Lateral Torsional Buckling Analysis BTII+

Contents

Application options

General scope of application

The *BTII+* application allows you to perform analyses of the ultimate and serviceability limit states of steel member systems with any types of supports. The steel members may have open or closed thin-walled cross sections.

The most important features of *BTII+* are the following:

- Calculation of *internal* forces, elastic deformations and axial and shear stresses on uniformly or three-dimensionally loaded girder systems with consideration of warping torsion in second order buckling torsion analyses.
- Calculation of the ideal buckling loads for the failure modes of lateral buckling and lateral torsional buckling as well as determination of the slenderness ratios and the reduction factors for stability analyses in accordance with the equivalent member method.
- Optional definition of moving loads to examine crane runways, for instance, in the ultimate and serviceability limit states.
- Calculation of secondary flange bending stress considered as local girder loading due to eccentric loading on the lower flange.

Special applications

- Purlins supported by the roof skin with or without hinges
- Ledgers supported by purlins or trapezoidal steel sections
- Columns supported by the wall lining and/or bracing
- Stability verifications of craneway girders with or without horizontal bracing
- Determination of the ideal buckling loads for the calculation of buckling slenderness ratios in concrete and timber construction.

Design standards

The *BTII+* application performs structural safety analyses in accordance with EN 1993-1-1 and takes the corresponding National Appendix into account. The following National Annexes are available:

- DIN EN 1993-1-1/NA
- ÖNORM B 1993-1-1
- BS EN 1993-1-1

System definition

The *BTII+* application allows you to define any member system composed of straight members including

- cross sectional jumps and/or haunches;
- simple- and double-symmetrical T-sections with and w/o angled top flanges, U-sections, thin-walled HSS and any type of thin-walled open cross sections;
- discrete three-dimensional supporting conditions with a distance to the shear centre; definable as rigid supports or supports with discrete spring stiffness;
- continuous three-dimensional supporting conditions such as elastic foundation or shear field foundation also with a distance to the shear centre;
- girder sections connected with shear force hinges and moment hinges.

Special notes concerning the system definition

- The material behaves elastically.
- The modulus of elasticity and the shear modulus are constant over the total girder.
- The z-axis is the symmetry axis for single-symmetrical cross sections.
- The finite elements have constant cross sections. Haunches are calculated by approximation.

Loads, load cases, superpositions and deformations

In *BTII*, linearly variable line loads and point loads in direction of or around the y/z-axis as well as bending, torsional and warping moments can optionally be defined. Loads that produce axial forces cannot be put out directly. To compensate for this restriction, you can define constant or linearly variable axial force distributions. Additional bending moments that result from an offset of the centre of gravity must be defined explicitly by the user. The loads are assigned to load cases. All loads that are member of the same load case are considered to act always simultaneously. The load case defines the action that produces the loads and indicates in addition, how it is to be handled in the automatic generation of the load case combinations.

The user can generate load case combinations either automatically with the help of a wizard or define them manually based on typical design practices.

In second order analyses, imperfections are taken into account. To include them in the form of initial bow or initial sway imperfections, you simply need to specify the zero-points and the amplitudes of the sinusoidal or parabolic half-waves.

Dynamic-/ moving loads

You can optionally define node loads in the form of a load train.

Local girder loading

For double-T girders either with or without angled upper flanges, node loads on the lower flange of the girder, e.g. due to wheel loads of suspension cranes or underslung trolleys, can be taken into account.

Calculation and analysis

- Verification of the cross sectional bearing capacity on the basis of elastic or plastic cross section properties.
- Verification of the system's load-bearing capacity in a second order buckling torsion analysis or in a structural safety analysis based on buckling loads for the failure modes of lateral buckling, torsional bucking and lateral torsional buckling.

Interfaces to BTII

A number of FRILO applications support the *BTII+* interface, which provides for the transfer of the system and the loads to *BTII*.

Analysis of the system's load-bearing capacity

1st order analyses

Internal forces, deformations and stresses are calculated in first order analyses.

The load-bearing capacity of the system cannot be verified in this type of analysis!

2nd order analyses

Internal forces, deformations and stresses are calculated in second order buckling torsion analyses whereby the imperfections are taken into account. Evidence of the system's load-bearing capacity is established via the verification of the cross sectional load-bearing capacity.

Equivalent member method

When using the equivalent member method for the examination of the lateral buckling and lateral torsional buckling behaviour, *BTII+* performs an eigenvalue calculation by applying the linear subspace method. The resulting ideal buckling loads $N_{ki,y}$, $N_{ki,z}$ and M_{kiy} are used to calculate the corresponding effective slenderness ratios. These ratios allow the calculation of the relevant reduction factors for the bearing resistances, which are required for the stability analysis.

Analysis of the cross sectional bearing capacity

The criteria and methods applying to structural safety verifications of cross sections are stipulated in EN 1993-1-1 Para. 6. The related verification equations take the classification of the cross sections into account and refer to the elastic or plastic cross sectional properties that are determined by the class of the cross section (classes 1 to 4). When selecting the "plastic" verification method, the resistance to the internal limit forces is verified.

Elastic

Cross section verification as per EN 1993-1-1, equation 6.1.

The design values of the internal forces calculated in accordance with the theory of elasticity are used to determine the axial and shear stresses acting on the cross section in accordance with the mechanics of materials. These stresses are compared to the design value of the yield strength. The structural safety of the cross section is ensured when the loading in all cross sectional parts is smaller or in, the worst case, equal to the design values of the resistances. The plastic bearing reserves are not taken into account.

Plastic

Cross section verification as per EN 1993-1-1, equation 6.2

The internal forces and deformations are calculated on the basis of the theory of elasticity. The resistances are determined with utilization of the plastic bearing capacity. The structural safety of the cross section is ensured when the design values of the internal forces do not exceed the limit internal forces in the plastic state.

Basis of calculation

The theoretical fundamentals of this application are described in detail in the reference literature, particularly in reference [7] and [10].

In the majority of the cases relevant in practice, you cannot describe the exact deformations of the general buckling torsion problem in a single closed system. Therefore, the girder is verified in accordance with the finite elements method, which means that it is divided into a number of sections of different lengths (finite elements). The number of sections is pre-set by the user.

The state of deformation within an element is described with the help cubic polynomials for the shift perpendicular to the member axis and the distortion. The elements are linked via the nodes in-between them. The elements have 6 degrees of freedom each at the left and right node.

- Shift v and w in the y/z-direction
- Torsion Θx, Θy, Θz around the x/y/z-axis.
- Warping $\Theta x'$

<table>
<tr><th>Node loads and node deformations</th><th>Cross sections</th></tr>
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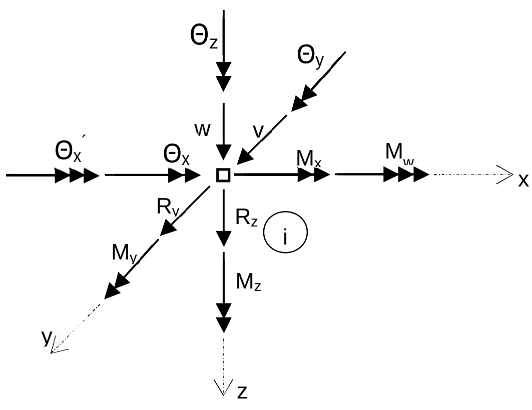
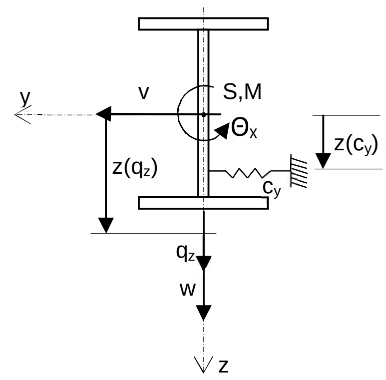
<tr><td>
</td><td>
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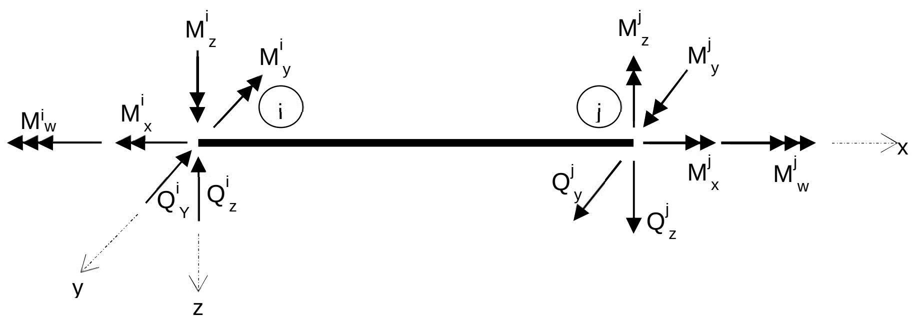
<tr><th>Internal forces in the system of coordinates</th></tr>
<tr><td>
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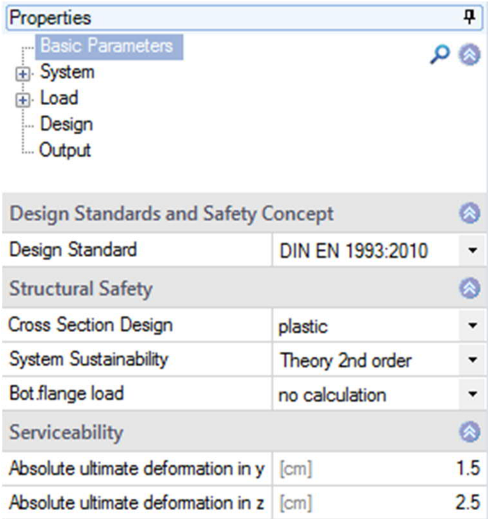
Basic Parameters

Note: *When using the software for the first time, please read first the instructions in the annex: Program settings and definition wizard.*

Design standard

Allows you to select the design standard that constitutes the basis of the structural safety analysis.
See also Application options.



Structural safety

Cross section design — the design of the cross section is performed in accordance with the elastic method as per eq. 6.1 or in accordance with the plastic method as per eq. 6.2.

System Sustainability — selection of the method for the verification of the load-bearing capacity of the structural system. Keep in mind that the first-order analysis does not include the verification of the resistance to stability failure.
Equivalent member verification:
the verification in accordance with the equivalent member method is based on 6.3.3 (annex A or B) or on 6.3.4.

Bottom flange load — load transfer stress due to loading on the lower flange: No calculation, calculation without/with consideration for the load position.

Serviceability

Absolute limit deformation represents the absolute permissible maximum deformation of the system in the y- and/or z-direction.

Note concerning the loading on the lower flange

When underslung overhead cranes travel along the girder on wheels or trolleys, the crane wheel loads or trolley loads apply eccentrically to the girder web. Therefore, secondary flange bending stresses occur in the proximity of the load application point in two directions. The application calculates the local load introduction stresses for double-T sections on the basis of the experimental and theoretical examinations of Hannover and Reichwald and superimposes these stresses with global axial girder stresses in accordance with the von-Mises yield criterion. The following options are available for this calculation:

- No calculation
  A point load in z-direction is considered as a force entity.
- Calculation w/o consideration of the load position
  The decisive load position underneath the travelling crane is calculated without consideration of the secondary flange bending stresses. A point load in z-direction is interpreted as two force entities, one acting on the left and the other on the right lower flange with a distance ey to the outer flange edge.
- Calculation with consideration of the load position
  The decisive load position underneath the travelling crane is calculated with consideration of the secondary flange bending stresses. The decisive load position results from the superposition of the axial girder stresses with the load transfer stresses in x-direction.

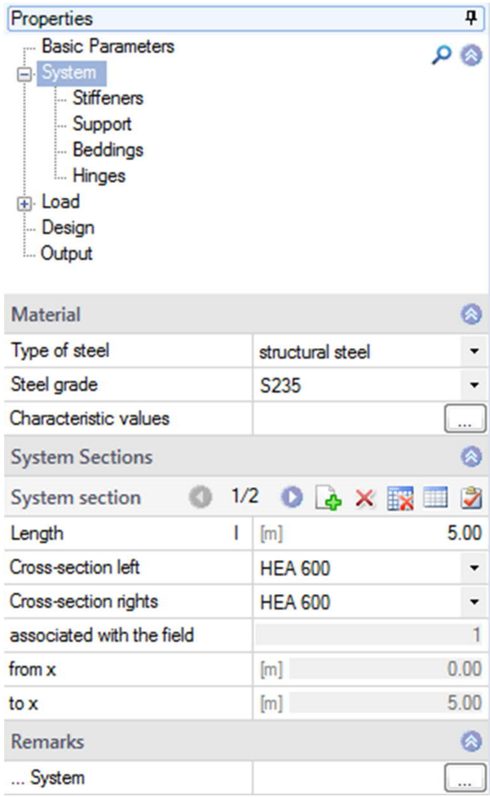
System

Material

Type of steel

Allows you to select the type of steel.

- Non-alloy structural steel
- Structural steel, normalized
- Structural steel, thermo-mechanically rolled
- Structural steel, weatherproof
- High-temperature steel
- Hot-finished hollow sections
- Hot-finished hollow sections, normalized rolled
- User-defined steels



Steel grade / characteristic values

Allows you to select the steel grade depending on the selected steel type.
If you have selected "User-defined type" among the type options, a dialog for the definition of the user-defined parameters is displayed, otherwise the characteristic values of the selected steel are displayed.

System sections

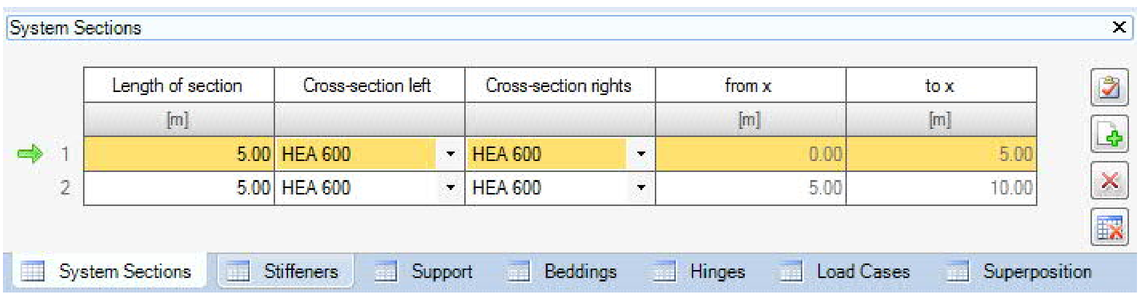
You can enter the lengths and cross sections of the individual spans via this table.

You can divide the girder into several sections. This allows you to describe cross sectional offsets and haunches.

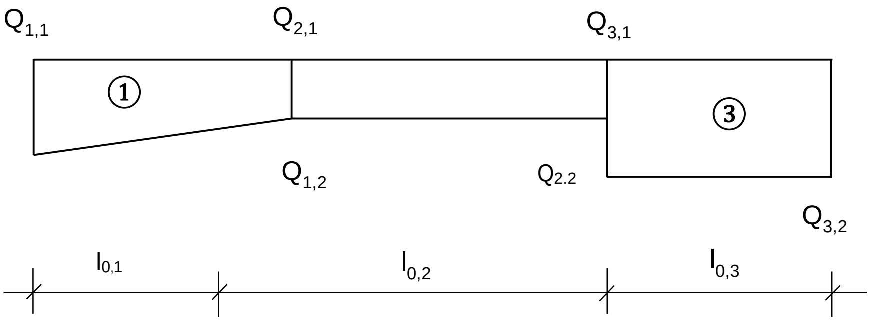
You can generate a new span by pressing the + button. The right/left arrows allow you to move the cursor to the next/previous span:

Alternatively, you can access the data-entry table (System section tab, below the graphical representation).

See also Data entry via tables in the Basic Operating Instructions.



Definition of the girder sections



Length length of the girder section

Cross section a cross section is to be defined at the right end and left end of each span.

Selecting/editing a cross section

Click on "... New cross section" to access the [Cross section selection](#) dialog and select a cross section. You can also define cross sections manually and assign a name to them: Selection list "Series" ▸ "User-defined".

Existing cross sections can be edited via the option "... Manage cross sections".

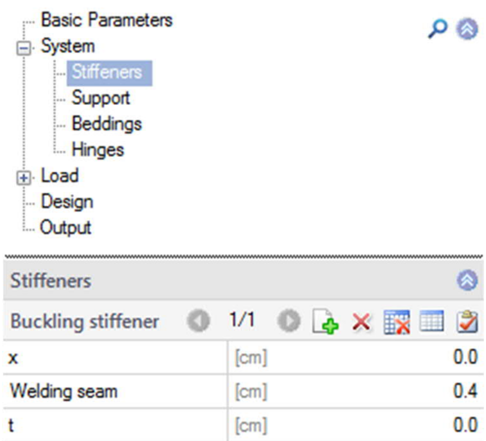
Haunches are available for profile sections of the same type.

Buckling stiffeners

Buckling stiffeners are currently not considered in the design.

The definition of multiple buckling stiffeners is described in the chapter [Data entry via tables](#) (Basic operating instructions).

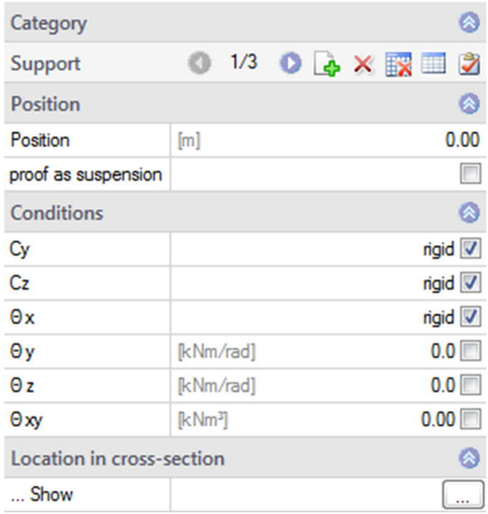
Alternatively, you can edit stiffeners in a well structured table that is accessible via the "Stiffeners" tab (below the graphic screen).



x	distance of the stiffener (central axis) to the left girder edge.
Weld seam	thickness of the weld seam of the buckling stiffener.
t	thickness of the buckling stiffener.

Supports

To define multiple supports, see the chapter Data entry via tables (Basic Operating Instructions).



Position distance of the discrete support to the left girder edge.

Verify as suspension check this option when the support is a suspension on the upper flange and the resistance against secondary flange bending stress is to be verified.

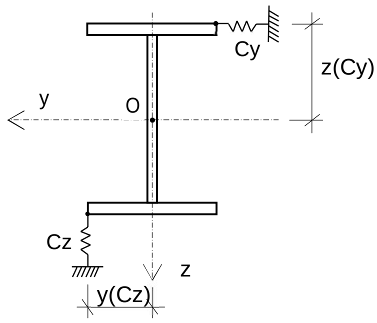
Conditions definition of discrete supporting conditions for translation, rotation and warping.

- Cy/Cz supporting condition for translation in the y-/z-direction.
- θ x/y/z supporting condition for torsion about the x-/y-/z-axis.
- θ xy supporting condition for warping

Location on cross section

displays a dialog for the definition of the location of the support on the cross section. This option is only enabled if a spring value was defined in the direction of the respective translational degree of freedom.

- ... in y-/z-direction: distance of the elastic support to the reference point in the z-/y-direction.



Notes concerning the definition of spring stiffnesses

After removing the tick "rigid" a value for the spring stiffness can be entered.

Discrete spring stiffnesses describe the stiffnesses of the components connected to the examined girder (e.g. purlins on top of girders, horizontal girders on top of wall columns, tension rods for purlins, etc) by approximation.

The locations are defined via their distance to the reference point. The reference point depends on the defined section type, however. See Reference points of the cross sections.

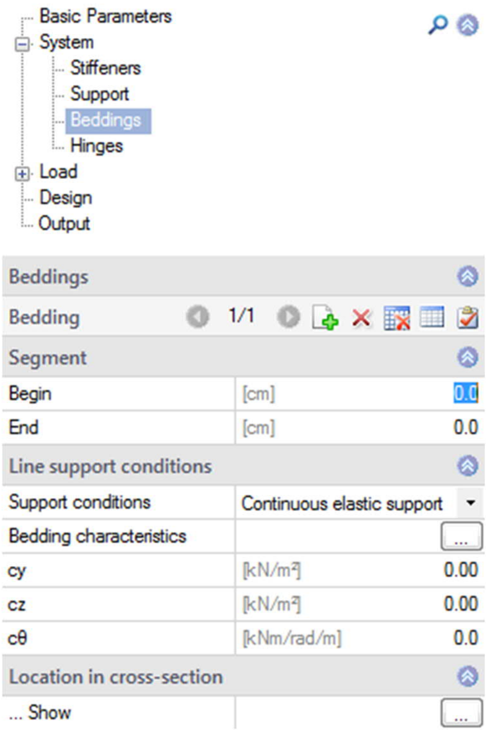
The application converts the distances to the shear centre.

You can also use eccentric discrete springs to provide fixity against lateral shifts in the y- or z-direction at any point of the cross section. For this purpose, you must define high, but not too high, spring stiffnesses. As a rule, stiffness should be < 10^{16}. In order to ensure the numerical stability of the calculation, discrete stiffnesses intended as shift fixities should not be greater than strictly necessary. You can check this by verifying the kinematic constraint conditions in the cross section.

Beddings

The term foundation in this context refers to continuous supporting conditions. Foundation regions must be located inside the girder and must not overlap. As with discrete elastic supporting conditions, you can define a distance of the foundation region to the reference point.

The definition of multiple foundation regions is described in the chapter Data entry via tables (Basic operating instructions).



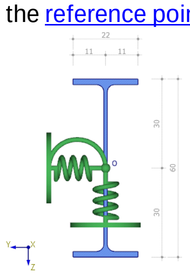
Begin	coordinate of the front end of the foundation region
End	coordinate of the rear end of the foundation region
Type of line support	elastic support or shear panel stiffness
...	launches the ST13 application for the calculation of the characteristic foundation parameters for trapezoidal sheet profiles.
cy/z	foundation modulus for translational support in the y-/z-direction.
S	shear panel stiffness in the y-direction
θ	modulus for torsional foundation about the x-axis

Location at cross section

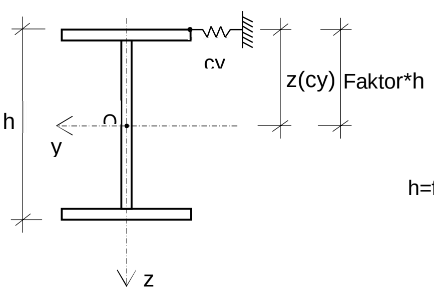
displays the dialog for the definition of the support position in relation to the cross section.

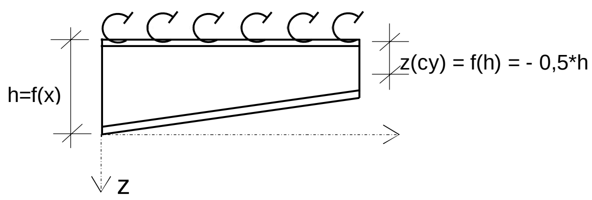
Section coordinate:
x-coordinate (in the foundation region) of the intersection point girder/foundation.

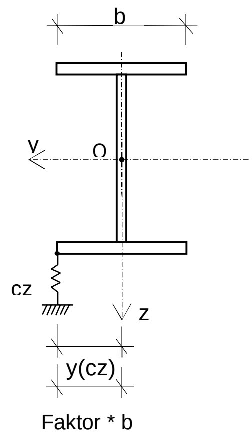
Select via "Distance" whether z(cy) or y(cz) is indicated as an absolute distance to the reference point or as a factor by which the profile height is multiplied.



See also the drawings:







Notes concerning the definition of foundations: Defining a fixed axis of rotation

The problem of lateral torsional buckling with a fixed axis of rotation at a distance z from the shear centre often occurs in practice. You can describe it in *BTII+* as follows:

Define an elastic translational foundation in the y-direction with the stiffness 10^8 to 10^{10} at the distance z to the shear centre. The resulting shift and torsion in regard to the centre of gravity and the shear centre are equal to zero along the pre-set fixed axis of rotation.

Calculation of the foundation constants with the application ST13

If the application *ST13 - Shear Field Stiffness* is installed on your computer, you can launch it by pressing the button [...].

ST13 allows you to calculate the foundation constants for trapezoidal sheet metal structures.

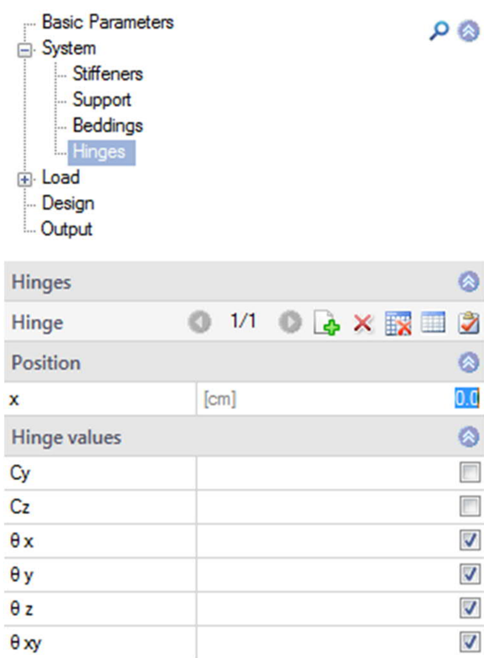
The application calculates the torsion spring $c\vartheta$ [kNm/m], the ideal shear stiffness S [kN] as well as the translational foundation cy [kN/m²]. These values allow you to take the stabilising effect of trapezoidal steel sheet sections into account. In addition to this, the application verifies the fixity against lateral shift and torsion. If the verification is not successful, an additional lateral stability verification is required. In practice, the verification whether the rotational foundation is sufficient is hardly ever successful. A lateral torsional buckling analysis is required in most cases. The spring constants calculated by *ST13* can be transferred to the relevant applications such as *BTII*.

These assumptions presume a constant double-T cross section and girder supports on both sides of the girder. Foundation regions extending over different cross sections must be divided accordingly. When you transfer data from *BTII+* to *ST13*, the cross section in the middle of the foundation region is considered to be relevant. You can edit the cross section in *ST13* to modify it subsequently.

Hinges

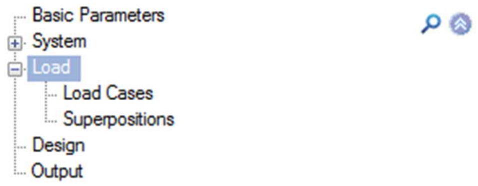
x	distance of the hinge to the left girder edge
Cy/Cz	shear force hinge in the y-/z-direction.
θ	moment hinge about the axis (x, y, z, xy = warping hinge).

The definition of multiple hinges is described in the chapter Data entry via tables (Basic operating instructions-PLUS).



Loads

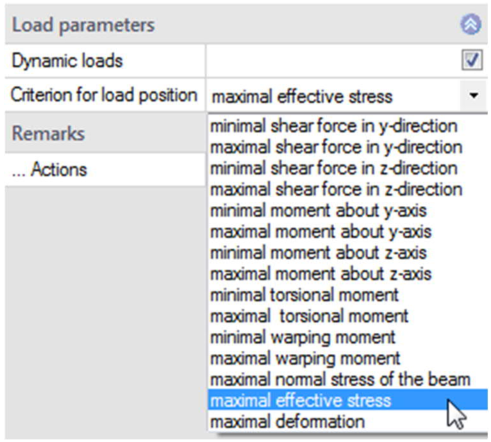
Load parameters



Dynamic loads: activate this option to define dynamic loads.

Criterion for the load position: selection of a default criterion for the decisive load position in combination with movable concentrated loads. All superpositions are adjusted correspondingly.

Comments: you can enter comments on the actions.



Dynamic loads

If you have selected the option "Dynamic loads", you must set the desired criterion of the decisive load position in the selection window. The available criteria for the decisive load position are the minimum or maximum internal forces or the greatest absolute axial stress or comparison stress.

If you select the maximum axial stress as a criterion for the decisive load position, you can choose among two additional options: These are either the absolute maximum axial girder stress or the greatest absolute stress considering the load transfer stresses, if the corresponding option was selected.

If you select the comparison stress as a criterion for the decisive load position, this criterion also includes the secondary flange bending stress in the x-direction, if applicable.

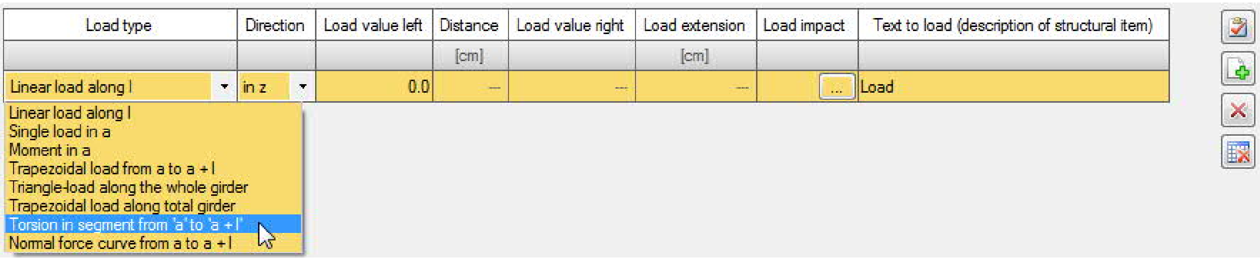
Load cases

Definition of multiple load cases: see Data entry via tables (Basic operating instructions)

Designation	allows you to assign a freely selectable name to the load case
Action	defines the action as per EN 1990 which forms the basis of the load case.
Self-weight	tick the corresponding check box to include the self-weight automatically together with this load case.
Loads	accesses the dialog for the definition of the loads of this load case (...).

Load definition

Click on the "+" button to add a row for a new load.



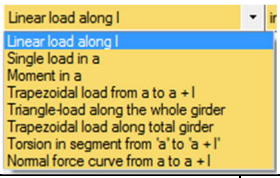
Load type	eight load types are available for selection. See the load types drawings.
Direction	direction of action of the load or axis of rotation of the moment.
Left load value	see the drawings of the "load types."
Distance	distance *a* of the front end of the load to the left girder edge. See "load types".
Right load value	see the drawings of the "load types."
Load extension	length of the loaded section/rear end of the load.
Load application point	accesses the dialog for the editing of the load application point.

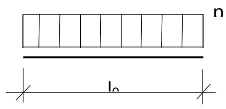
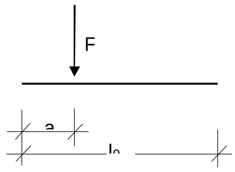
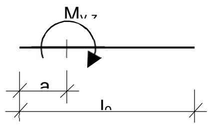
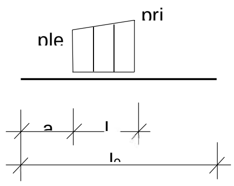
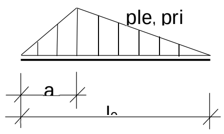
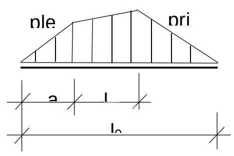
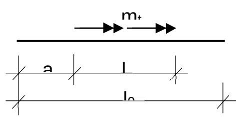
x-coordinate	distance of the considered cross section to the left girder edge.
ey/es	distance of the load application point to the reference point in y-direction or in z-direction.
Distance	absolute: absolute distance to the reference point or relative: factor to be multiplied with the section height.

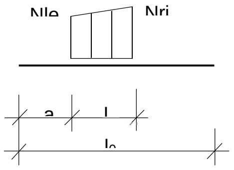
Descriptive text	allows you to enter an additional descriptive text for this load.

Load types

l_0 = Total length of the girder



Load type	Description	System sketch
Linear load along l	A linear load that applies constantly over the total length of the girder.	
Single load at a	A concentrated load applying at the distance a from the left girder edge.	
Moment at a	A moment applying at a distance a from the left girder edge	
Trapezoidal load from a to a+l	A linearly variable load applying over the length l at a distance a from the left girder edge	
Triangular load along the whole girder	A variable triangular load applying over the total length of the girder.	
Trapezoidal load over l_0	A variable trapezoidal load applying over the total length of the girder.	
Torsional in segment from a to a+l	A torsional area moment applying over a length l at a distance a from the left girder edge	

Normal force curve from a to a+l	A linearly variable axial force applying over the length l a distance a from the left girder edge	

Definition of the distances to the reference point

See also Load types

See also Reference points on the cross section

Some loads extend over a particular area of the girder. The distances are defined consistently over the total area. If required, several loads must be entered.

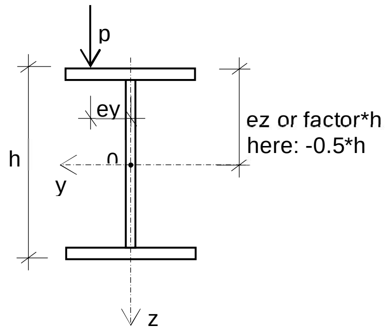
The following rules apply to the definition of distances:

1. Linear loads extending in both directions (y- and z-direction, types 1, 4, 5, 6) can be defined via a distance in the y-direction and in the z-direction. These kinds of loads can produce a torsional moment.
2. Concentrated loads can be defined only via one distance in the load direction. Therefore, concentrated loads cannot produce torsional moments except when applying to open polygonal cross sections.
3. Concentrated loads in z-direction can be included as wheel loads acting on the lower flange. Half of the value is assigned to the right flange and half of the value to the left flange. The corresponding option must be set in the Basic Parameters.

Note:

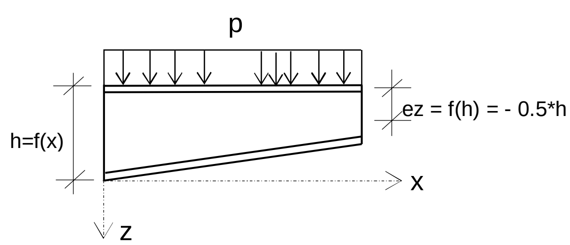
If a girder is composed of different cross sections, you should be aware that the reference points may vary and with them the decisive distances to the centre of gravity or the shear centre of the cross section in question.

Load distances without loading on the lower flange

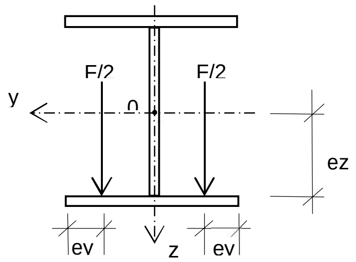


Value	Description
Absolute distance	The distance to the reference point is defined via an absolute value
Relative distance	The distance to the reference point is defined via a factor to be multiplied with the height of the cross section.
ez	Distance of the load to the reference point in the z-direction, absolute value
Factor	Factor for the distance of the load to the reference point in the z-direction, relative value
ey	The load applies at a distance ey to the reference point of the cross section.

Illustration

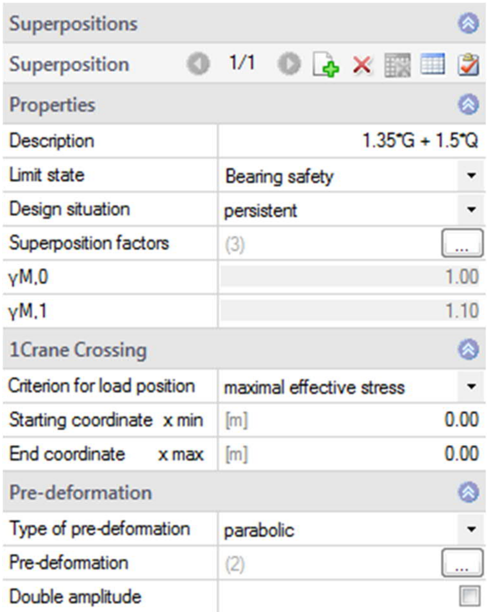


Load distances with loading on the lower flange



Value	Description
ez = the distance to the reference point	The distance to the reference point is defined via an absolute value
ey = the distance to the outer edge of the flange	The load is defined as lower flange loading with F/2 on each flange side and applies at a distance ey to the outer edges of the flange sides.

Superpositions



The calculation of the system is based on load case combinations (superpositions). They comply with the combination rules stipulated by EN 1990.

The load case combinations are to be defined by the user himself on the basis of engineering opinion. However, an assistant is available to the user for determining the combinations.

Note: *If a new load case is created, then the superposition factor in the existing load case combinations is always "0.00".*

Load case combinations are assigned to a design situation and to a limit state independently of each other. The user defines the partial safety factors and the combination factors for the actions. The partial safety factors for the resistances are determined by the limit state.

Designation	allows you to assign a freely selectable name to the respective superposition.
Limit state	limit state as per EN 1990: bearing safety (ultimate) / serviceability.
Design situation	design situation as per EN 1990: permanent, transient, accidental, fire, earthquake.
Superposition factors	displays a dialog for the definition of the superposition factors.

Superposition factors

The load cases are automatically numbered in consecutive order.

γF	defines the partial safety factor for actions included in the superposition factor.
ψi	defines the combination coefficient ψ(0,1,2) for actions included in the superposition factor.
Factor	the factor by which the load case is multiplied when assigned to the load case combination.

Crane crossing / dynamic loads

The definition fields for the crane crossing are only displayed if the Dynamic loads option was checked in the Loads definition section.

Criterion for load position
selection of the target function on which the decisive load position of a crane crossing (minimum/maximum shear force ... maximum deformation) should be based.

Front/rear end coordinates
coordinates of the front end and the rear end of the first wheel of the first (front) crane in the x-direction
Note concerning moving/dynamic loads:
When the "Dynamic loads" option was selected in the "Load parameter" menu, areas where the wheel loads move must be defined on the girder for each superposition. To define such a travelling area, the smallest and the greatest permissible x-coordinate must be specified for the front wheel in travelling direction. Limit load positions may be defined in such a manner that individual wheels are beyond the girder.

Initial imperfection

The input fields for the initial imperfection (pre-deformation) are only displayed if a 2nd order analysis was selected in the basic parameters menu.

Type	selection whether the initial imperfection half waves shall be sine-shaped or parabola-shaped.
Pre-deformations (initial imperfections)	displays a dialog for the definition of the initial imperfections.
Double amplitude	according to DIN EN 1993, the amplitudes of the initial bow imperfections are to be doubled if 0.7 < lambdaLT < 1.3.

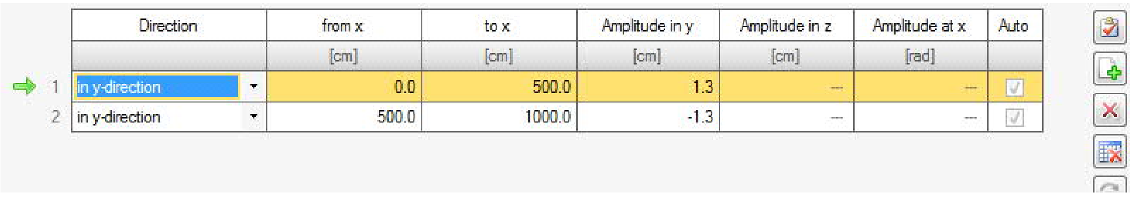
Imperfections

General

BTII+ allows you to define imperfections in the directions of the both cross sectional major axes y and z as well as initial sway imperfections around the longitudinal axis of the member. In order to reduce input work in connection with the inclusion of imperfections, you simply need to specify the zero-points of the half-waves and their amplitudes. On the basis of these specifications, the application calculates the magnitude of the imperfections in all node points in-between the zero-passages of the half-waves. The equivalent imperfection loads required for the 2nd order analysis result from the multiplication of the imperfections with the geometric stiffness matrices.

Definition of imperfection half-waves

Click on Button “Pre-deformation”



	Direction	from x [cm]	to x [cm]	Amplitude in y [cm]	Amplitude in z [cm]	Amplitude at x [rad]	Auto
1	in y-direction	0.0	500.0	1.3	---	---	✓
2	in y-direction	500.0	1000.0	-1.3	---	---	✓

Direction	direction of the amplitude of the initial imperfection half-wave. Displacement in the y-,z-direction or initial sway imperfection around the y-axis.
From x/to x	front-end and rear-end coordinates of the initial imperfection half-wave (outgoing from the left girder edge).
Amplitude in y/z/x	amplitude of the initial imperfection half-wave in the middle of the initial imperfection region in the y-direction or the z-direction or around the x-axis.

The amplitudes are generated automatically by the software in accordance with the cross sections and the spacing of the supports. You can edit these values if required. After editing, these values will not be adjusted automatically to subsequent changes in the structural system!

Functions of the icons

The functions of the icons on the right are described in the tooltips, which are displayed when the mouse cursor points to an icon, e.g.

- Inverts the amplitudes
- Applies to all superpositions
- Generates the initial imperfections (pre-deformations) automatically in all superpositions

Inclusion of imperfections in the second order analyses only

If geometric and structural imperfections should be calculated in second order analyses, geometric equivalent imperfections must be taken into account. These are initial sway imperfections caused by angles of member rotation for sway systems and initial bow imperfections in the form of sinusoidal or parabolic half-waves for non-sway systems. Even-though geometric equivalent imperfections are not defined in the form of an imperfect system geometry in design practice but, for reasons of simplification, via static equivalent loads, *BTII+* allows the inclusion of imperfection half-waves.

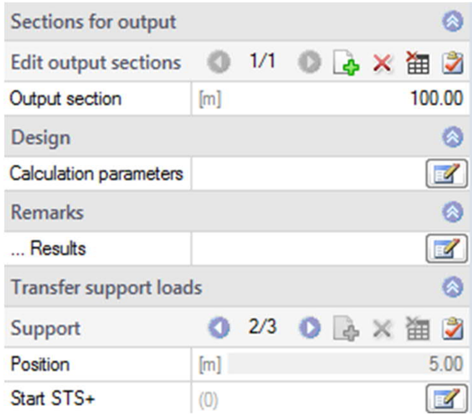
Notes concerning the course of imperfection half-waves

The course of the imperfection half-waves should correspond to the lowest mode shape of lateral buckling or lateral torsional buckling.

The amplitudes should be determined on the basis of the buckling curves as per EN 1993-1-1 and the direction of deflection (y or z).

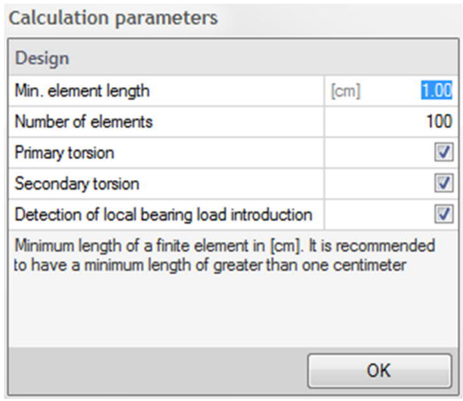
Design and analysis

Output sections



The application determines automatically the verification points at which the design values, stresses and structural safety verifications are put out. The user can define additional output sections by specifying the corresponding x-coordinates.

Calculation parameters



Min. length	minimum length of a finite element. A minimum length greater than one centimetre is recommended.
No. of elements	number of finite elements to obtain during system discretisation. (1 <= n <= 5000).
Torsion	determines whether the shear stresses due to primary/secondary torsions are taken into account in the calculation of the comparison stresses.

Minimum number of elements on the girder

The real number of elements could be considerably higher. The quotient of the girder length and the minimum number of elements gives orientation for the element length in the girder sections.

As a rule, the user should define between 5 and 15 elements in order to ensure that, with average shift gradients, the difference in the deformations is less than 5 % compared to the exact solution. The number of required elements depends on the gradient of the bending curve. With steep gradients such as those of point loads, individual springs and stiffness jumps and with elastic foundation in combination with stability-critical loading, the number of elements must be increased. If you are unsure about the number of required elements simply perform a new calculation with refined elements. If the results differ considerably perform another calculation with even more refined elements.

Discretisation of the system

The girder is described by its areas and one or more cross sections. This allows the user to define cross section jumps and haunches. For the calculation, however, the girder must be divided into sections with constant cross sections. Haunches are represented by a suitable number of similar cross sections with gradually increasing sizes.

In the discretisation process, the node mesh is first generated from the front and rear end coordinates of the girder regions. Due to the fact that *BTII+* displaces node loads, supporting conditions, region borders as well as the zero-points of the imperfection half-waves automatically to the next-closest node, additional section borders have to be defined in these points. This will only happen, however, if the distance between the section border to be inserted and the existing section borders exceeds the specified minimum size. The minimum size is defined via the minimum element extension.

Transfer support loads

Design values of the supporting forces can be passed to the program single-span steel column STS+ as result load cases.

Method of calculation

Second order analysis

The second order analysis is based on iteration. The first step in each calculation is a first order analysis. The resulting internal forces form the basis of the next iteration step to calculate the geometric stiffness matrix describing the non-linear behaviour. As typical in structural engineering, the modification of the internal forces is not considered in the following iteration steps for the generation of the geometric matrix ("Disregard of the modification of the main deflection"). This corresponds to the freezing of the axial member forces after the first iteration step in connection with the two-dimensional stability problem. The iteration ends with the 2nd iteration step. If the defined loads are greater than the lateral buckling or lateral torsional buckling loads, the load-deformation problem can be solved but the equilibrium becomes unstable in this state. The determinant of the system stiffness matrix is negative in this case. Therefore, *BTII+* aborts the calculation and displays a corresponding message.

If a load level was defined that is only slightly below the load level of the lowest eigenvalue (=smallest torsional buckling load), deformations increase considerably. In this case, the results are useful only under certain conditions because the theoretical basis still describes the equilibrium of the deformed system but assumes only small deformations.

The forces and moments calculated in the 2nd order analysis are already referenced to the major axis system. Therefore, no transformation is required for the subsequent stress examination.

Warping torsion

Torsional loading on thin-walled open sections is distributed via Saint-Venant's torsion M_{tp} (primary torsional moment) and warping torsion M_{ts} (secondary torsional moment). The larger the fixity against cross section warping the larger the portion that is distributed via warping torsion and vice versa. The fixity depends on the shape of the cross section and the behaviour of the torsional moments. With solid cross sections and circular hollow cross sections, for instance, warping fixity is low. The same applies to the area of torsional moments with constant behaviour. Accordingly, the load distribution via Saint-Venant's torsion prevails. In contrast to this, the distribution via warping torsion is predominant particularly at jumps in the torsional moments behaviour and at warping restraints.

Axial warping stresses in the longitudinal direction of the member and warping moments, also referred to as bending moments, occur due to warping fixity. In stress analyses on open cross sections, warping stresses resulting from warping torsion must therefore be considered in addition to the axial stresses caused by the axial force and the bending moments.

The equation for the total axial stresses is as follows:

$$\sigma_x = \frac{N}{A} + \frac{M_y}{W_y} + \frac{M_z}{W_z} + \frac{M\omega}{I_\omega} \cdot \omega$$

N	axial force
M_y, M_z	bending moments about the y- or z-axis on the deformed cross section
M	warping moment, also indicated with M_w or B
A	cross sectional area
W_y , W_z	section moduli around the y- or z-axis
I_ω	warping moment of inertia, also indicated with I_w or C
ω	standard main warping, also indicated with w_M

Equivalent member verification

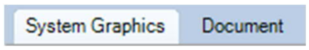
When using the equivalent member method for the stability examination, *BTII+* performs an eigenvalue calculation by applying the linear subspace method.

Output

A general description of the output options is available in the document:

- Output and printing

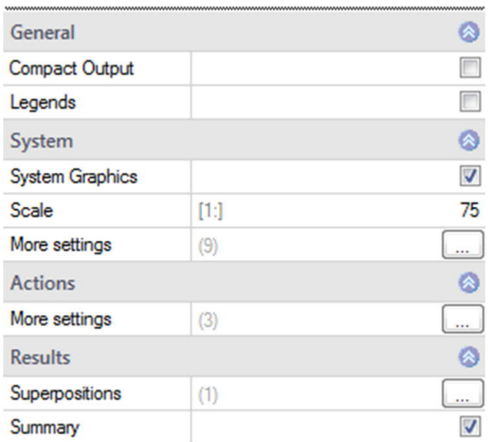
View selection



The tabs "System Graphics" and "Document" allow you to toggle between the representation of the structural system and the preview of the text documents.

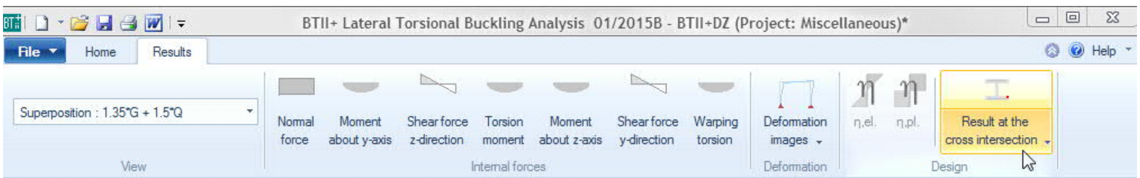
Output options

The different options and the corresponding ... buttons allow you to determine and limit the output scope.



Results

You can access the views of the different result graphs via this tab (select by clicking).



The calculation results are displayed for the load case combinations not the individual load cases. You can select the relevant load case combination via the tool bar.

Notes concerning the practical applications

The following topics are treated in the separate document BTII-Additional-Notes:

- Purlins with torsionally elastic support by the roof skin
- Trusses with torsionally elastic support by purlins
- Trusses with elastic translational support at the top chord by purlins
- Trusses with elastic torsional support by columns
- Girder with elastic warping support
- Girder with shear field support
- Torsion with solid cross sections
- Stresses due to local girder loading
- Lateral buckling of frame systems

Reference literature

[1] Fédération Européenne de la Manutention, section XI: *Rules for the design of series lifting equipment; Local girder stresses* FEM 9.341, 10.1983.

[2] W.F. Chen, T. Atsuta: *Theory of Girder- Columns. Vol. 2: Space Behaviour and Design,* McGraw-Hill, New York 1976.

[3] *Traglastermittlung ebener Stabwerke mit räumlicher Beanspruchung,* Mitteilung Nr. 81-3, Institut für konstruktiven Ingenieurbau, Ruhr Universität Bochum 1981.

[4] J. Lindner: *Der Einfluß von Eigenspannungen auf die Traglast von I-Trägern.* Habilitationsschrift (professorial dissertation). Technical University of Berlin, 1972 Abbreviated version in: *Der Stahlbau 43* (1974), p. 39 - 45 and 86 - 91.

[5] J. Lindner: *Berichte aus Forschung und Entwicklung, DASt 15* (1986) and: *Stabilisierung von Biegträgern durch Drehbettung - eine Klarstellung*, Stahlbau 12 (1987), p. 365 - 373.

[7] P. Osterrieder: *Traglastberechnung von räumlichen Stabtragwerken bei großen Verformungen mit finiten Elementen.* Dissertation. University of Stuttgart 1983.

[8] Chr. Petersen: *Statik und Stabiltät der Baukonstruktionen*, Vieweg & Sohn, Braunschweig 1981.

[9] G. Powell, R. Klingner: *Elastic Lateral Buckling of Steel Girders*, in: Proceedings ASCE: J. of Structural Division 96 (1970) pp. 1919 - 1932.

[10] S. Rajasekaran: *Finite Element Analysis of Thin - Walled Members of Open Cross Sections. (Structural Engineering Report No. 34)*. Department of Civil Engineering, University of Alberta. Edmonton, Canada, Sept. 1971.

[11] K. Roik, J. Carl, J. Lindner: *Biegetorsionsprobleme gerader dünnwandiger Stäbe*. Ernst & Sohn, Berlin, München, Düsseldorf 1972.

[12] H. Rubin, U. Vogel: *Baustatik ebener Stabwerke*, in: Stahlbau Handbuch Band 1. Stahlbau-Verlags-GmbH, Köln 1982.

[13] U. Vogel, W. Heil: *Traglast-Tabellen.* Published by Beratungsstelle für Stahlverwendung, Stahleisen GmbH, Düsseldorf 1981.

Appendix

Settings

‣ File ‣ Program Options

Displays a dialog for the adjustment of general settings. You can set dimensions/units, graphic colours and you can switch the wizard on/off.

Dimensions / Units

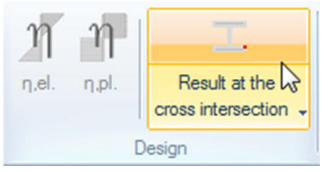
This option allows you to set the desired units for dimensions, forces etc. The number of decimals is set by the application according to selected unit. The selected units apply also to the output.

Wizard

The wizard is launched automatically when you start the application program. You can enter quickly the most important key figures of the structural system in the displayed window. These values can be edited subsequently in the parameter definition section or on the graphical user interface.

Note: You can disable the automatic start of the wizard via the corresponding option on the bottom of the window.

Stress points on the cross section

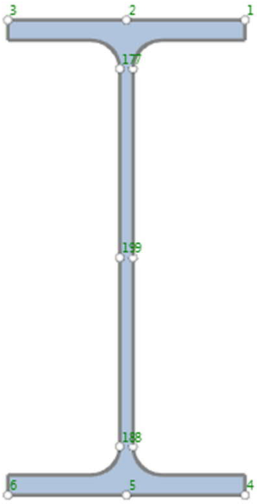


The stress points on the cross section are displayed in the graphical representation of the cross section:

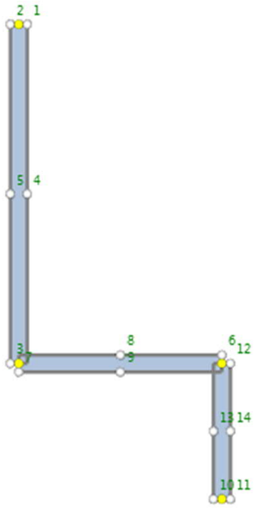
- in the cross-section selection section
- in the software BTII+ in the representation of the results
- optionally in the document in the form of a table and a graphic

Examples:

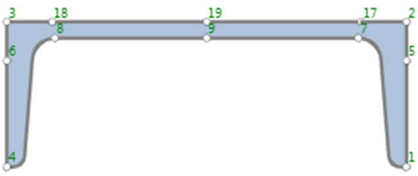
Double-symmetrical and single-symmetrical I-section



Thin-walled angle section



U-section



Reference points on the cross section

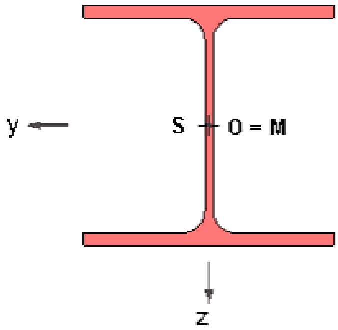
If the shear centre of a standard section is known, it is always the reference point of this section.

The following rules apply to user-defined cross sections:

- The reference point of single-symmetrical I- and T-sections and single-symmetrical I-sections with angled top flanges is always the centre of the clear web height.
- The reference point of user-defined U-sections is the shear centre in horizontal direction and the centre of the clear flange height in vertical direction.
- The reference point of thin-walled open sections is given by the zero-point of the coordinate system which is implicitly defined when the user enters the cross section.

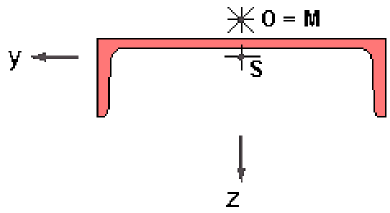
Double-T-section

The reference point is the shear centre.



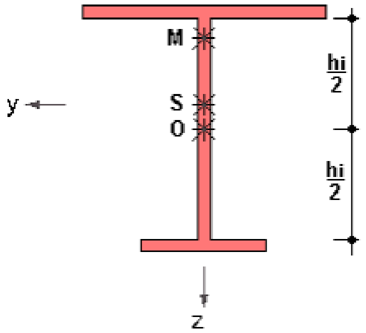
U-section

The reference point is the shear centre.



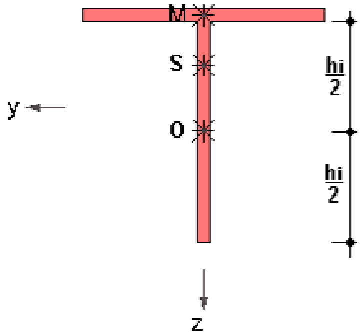
Single-symmetrical I-section

The reference point is the centre of the clear web height.



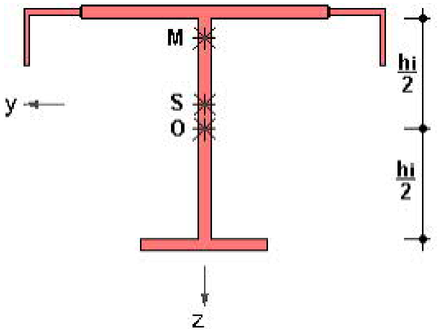
T-section

The reference point is the centre of the clear web height.



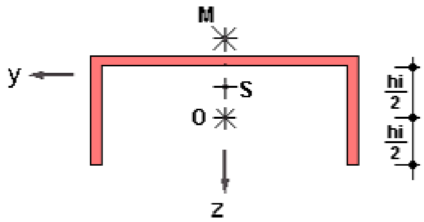
Double T with angled top flanges

The reference point is the centre of the clear web height.



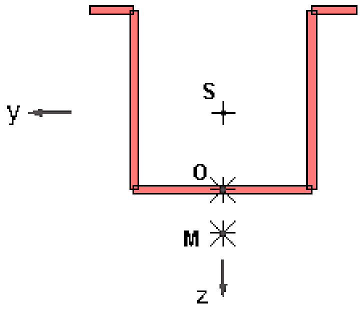
User-defined U-section

The reference point is the centre of the clear web height.

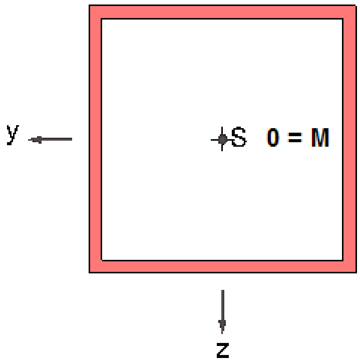


Thin-walled open section

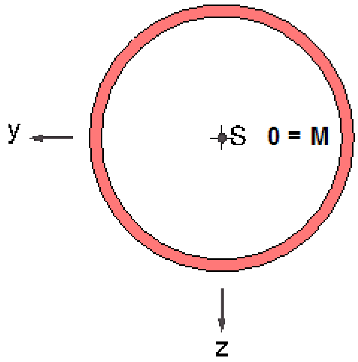
The reference point is given by the zero-point of the implicitly defined system of coordinates.



HSS square



HSS circular



General notes concerning BTII+

Dynamic- / moving loads

You can optionally define node loads in the form of a load train. The limit load positions for the first wheel in travelling direction must be specified by the user. You can select among various criteria to define the target for the decisive load position.

For each load position, a linear or non-linear calculation of the girder is performed depending on the defined target. If you select the maximum axial stress as a target value for the decisive load position, you can choose among two alternative criteria. These are either the absolute maximum axial girder stress or the greatest absolute stress considering the load transfer stresses described below. The application calculates automatically deformations, internal forces and stresses for the decisive load position in firstorder and second-order analyses.

Local girder loading

When underslung overhead cranes travel along the girder on wheels or trolleys, the crane wheel loads or trolley loads apply eccentrically to the girder web. Therefore, secondary flange bending stresses are generated in the proximity of the load application point in two directions. The application calculates local load transfer stresses on the basis of [1] and superimposes them with the global girder stresses in accordance with the von-Mises yield criterion.

The experimental and theoretical examinations by Hannover and Reichwald form the basis for the consideration of local girder loading caused by the operation of underslung overhead cranes in the *BTII+* application. In the current version, this type of calculation can be performed on double-T girder cross section types.

Coordinates for supports, springs and concentrated point loads

The locations of supports, discrete springs, concentrated loads, element borders as well as zero-points of imperfection half-waves are defined by specifying the x-coordinate. Internally, the application generates nodes at supports, springs, loads and deformation zero-points. If the distance of a node to the relevant point is smaller than the minimum element extension specified by the user, no node is generated and the support, spring or individual load is displaced to the next closest node. If this displacement is not acceptable for the analysis, the user must subsequently adjust the minimum element extension accordingly and perform a new calculation.

Variable cross sections

The application allows you to couple asymmetric cross sections. You should note in this connection that the relative location of the centre of gravity and that of the shear centre do not coincide if different shapes of cross sections are used. Since internal forces and deformations refer partly to the centre of gravity and partly to the shear centre, the principle of equilibrium in the strict sense is violated in the nodes. This problem can be neglected with haunched girders, however.

Thin-walled open sections

This option allows the user to define any open cross section in a freely selectable local system of coordinates.