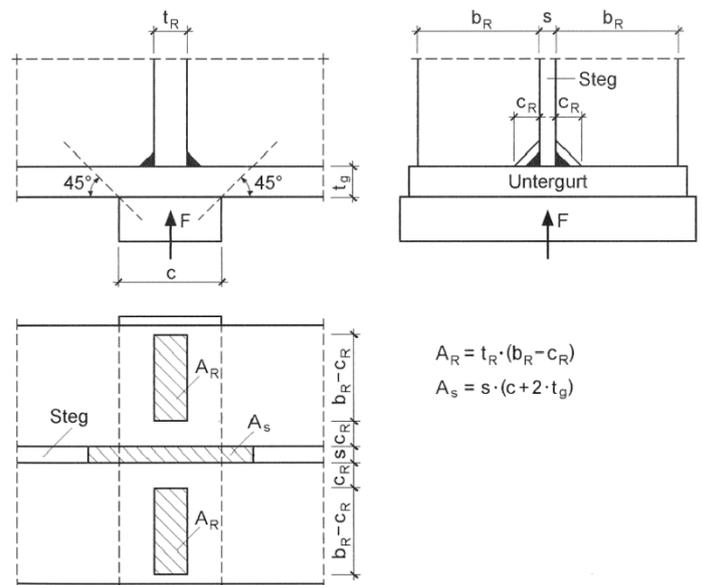
$A_R = t_R \cdot (b_R - c_R)$
$A_s = s \cdot (c + 2 \cdot t_g)$

Stiffener connection on three sides

The maximum height hr of the stiffener is equal to the steel shape size minus the thickness of the flanges. In this case, three sides of the stiffener are connected to the shape with welds. This type of stiffener is suitable in combination with high thin webs, in order to avoid web buckling. The measure improves the stability against tilting at the end of the beam.

Stiffener connection on two sides

If the stiffener size is lower than in the above case, only the welds on the web and the flange of the loaded steel shape side are considered for the load introduction.

Verification of the welds on the stiffeners

The load on the welds results from the forces F_R and F_S (force distribution in the stiffeners). All welds are double fillet welds with the thickness a_w and the length l_w, separately for each side.

Stiffener connection on two sides

Weld on the loaded flange (index 1)

Weld length: $l_{w,1} = b_R - c_R$

- Vertical axial force in direction of the weld due to F_1

$$w_{s,1} = F_1 / (2 \cdot l_{w,1} \cdot a_{w,1})$$

- Shear force in direction of the weld due to F_2

$$w_{s,1} = F_2 / (2 \cdot l_{w,1} \cdot a_{w,1})$$

Comparison stress verification

$$\sigma_{wV,1} = \sqrt{\sigma_{ws,1}^2 + \tau_{wp,1}^2}$$

Weld on the web (index 2)

Weld length: $l_{w,1} = b_R - c_R$

- Vertical axial force in direction of the weld due to F_2

The force F_2 applies in the centre of gravity of the axial stress triangle as follows:

$$\max \sigma_{ws,2} = 2 \cdot F_2 / (2 \cdot l_{w,2} \cdot \alpha_{w,2})$$

Shear stress parallel to the weld due to F_1

$$\tau_{wp,2} = \frac{F_1}{2 \cdot l_{w,2} \cdot a_{w,2}}$$

- Comparison stress verification

$$\sigma_{wV,2} = \sqrt{\sigma_{ws,2}^2 + \tau_{wp,2}^2}$$

Stiffener connection on three sides

Weld on the loaded flange (index 1)

→see case 1

Weld on the web (index 2)

Only shear stresses due to F_1 act on the weld

$$l_{w,2} = h_R - 2 \cdot c_R$$

$$\tau_{wp,2} = F_1 / (2 \cdot l_{w,2} \cdot \alpha_{w,2})$$

Weld on the unloaded flange (index 3)

Only shear stresses due to F_2 act on the weld

$$l_{w,3} = b_R - c_R$$

$$\tau_{wp,3} = F_2 / (2 \cdot l_{w,3} \cdot \alpha_{w,3})$$

Welds

The weld thickness should at least be equal to 3 mm or $\sqrt{\max t} - 0.5$ and not exceed a maximum value of 0.7 x t min.

The length of the weld lw may only be taken into account in the calculation if

$l_w \geq 6 \cdot \alpha_w$ or l_w is 30 mm at least.

t = thickness of the cross-section part to be connected

If $t > 30 \rightarrow \alpha_w \geq 5mm$

The load-bearing capacity of fillet welds is calculated in accordance with EN 1993-1-8, chap. 4.5.3.

Verification process

$F_{w,Ed} \leq F_{w,Rd}$

The variables of the expression are:

$F_{w,Ed}$ design value of forces acting on the effective fillet weld area per length unit

$F_{w,Rd}$ design value of the weld's load-bearing capacity per length unit with

$$F_{w,Rd} = a \cdot \frac{f_u / \sqrt{3}}{\beta_w \cdot \gamma_{M2}}$$

a   weld thickness

f_u tensile strength

β_w correlation coefficient

γ_{M2} partial safety factor for breakage failure due to tension load

Additional verifications

Cross section verifications

In addition to the verification of the load introduction, the user can analyse the cross-section in regard to a combination of applying internal forces.

The verifications are performed in accordance with EN 1993-1-1, chap. 6.2.

The general expressions for the verifications are as follows:

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{Ed}}{M_{Rd}} \leq 1$$

and

$$\frac{V_{Ed}}{V_{Rd}} \leq 1$$

The variables are as follows:

N_{Ed} design value of the applying axial force

N_{Rd} design value of the resistance to axial force

N_{Ed} design value of the applying shear force

N_{Ed} design value of the plastic resistance to shear force

M_{Ed} design value of the applying bending moment

N_{Rd} design value of the resistance to moments

The verifications are valid independently of the applying superimposed load. If superimposed loads are not defined, no verification of the cross section is performed. If a cross section was assigned to class 4, no verification is performed either.

Interactions

Interactions between external load, bending moment and axial force

If F_d, N_{Ed} and M_{Ed} apply simultaneously, a possible interaction relation should be checked in accordance with EN 1993-1-5, chap. 7.2.

The expression is as follows:

$$\eta_2 + 0.8 \cdot \eta_1 \leq 1.4$$

The variables are:

η_2 the verification of F_d / F_{Rd}

η_1 the verification of M_{Ed} / M_{Rd} with consideration of potential axial force influence

Interaction between external loading and shear force (only DIN EN)

If both, F_d and V_{Ed} apply, an interaction relation in accordance with EN 1993-1-5, NA Germany, chap. 4 (conflict-free national supplements) should be checked.

The expression is as follows:

$$\left[\eta_3 \cdot \left(1 - \frac{F_{Ed}}{2 \cdot V_{Ed}} \right) \right]^{1.6} + \eta_2 \leq 1$$

The variables are:

η_2 the verification of F_d / F_{Rd}

η_3 the verification of M_{Ed} / M_{Rd} with consideration of potential axial force influence

$V_{b,Rd}$ the resistance of the cross section to shear force with consideration of potential shear buckling

Definition of the system

In a new item, first select the desired standard and the **load introduction option** per double-click in the main tree:

- Beam on beam
- Beam on wall
- Beam on cleat
- Load on beam
- Beam on column

Define subsequently the material, the loads, cross sections (steel shape selection), supports, stiffeners, flange bending, etc.

The user interface is aligned to the requirements of the respective load introduction option, i.e. a separate interface is available for each load introduction option.
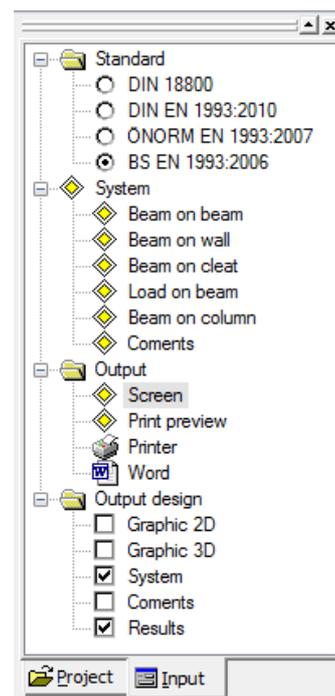
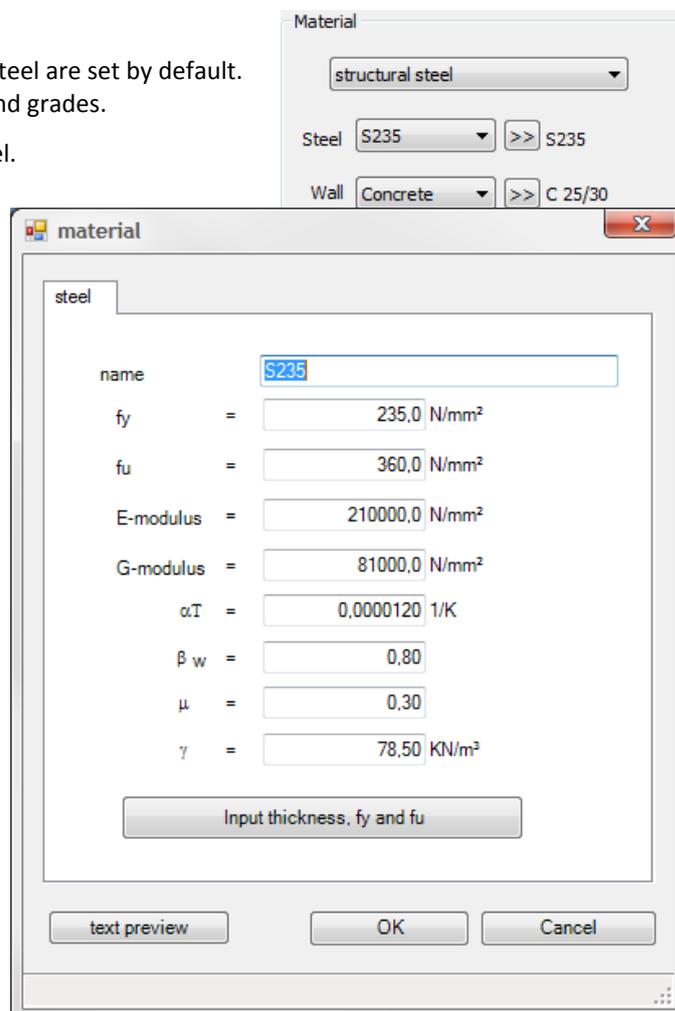## Material selection

Steel selection

When setting up a new item, the values for structural steel are set by default. Selection boxes allow you to define other steel types and grades.

Clicking to $\boxed{>>}$ displays the details of the selected steel.

The software sets the appropriate yield strength in line with the specified material thickness of the cross section.

Activating the option "user-defined steel type" and clicking to $\boxed{>>}$ displays a dialog where the user can enter the properties that should be used in the calculation:

- Material designation
- Yield strength fy
- Tensile strength fu
- Modulus of elasticity
- Shear modulus
- Thermal expansion coefficient αT
- Correlation coefficient βT
- Poisson's ratio μ
- Specific weight γ
- Thickness-specific parameters for fy and fu

Selection of the wall material

Available options are concrete, masonry and user-defined material.

Concrete

Concretes of the classes C12/15 to C50/60 are available for selection in accordance with EN 1992-1-1.

Masonry

Material:

In the Material section, the compression strength of the masonry, the group and category of the masonry block are determined.

Either specify the values manually or activate the option "Select values in dialog". The dialog allows you to define the masonry with the help of the standard, the approval or by specifying user-defined values.

Options:

In the Options section, select the calculation parameters that are relevant for the calculation of the masonry:

- calculation method: simplified or more accurate

- design situation: standard, accidental, earthquake

- execution class: 1 to 5

Wall geometry:

The user can select additional geometric parameters that are relevant for the calculation of the masonry (as per EN 1996).

- distance to the edge a_1 (see sketch)

- wall length l_0

- load introduction height (normally the wall height)

Please note that the available options are determined by the selected standards and its National Annex. Some options might be disabled.
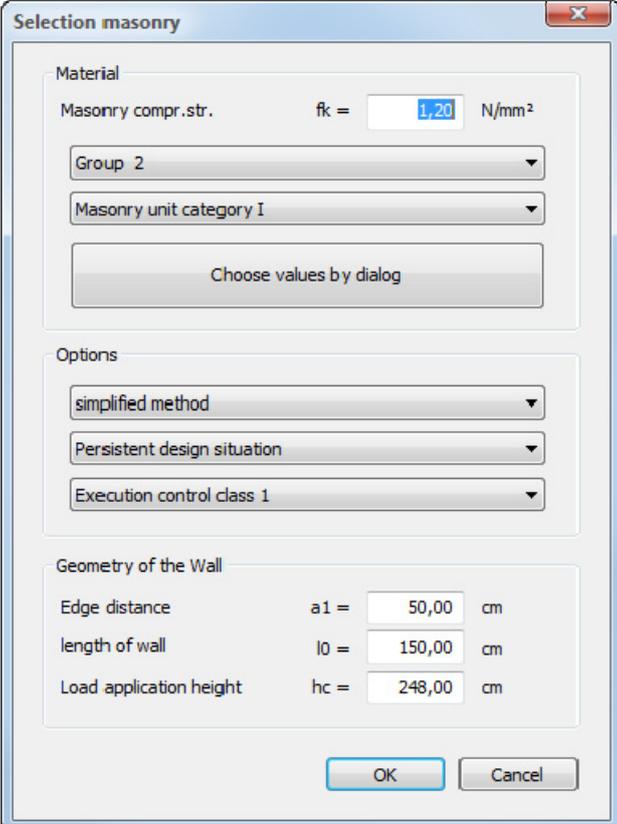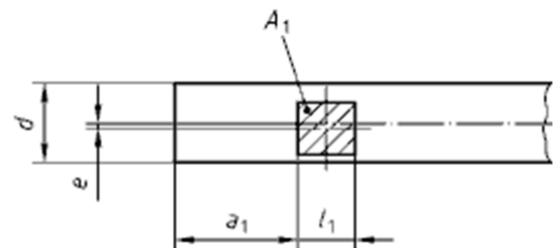
Load introduction options

General options

Fd	Supporting force [kN], specify a positive value (gammaF-fold).
GammaM	Partial safety factor of the material (disabled with Eurocode)
Beam	Activating the "Beam" button displays the dialog for the <u>selection of the steel shape</u> of the beam(s).
Column	Activating the "Column" button displays the dialog for the <u>selection of the steel shape</u> of the column.
Sigmax	Existing axial stress at the upper or lower web end of the upper or lower beam (only available with DIN).
Welded	This option is only enabled if a user-defined cross section was selected. It can become relevant for the load propagation.
Ned / VEd / MEd	Design forces in the beam to take into account the common effect of (external) transversal load and (internal) bending moment/axial force/shear force (see EN 1993-1-5, Eq. (7.2) and DIN EN 1993-1-5/NA Eq. (NA 7)

Stiffeners (Ribs)

Activating the "Ribs" button displays a dialog for the <u>definition of the stiffeners</u>.

For the verification of the load introduction with or without stiffeners, → see the chapter <u>Basis of calculation</u>.

Comments

You can enter additional text concerning the item in an editing window. These comments are included in the output of the result/system data.

Eta

Indication of the utilization ratio (immediately below the graphic screen).

The specific definition options for the different ways of load introduction are described below.

Beam on beam

Type of bearing

"Intersection" and "Edge bearing" are the available options. The effect of the selected type is immediately displayed on the graphic screen.

Edge bearing:	The "distance" option allows the user to specify a value for the distance of the upper beam to the central axis in [mm]. The specified distance is immediately shown on the graphic screen.

Beam on wall

Type of bearing

→ as described for the beam on beam option.

Direct support

The available options are: - Mortar joint
- Neoprene
- Steel plate

Bearing dimensions

Specification of the following dimensions:

- Support

- Joint

- Projection (Excess end)

The specified dimensions are immediately transferred to the graphic screen where you can check visually the assignment of the specified dimension.

For Neoprene supports, the permissible tension [N/mm^2] is prompted in addition ("permissible=").

For steel plate supports, you can define the cross section of the steel plate via the button Steel shape selection.

Flange bending

The option Flange bending allows you to select whether flange bending should be verified.

A verification of flange bending is only performed if no stiffeners are assigned to the steel shape.

In the verification of flange bending, the flange of the steel shape is examined as a cantilever with the height **t**. The length **Lk** of the cantilever is determined by the affected width **c** of the steel shape.

Load propagation is assumed with the ratio 1:1 as per EN 1993-1-5.

The loading **p** on the cantilever is determined by the action F_d / (support depth $l_a \cdot c$). The verification considers a section of 1 cm of the flange.

Loading	$p = F_d /(l_a \cdot c)$
Moment	$M = p \cdot L_k \cdot L_k / 2$
Section modulus per cm	$W = t \cdot t / 6$

Verification of the wall

Calculation of the bearing stress:

$\sigma_D = F_d /(L_x \cdot L_y)$
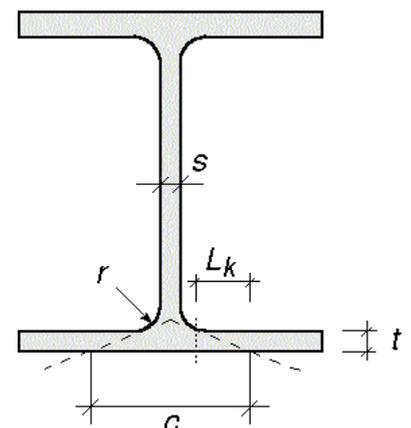
$F_d = $ Auflagerkraft

Dimensions of the support:

L_x supporting length (depth)

L_y the maximum section width with mortar joints or the width of the steel plate

The pressure on the concrete support is assumed as being evenly distributed.

In the case of a masonry support, the regulations of EN 1996 apply.

Verification of the steel plate

The maximum moment *M* acting on the steel plate is calculated from the bearing pressure σ_D (Sigma,D), which is assumed as being evenly distributed

(see Thiele/Lohse, Stahlbau 1).

$$M \quad = \frac{F_d \cdot L_y}{8} \cdot (1 - 0{,}782 \cdot \frac{b_{Flu}}{L_y})$$

b_{Flu} Width of the lower flange

The existing stress in the steel plate results from the following expression:

$$\sigma \ = M/W$$

with $W = L_x \cdot t_p \cdot t_p / 6$

      t_p thickness of the steel plate

Verification of a neoprene support

A permissible compressive stress 5 N/mm^2 is assumed for neoprene supports as a standard. The value is editable.

Beam on cleat

Cleat	**t**hickness of the cleat in [mm] = supporting length of the beam + distance
	width of the cleat in [mm], underneath the beam, in the section projection
	h**eight** of the cleat in [mm], length of the weld between the cleat and the column.
Weld	between cleat and column, in [mm]
Distance	between column and beam, in [mm]

Contact pressure between the beam flange and the cleat:

$$\sigma_D \ = \ F_d / (L_x \cdot L_y)$$

F_d =   supporting force

Dimensions of the support:

   Lx   support length (depth)

   Ly   load introduction width

Verification of the weld on the cleat

A circumferential fillet weld between the cleat and the column is assumed.

The eccentricity moment produced by the small cantilever of the cleat is neglected.

In the examination of the load bearing of F_D only the welds running in parallel to the force are verified.

The column shape is either an I-section or a hollow section.

$\rightarrow$ See <u>steel shape selection</u>

Load on beam

Load plate	Steel shape selection (flat steel) for the load plate. Additional input fields for the length (in parallel to the beam web), width (along the beam flange) and thickness of the load plate in [mm].

Beam on column

Longer side	Select whether the beam and the column web are parallel (in the same plane) or orthogonal to each other (see also "Verification of the beam" below). Check the presentation on the graphic screen.
Steel plate	Steel shape selection (flat steel) for the steel plate. Additional input fields for the length, width and thickness of the load plate in [mm].
Thickness aw	Weld between column and steel plate in [mm].

Contact pressure between the beam flange and the top plate:

$$\sigma_D \ = \ F_d /(L_x \cdot L_y)$$
$$F_d \ = \ \text{supporting force}$$

Dimensions of the support:

- Lx   maximum top plate length
- Ly   load introduction width

Verification of the beam

The beam is verified at the critical fibre at the beginning of the lower web curvature.

If the webs of the beam and the column lie in the same plane (parallel to each other), the flange forces of the column can optionally be transmitted to the beam via stiffeners.

If the webs of the beam and the column are perpendicular to each other, the force application can only be verified without stiffeners (the corresponding button is disabled).

Verification of the fillet weld between the column and the top plate

A circumferential fillet weld is assumed.

The compressive stress caused by Fd is proportionally distributed to the column web and the column flange.

Definition of stiffeners

The dimensions to be defined are shown in the illustration below, t = stiffener thickness.

A short description of each input fields is displayed in the status line (on bottom left).

In addition, notes concerning the definition are displayed in the window:

|	
Req. stiffener thickn. t	displays the required thickness of the stiffener. If the specified thickness is below this value, the verification of the stiffener fails. The specification of a thickness equal to the required minimum means that the stiffener is fully utilized.
Welds	depending on the specified stiffener sizes, the maximum and minimum values for the welds to be defined are displayed.
Max Eta	a summary of the stiffener utilization. A value of 10.0 indicates a situation which cannot be verified. In most of these cases, the stiffener dimensions are too small to comply with the required weld lengths. You should use a greater shape in this case.
Steel shape selection	selection options are flat steel and wide flat steel.
Delete rib	deletion of the current stiffener
Tolerance	assembly allowance. The user can specify a dimensional value in [mm]. For stiffeners connected on three sides, the height of the stiffener h_R is reduced on each size by this dimension to ensure an easy installation of the stiffener between the flanges.

This dimension is only relevant for the output of the results.
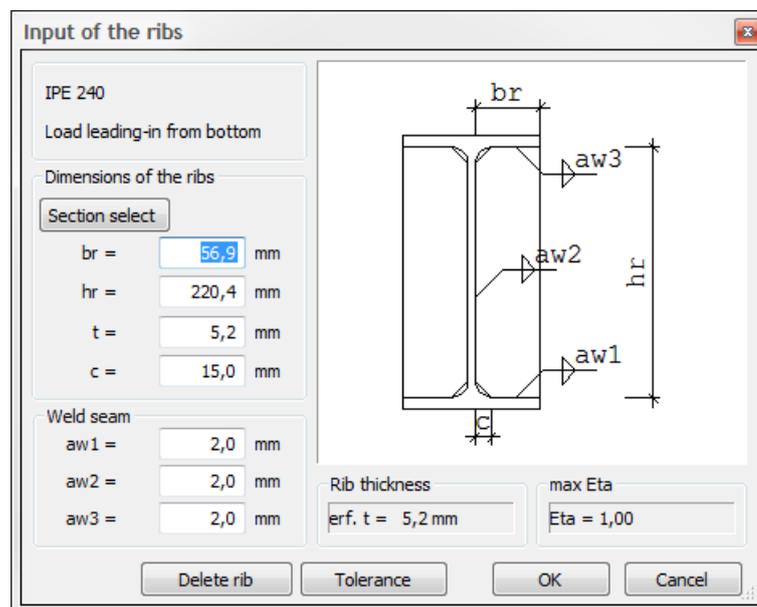
Cross sections and steel shape selection

The present software application is only suitable for beams with an I-shaped cross section. For the definition of the column (beam on cleat), also a hollow cross section is optionally available. Standard sheet metal can be used for the cleat or the stiffeners, for instance.

The selection, definition and editing of cross sections is described in the general document "Selecting or defining cross sections".
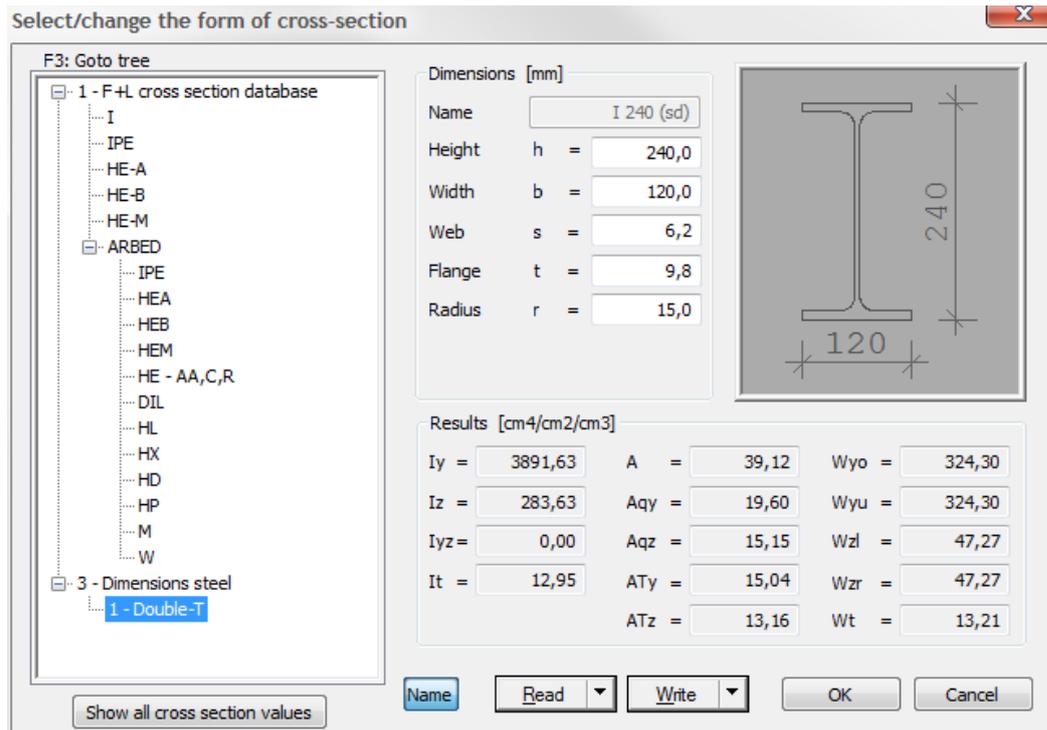
Output

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

Screen   displays the values in a text window on the screen

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 to be put out in Word as required.

Graphical representation

Launches the 3D graphical representation

Toolbar of the 3D graphical screen

Zoom window. Allows you to zoom in (enlarge) the desired screen section with the help of the mouse.

Zoom using the mouse. The mouse cursor is transformed to a hand. Moving the mouse while keeping the mouse button pressed changes the size of the representation.

Zoom full screen. The entire graphical representation is shown on the screen.

Move. An enlarged section can be moved while keeping the mouse button pressed.

Rotate using the mouse. Keep the mouse button pressed to rotate the represented object.

Previous section. The previously displayed section is shown.

Saves the graphical representation in a BMP or WMF file.

Displays the view of the system as shown on the button.