Version
June 2013

Program

CRANEWAY

Design of Crane Supporting Structures According to EN 1993-6 or DIN 4132 (02.81) Including Adaptations to Technical Progress

Program Description

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1. Introduction

1.1 About CRANEWAY

Dear user of CRANEWAY,

this program expands DLUBAL'S product range by the crane runway girder design. Thanks to the well-known user-friendliness of Dlubal programs, you can carry out even complicated analyses according to EN 1993-6, DIN 4132, and DIN 18800 in an easy and comprehensible way.

The crane runway girder is specified in the CRANEWAY module. Based on the defined loadings, the program creates load cases that are combined in load positions. Each load position results in three load combinations. Each load combination is calculated with three loading levels in order to determine the internal forces for the general stress design, the deformation analysis, or the fatigue design. The internal forces are determined according to the second-order analysis for warping torsion. With these calculated internal forces, CRANEWAY provides the appropriate analyses according to EN 1993-6, DIN 4132, or DIN 18800.

CRANEWAY includes the following features:

- **Input**

  Clearly structured input options

  Graphic representation and 3D visualization of nearly all input data

  Import of cross-sections from the extensive RSTAB/RFEM cross-section library

  Import of cranes from the crane library or a user-defined crane database

  Calculation of eigenvalues considering loading with automatic assignment of the eigenvalues as imperfections

  Automatic determination of stress points and assignment of detail categories

  Numerous parameters for control of calculation

- **Results**

  Clear summary of all results

  Clear structure of separate results windows for each analysis

  Representation in result tables: overall, by x-location, by stress points

  Easy verification of the results by means of the detailed intermediate values

  Results evaluation in tables as well as in the corresponding graphic

  Printout report with individual layout options

  Export of graphics to the printout report

We hope that this program will make your work easier. Please do not hesitate to share your ideas, remarks, or suggestions on how to improve CRANEWAY.

We hope you will enjoy working with CRANEWAY.

Your DLUBAL Team

1.2 CRANEWAY Team

The following people were involved in the development of CRANEWAY:

Program coordination

Dipl.-Ing. Georg Dlubal
Ing. Marek Posch

Programming

Ing. Marek Posch
Ing. Martin Deyl

Program design, dialog box figures, and icons

Dipl.-Ing. Georg Dlubal
MgA. Robert Kolouch

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Dipl.-Ing. (FH) Steffen Clauß
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Dipl.-Ing. (FH) Alexander Meierhofer
M.Eng. Dipl.-Ing. (BA) Andreas Niemeier
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Dipl.-Ing. (FH) Christian Stautner
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Dipl.-Ing. (FH) Robert Vogl

1.3 Using the Manual

Topics such as installation, graphical user interface, results evaluation, and printout reports are described in detail in the manuals for RSTAB/RFEM and will not be introduced here. Instead, this manual focuses on the particular features of CRANEWAY.

The description follows the order and structure of the input and output windows. The text of the manual shows the described **buttons** in square brackets, for example [View mode]. At the same time, they are depicted at the left margin. The **Expressions** used in program dialog boxes, tables, or menus are emphasized by *italics* so that the explanation is easy to follow.

At the end of the manual, you can find an index. If you still cannot find what you are looking for, please check our website www.dlubal.com where you can go through the *FAQ* pages and find a solution for the problem by using various criteria.

1.4 Installation Process

The program **CRANEWAY** is delivered on the DVD *Stand-Alone Applications*. This DVD contains the stand-alone programs RX-TIMBER, CRANEWAY, COMPOSITE-BEAM, and PLATE-BUCKLING.

Before you install CRANEWAY, close the applications running in the background.

Please make sure that you are logged on as administrator or have administrator rights for installing the program. When working with CRANEWAY, user rights will be sufficient. For detailed instructions, see the Assignment of user rights video on our website.

On the back side of the DVD case, you can find installation instructions.

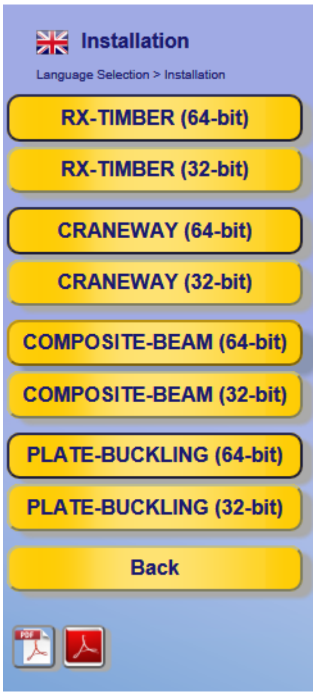
- Insert the DVD into your DVD-ROM drive.
- The installation process starts automatically. If this does not happen, the *autorun* function is probably deactivated. In this case, start the file *setup.exe* on the DVD by using the explorer or by entering the command ‚*D*':*setup.exe* in the input field of the start menu (‚*D*' stands for the drive letter of your DVD drive).
- In the start dialog box, select the language.

Figure 1.1: Language settings

- In the next dialog box, select the CRANEWAY program version (*64-bit* or *32-bit*).
- Follow the instructions of the *Installation Wizard*.

Connect the dongle to a USB port of your computer only after the installation is complete. The dongle driver will be installed automatically.

The DVD also contains installation instructions and the CRANEWAY manual as PDF file. To view it, you need the Acrobat Reader, which you can install from the DVD.



Program selection

CRANEWAY as full or trail version

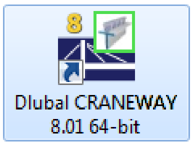
If you start the program after the successful installation for the first time, you have to specify if you want to use CRANEWAY as full version or as trail version (30 days).

To use this program as full version, you need a dongle (hardlock) and an authorization file *Author.ini*. The dongle is a plug-in device that you have to connect to a USB port of the computer; the authorization file contains coded information for your license(s). Usually, we send you the *Author.ini* file via e-mail. You can also use the Extranet on www.dlubal.com to access the authorization file. Save this *Author.ini* file on your computer, an USB flash drive, or in the network.

The authorization file is needed for every work place. You can copy the file as often as you like. If, however, the content of this file is changed, the authorization becomes invalid.

The full version of CRANEWAY can also be run as a *softlock* license without a dongle.

1.5 Start CRANEWAY



Direct start of CRANEWAY

To start the program, use the Windows start menu or the Dlubal icon on the desktop.

RSTAB or RFEM navigator

You can also start CRANEWAY in RSTAB or RFEM in the project navigator: In the *Data* navigator, select

Stand-Alone Programs → CRANEWAY 8 - Design of crane runway girders.

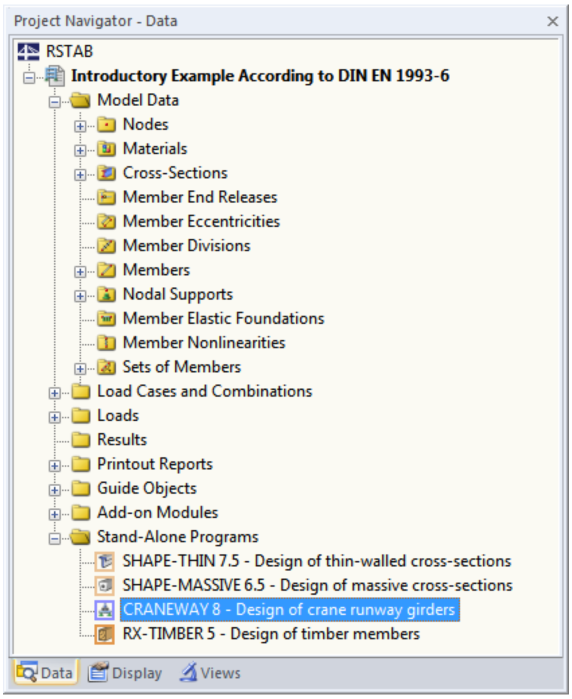
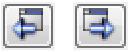


Figure 1.2: Data navigator of RSTAB: *Add-on Modules → CRANEWAY 8 - Design of crane runway girders*

2. Input Data

When you have started the program, the CRANEWAY window appears. A navigator on the left manages the available input and output windows. All settings required for the design are entered in the six input windows of the program.



To go to a particular CRANEWAY window, click the corresponding entry in the navigator. In addition to that, you can use the button shown on the left to set the previous or next window. Alternatively, you can also use the function keys [F2] (next) or [F3] (previous) to browse through the windows.

By clicking [Details], you open the *Details* dialog box for specific calculation settings (see chapter 3.1).

With the [3D-Rendering] button, you can visualize the input data as 3D graphic (see chapter 6.3).

To save the input and results data before you exit CRANEWAY, click [OK]. To exit the program without saving the data, click [Cancel].

In the results windows, you can use the [Graphics] button to check the internal forces, deformations, stresses, etc. in the work window of RSTAB or RFEM (see chapter 6.3.2).

2.1 General Data

The 1.1 *General Data* window manages the general specifications for the material, design standard, and crane type.

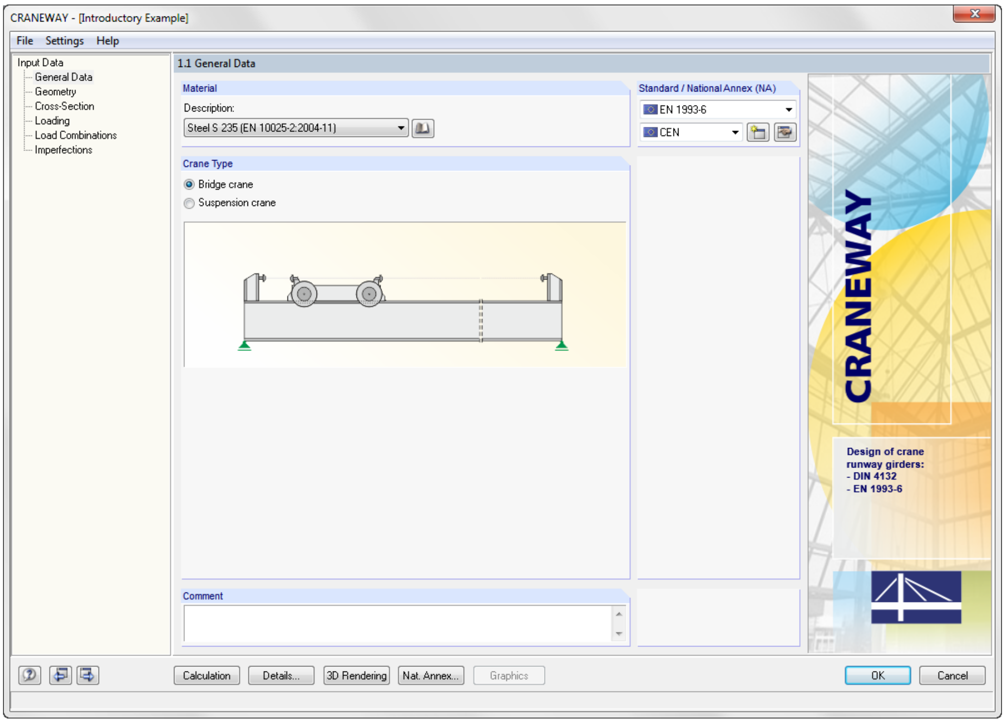


Figure 2.1: Window 1.1 *General Data*

Material

In the *Description* drop-down list, you can select one of the materials stored in the program. It contains the steel grades, which are dependent on the selected standard.

The parameters of the steel grade are stored in a [Library], which you can access by clicking the corresponding button.

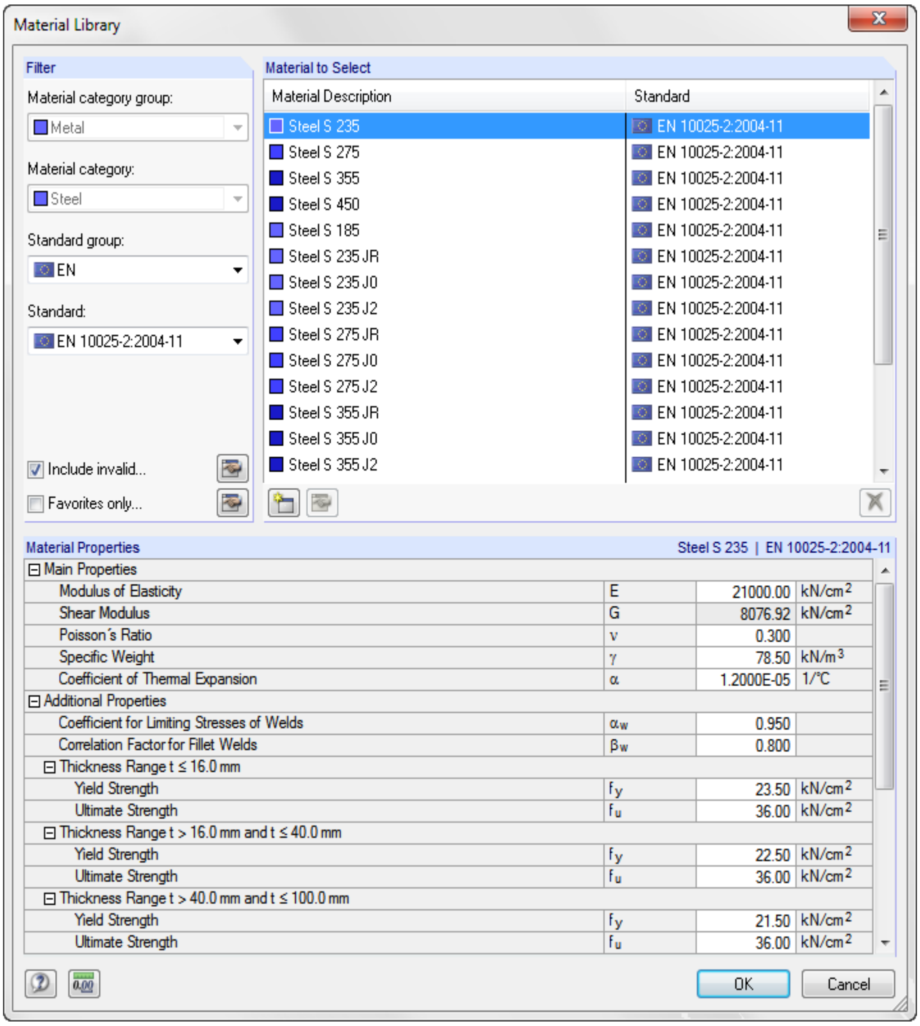


Figure 2.2: Material Library

The material properties are also included in the library. There, you can select a material, and then import it to window 1.1 by clicking [OK].

If you calculate according to DIN 4132, it is not possible to define a new steel grade in the library: According to this standard, only materials with defined allowable stresses for the fatigue analysis may be selected. In contrast to that, you can define your own materials in a calculation according to EN 1993-6. Notice that all parameters necessary for the design are preset or else are to be defined.

Standard / National Annex

In the drop-down list of this section, you select a standard for design and, if necessary, the according National Annex (NA). You can select either the standard EN 1993-6 or DIN 4132.

If you design according to EN 1993-6, you can also select a National Annex whose parameters will be used for the design. The list of the design standards will be extended as we continue to develop CRANEWAY.

To check and, if necessary, adjust the current default parameters of the Standard or National Annex, click [Edit]. This is particularly useful if you want to modify the partial safety factors and combination coefficients for the combination rules.

To create a user-defined national annex, click [New].

Crane Type

With CRANEWAY, you can design bridge cranes as well as suspension cranes. To select the desired crane type, use the respective option buttons. The graphic will be automatically adjusted according to the crane type.

For the design according to DIN 4132, only bridge cranes are available.

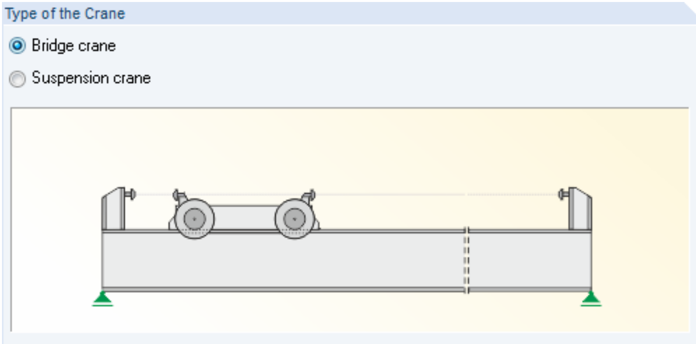


Figure 2.3: Crane type *Bridge crane*

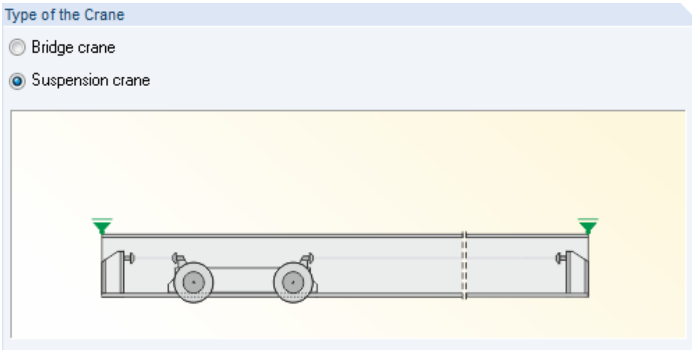


Figure 2.4: Crane type *Suspension crane*

Comment

In this input field, you can write your comments.

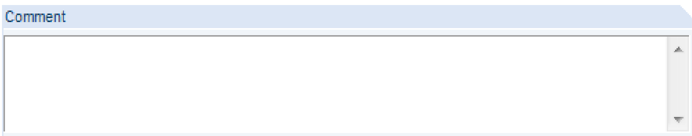


Figure 2.5: *Comment*

2.2 Geometry

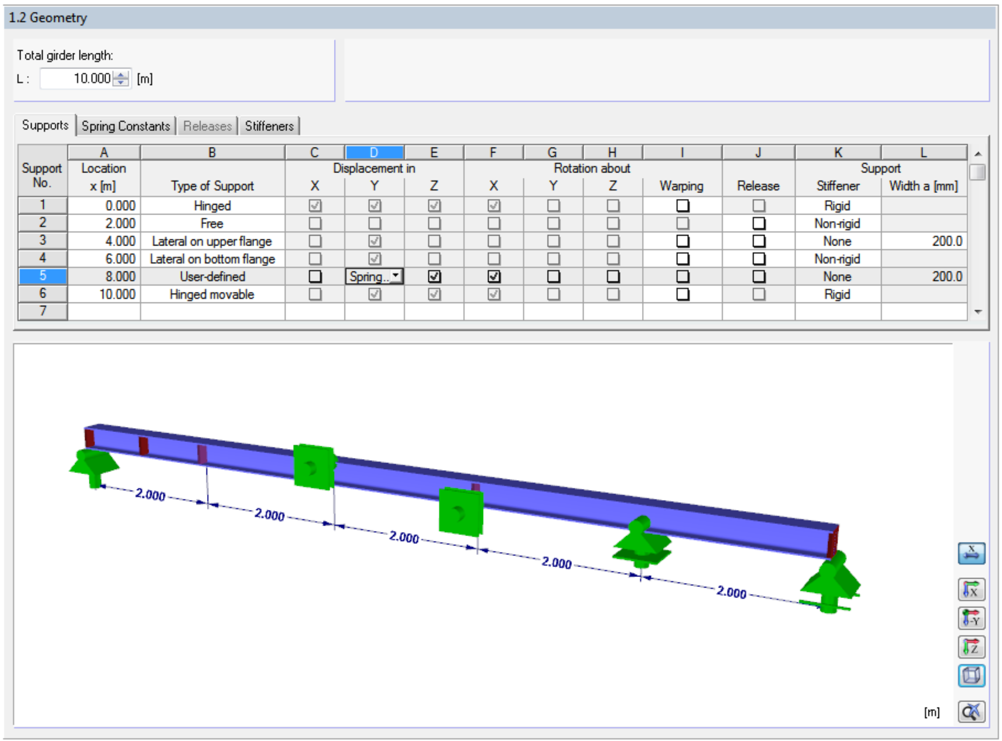


Figure 2.6: Window 1.2 *Geometry*

Total girder length

First, you must define the *Total girder length* for the one-span or continuous girder. If there are already entries in the *Supports* tab for the location *x* of the supports, the total length may not be less than the maximum distance of the x-location from the beginning of the girder. Otherwise, the maximum distance x will be automatically reduced to the total length.

Supports

In this tab, you define the support locations and degrees of freedom of the supports. By placing the cursor inside a row, you can define the *Location x* of the support manually.

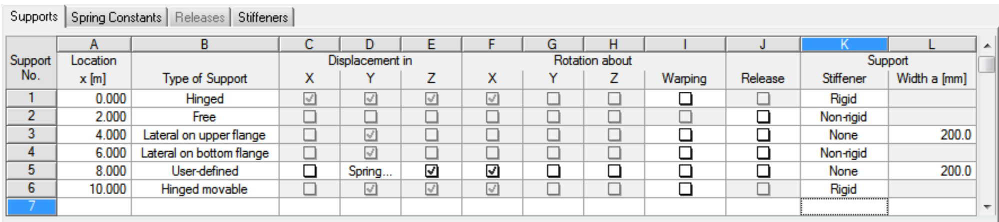


Figure 2.7 Window 1.2 *Geometry*, tab *Supports*

In column B, you assign the *Type of Support* to the respective support by using the drop-down list. You can select from the following types:

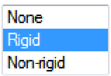
- Hinged
- Hinged movable
- Rigid
- Free
- Lateral on upper flange
- Lateral on bottom flange
- User-defined

The types of support *Hinged* and *Hinged movable* do not allow any changes in the displacement or rotation definition (columns C through H).

A lateral spring support on the upper or bottom flange of the girder cross-section can only be assigned if you select the options *Lateral on upper flange* or *Lateral on bottom flange*. The corresponding spring constant is to be specified in the following tab.

For the *User-defined* type of support, you can specify the displacement, rotation, or warping restraint manually. To define the possibility of displacement or rotation as well as spring behavior, you can use the lists or check boxes in columns C through I. This is possible for an elastic support, elastic restraints, and warping.

Furthermore, it is possible to apply *Releases* at the supports. To assign a release, select the check box in column J of this tab. The release properties are then to be defined in the *Releases* tab. In this way, you can, for example, create a chain of one-span girders.

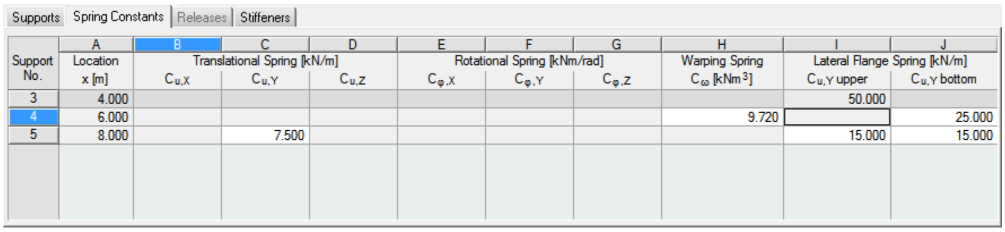


For each support, you can specify manually if there is a stiffener (end post). You can select from the options *None*, *Rigid*, and *Non-rigid*. The type of stiffener has an influence on the plate-buckling analysis of the girder, as it influences the shear buckling resistance of the web.

If no stiffener is defined, you must specify the *Width a* of the support in order to perform the stress, fatigue, and plate-buckling analyses.

Spring Constants

The second tab becomes available if you select a spring in the *Supports* tab.



	A	B	C	D	E	F	G	H	I	J
Support No.	Location x [m]	Translational Spring [kN/m] $C_{u,X}$	$C_{u,Y}$	$C_{u,Z}$	Rotational Spring [kNm/rad] $C_{\varphi,X}$	$C_{\varphi,Y}$	$C_{\varphi,Z}$	Warping Spring C_{ω} [kNm³]	Lateral Flange Spring [kN/m] $C_{u,Y}$ upper	$C_{u,Y}$ bottom
3	4.000								50.000	
4	6.000							9.720		25.000
5	8.000		7.500						15.000	15.000

Figure 2.8: Window 1.2 *Geometry*, tab *Spring Constants*

By placing the cursor in the relevant row, you can define the constants for the translational, rotational, or warping spring.

The stiffness of the *warping spring* is dependent on the type of warping restraint. This calculation can be done automatically in CRANEWAY. If you click in a cell of column H, the [...] button appears. By clicking this button, you open a new dialog box. After you specify the relevant parameters, the resulting stiffness is shown (see the following figure).

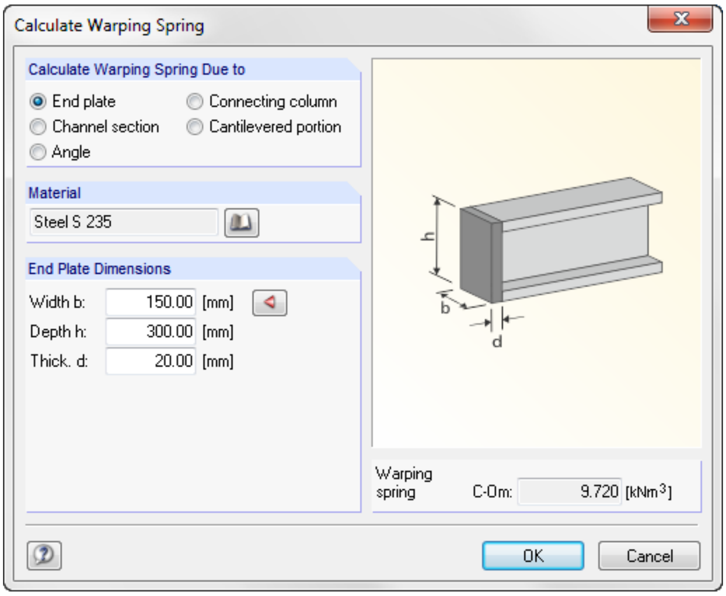
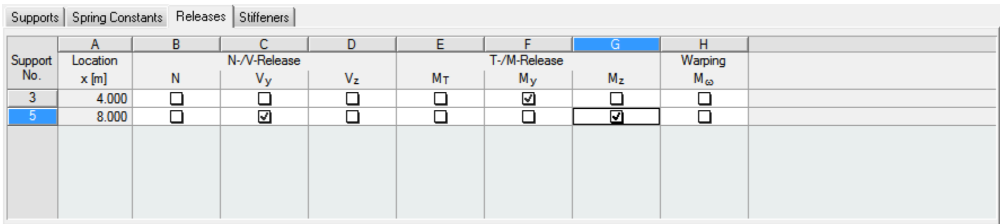


Figure 2.9: Dialog box *Calculate Warping Spring*

The input options in this dialog box differ depending on the type of warping spring. You define the spring type in section *Calculate Warping Spring Due to*. Then, you can define the geometry.

Releases

The third tab becomes available if you select a release in the *Support* tab.



	A	B	C	D	E	F	G	H
Support No.	Location x [m]	N-/V-Release N	V_y	V_z	T-/M-Release M_T	M_y	M_z	Warping M_ω
3	4.000	☐	☐	☐	☐	☑	☐	☐
5	8.000	☐	☑	☐	☐	☐	☑	☐

Figure 2.10: Window 1.2 *Geometry*, tab *Releases*

In this tab, you define the degrees of freedom or release properties at the relevant x-locations. You can define a release by selecting the relevant check boxes.

Stiffeners

In the last tab, you can specify the number and arrangement of the stiffeners in the panels.

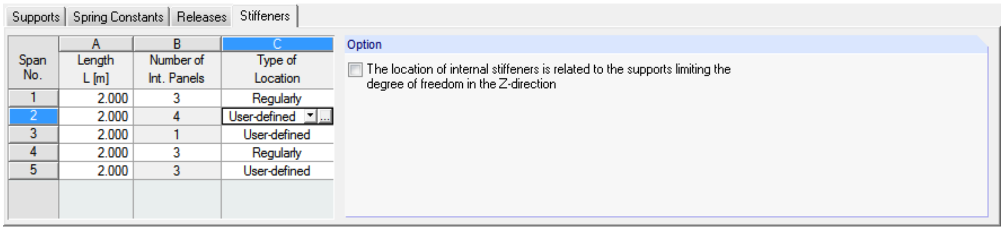


Figure 2.11: Window 1.2 *Geometry*, tab *Stiffeners*

The defined supports divide the girder in internal panels. Now, you can further modify the arrangement of the stiffeners in these panels. Column C provides two options of how to arrange the stiffeners.

By using the *Regularly* option, you generate a uniform distribution in respect to the number of internal panels. If the number of internal panels is one (minimum number for division), the stiffeners are always arranged at the support. If the number of internal panels is *2*, one more stiffener is considered in the middle of the span. If the numbers is *3*, the stiffeners will be placed in the third-points of the span. The stiffeners influence the plate buckling analysis.

To specify different distances of the stiffeners in the span, you can select the option *User-defined*. If you click in a cell of column C, the [...] button appears. By clicking it, you open the following dialog box where you can specify the stiffener locations for the selected span.

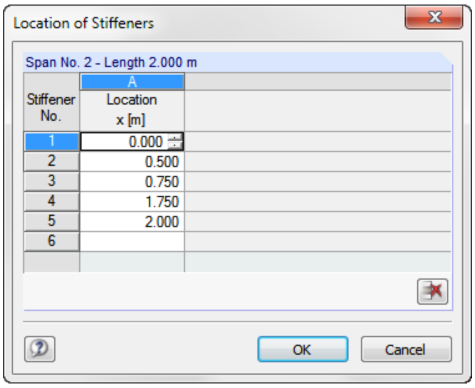


Figure 2.12: Window 1.2 *Geometry*, tab *Stiffeners*, dialog box *Location of Stiffeners*

The *Option* dialog box section provides you the possibility to position the stiffeners: By selecting this check box, the stiffeners will be arranged only between those supports that restrain the degrees of freedom in the Z-direction. The division is carried out based on the selected number of internal panels. The following figure illustrates this option:

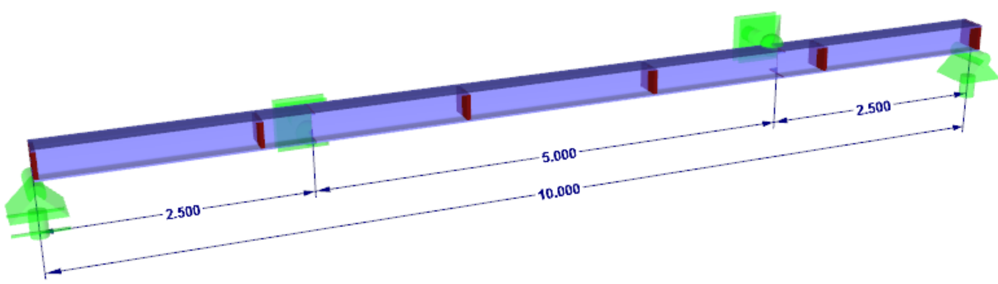


Figure 2.13: Regular positioning of the stiffeners only between the supports acting in the Z-direction

2.3 Cross-Section

In this window, you select the cross-section parameters, define rails, and specify requirements for the fatigue and weld designs.

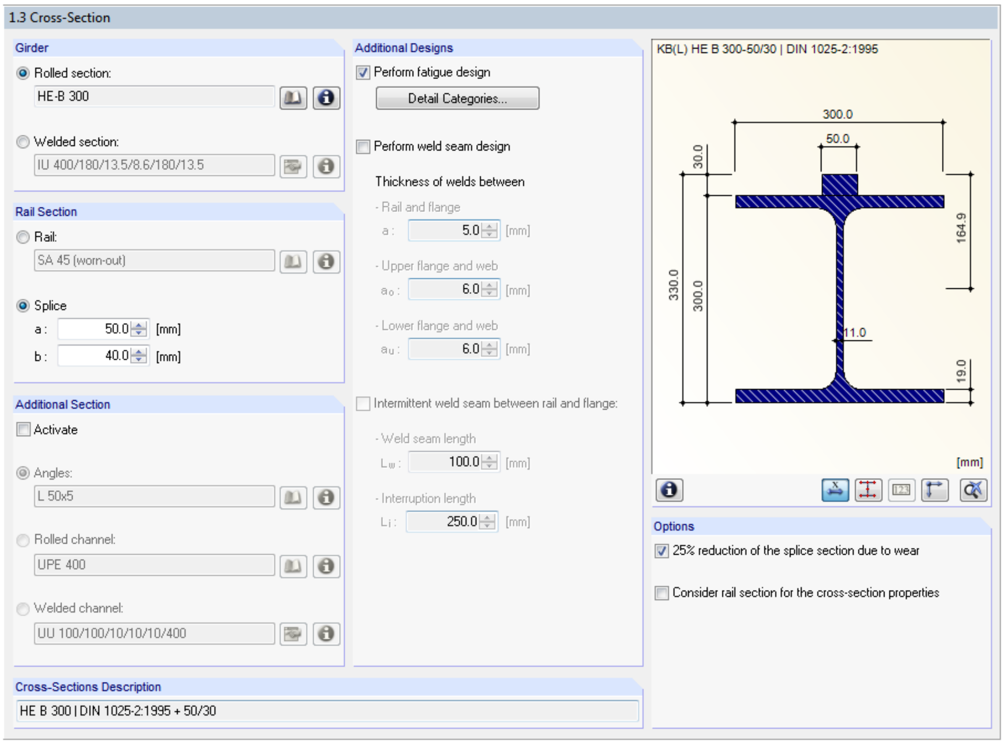


Figure 2.14: Window 1.3 *Cross-Section*

Girder

In this section, you define the cross-section of the crane runway beam.

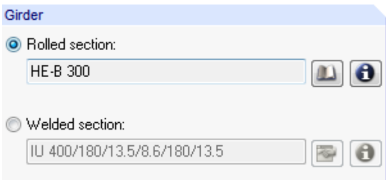


Figure 2.15: Section *Girder*

You can select the following cross-section types:

- Rolled section
- Welded section

For a rolled section, you can open an extensive [Library] of I-sections by clicking the according button. In the new dialog box, you can find the following I-section series (tables): I, IPE, IPEa, IPEo, IPEv, HE-B, HE-A, HE-M, HE-AA, etc. Having chosen an I-section series, you can then select the desired cross-section from the series. By clicking [Info], you can see the detailed information about the cross-section.

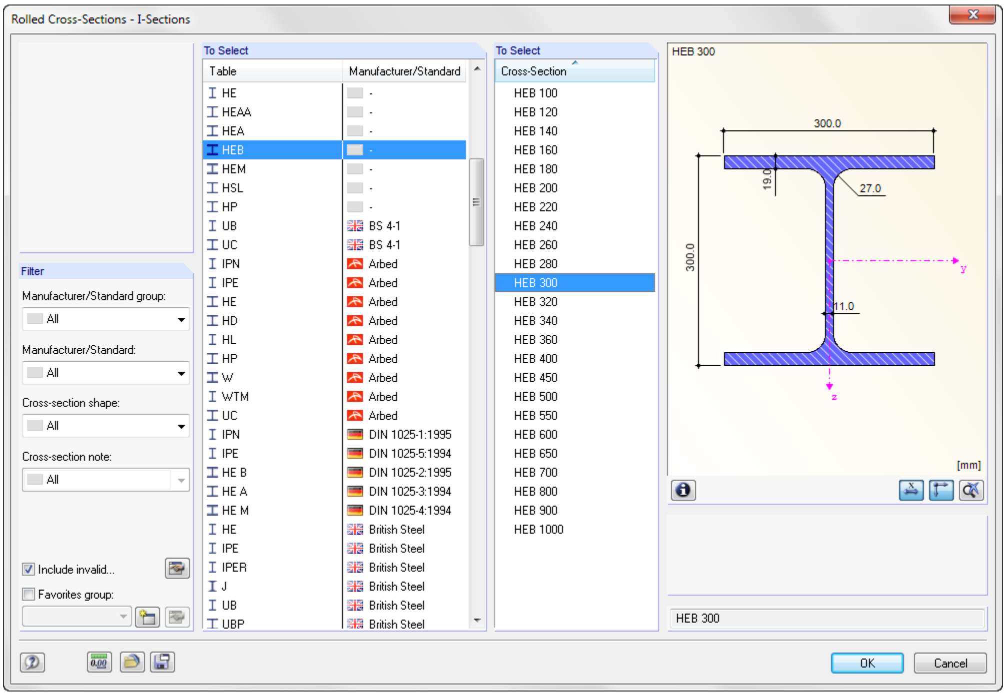


Figure 2.16: Cross-section library for *Rolled sections*

If you select a *Welded section*, you can define a uniaxially symmetric I-section by using the [Edit] button.

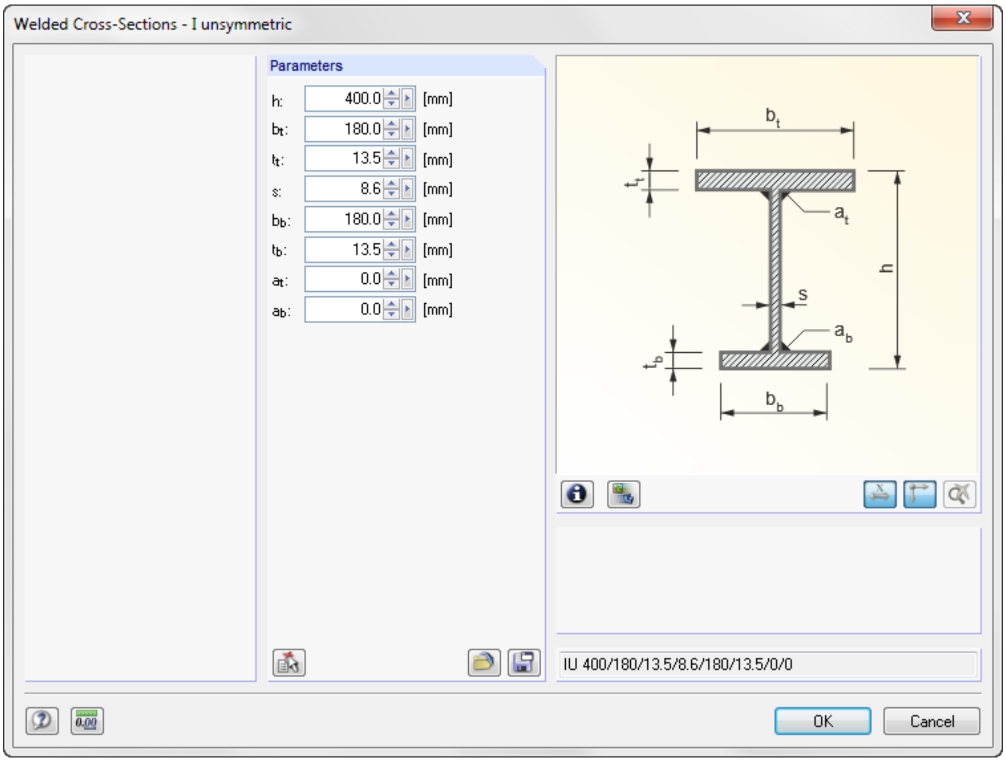


Figure 2.17: Parametric input for *Welded sections*

The dimensions must be defined manually, but you can also import them by using the [↖] button from the rolled I-sections. You can save the defined cross-section in the user-defined library by clicking [Save]. The saved sections can be loaded from the library by clicking [Load].

Rail Section

For a bridge crane, you can specify the crane rail in this dialog box section.

Figure 2.18: Dialog box section *Rail section*

Rolled rails can also be selected from the [Library].

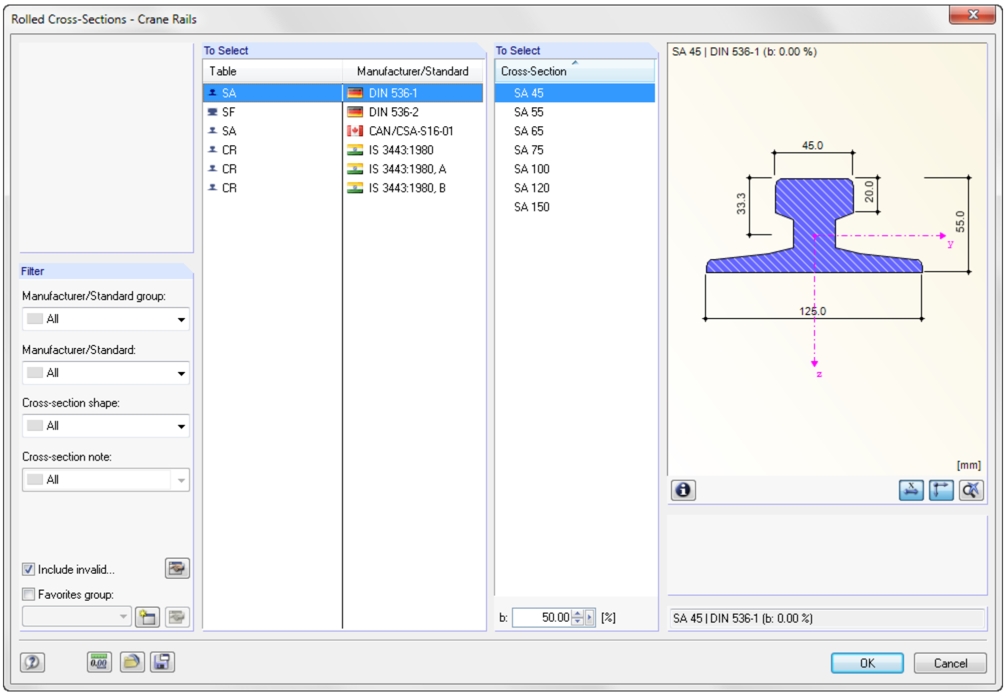


Figure 2.19: Cross-section library for *Rolled Cross-Sections - Crane Rails*

For *Splices*, you must define the dimensions manually.

Any girder cross-section with a rolled or welded section can be combined with any rail or splice.

If the selected rail section is too large for the girder or the girder section too small for the rail, the input cannot continue until a plausible runway girder section is selected.

Additional Section

For a bridge crane, you can arrange additional cross-sections on the runway girder.

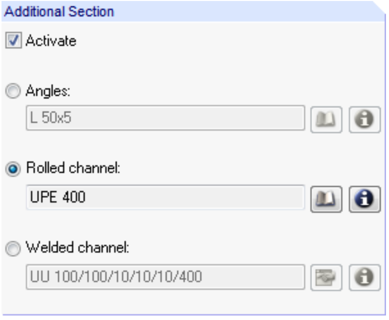


Figure 2.20: Dialog box section *Additional Section*

The following options can be selected:

- Angles
- Rolled channel
- Welded channel

The additional sections can be selected from the [Library] in the same way as for girders.

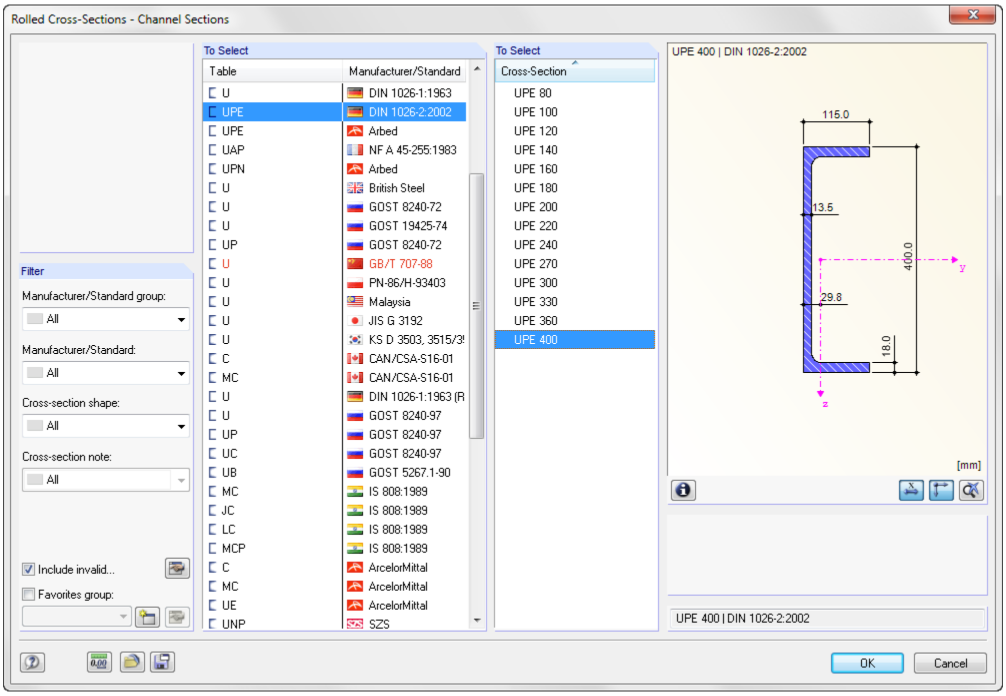


Figure 2.21: Cross-section library for *Rolled Cross-Sections - Channel Sections*

The selection and input in this dialog boxes is done in the same as for the girder cross-sections.

At the end of the input fields for the individual section as well as the total cross-section, you find the [Info] button. The button opens the dialog box *Info About Cross-Section* with the properties of the selected cross-section.

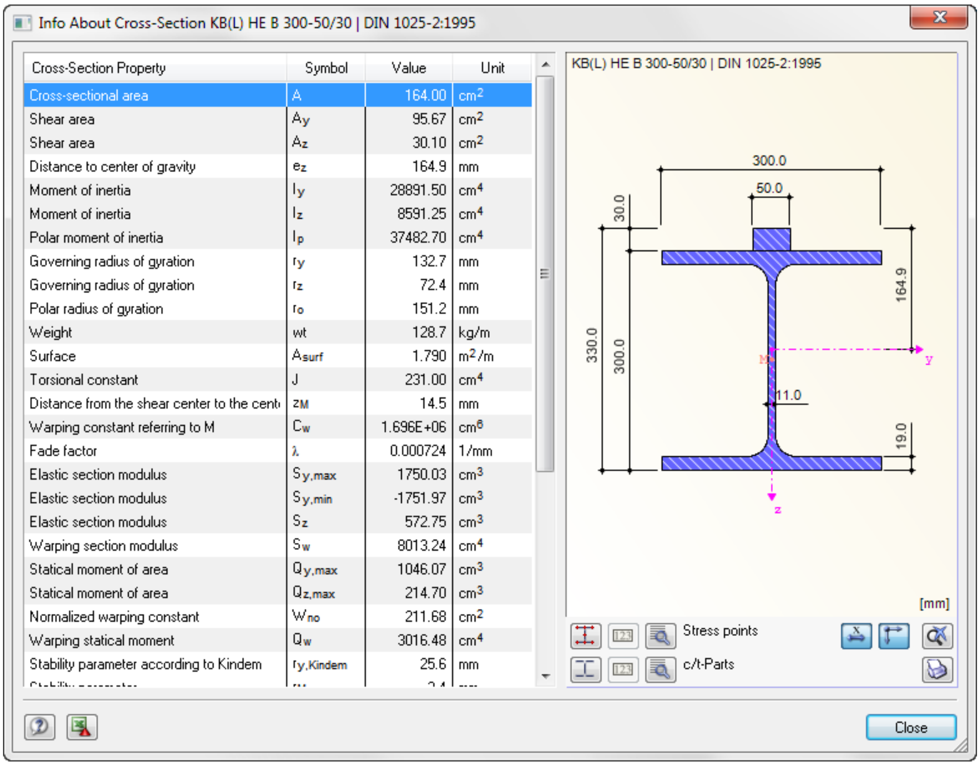


Figure 2.22: Dialog box *Info About Cross-Section*

This dialog box provides also information about the *Stress points* and *c/t-Parts*.

The buttons below the graphic have the following functions:

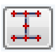
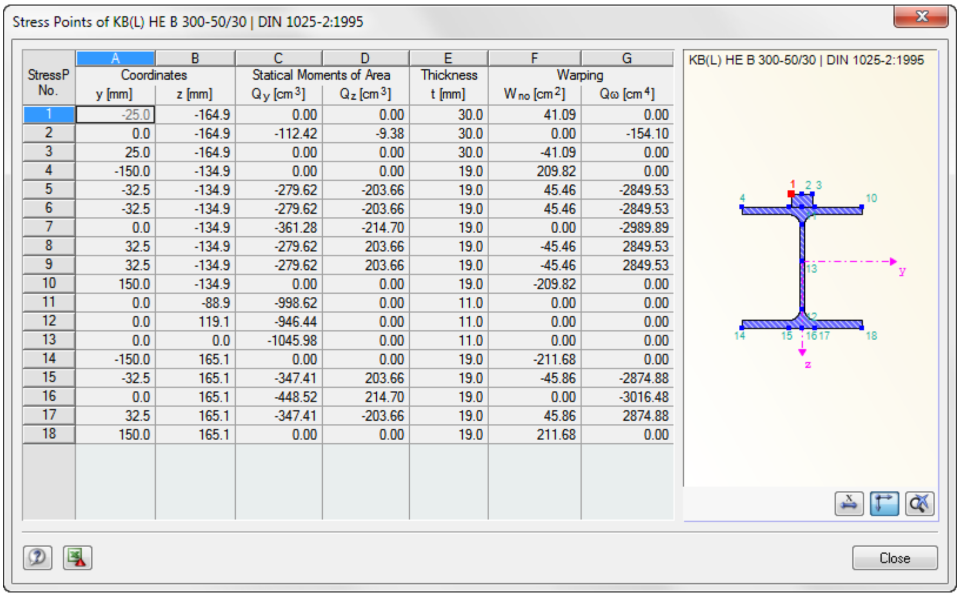
Button	Function
	Displays or hides the stress points
	Displays or hides the c/t-parts
	Displays or hides the numbers of stress points or c/t-parts
	Shows details of the stress points or c/t-parts
	Displays or hides the dimensions of the cross-section
	Displays or hides the principal axes of the cross-section
	Shows entire graphic of the cross-section

Table 2.1: Buttons in the dialog box *Info About the Cross-Section*

If you activate the buttons [Stress Points on/off] and [Numbering], all automatically created stress points are displayed in the cross-section graphic.

If you click [Details of Stress Points], a dialog box opens showing the coordinates, statical moments of area, thicknesses, and warping ordinates of the stress points.



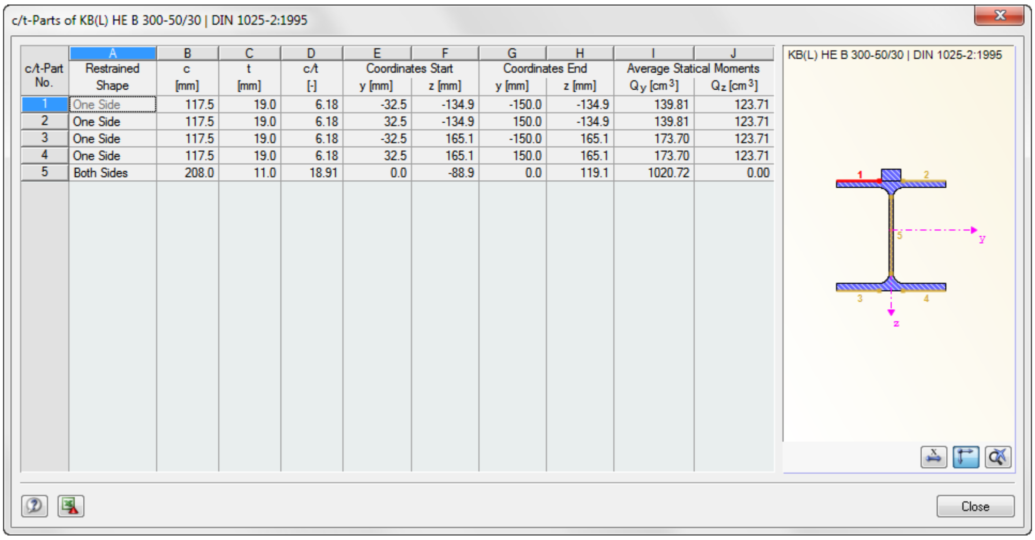
Stress Points of KB(L) HE B 300-50/30 | DIN 1025-2:1995

StressP No.	A Coordinates y [mm]	B z [mm]	C Statical Moments of Area Q_y [cm³]	D Q_z [cm³]	E Thickness t [mm]	F Warping W_{no} [cm²]	G Q_ω [cm⁴]
1	-25.0	-164.9	0.00	0.00	30.0	41.09	0.00
2	0.0	-164.9	-112.42	-9.38	30.0	0.00	-154.10
3	25.0	-164.9	0.00	0.00	30.0	-41.09	0.00
4	-150.0	-134.9	0.00	0.00	19.0	209.82	0.00
5	-32.5	-134.9	-279.62	-203.66	19.0	45.46	-2849.53
6	-32.5	-134.9	-279.62	-203.66	19.0	45.46	-2849.53
7	0.0	-134.9	-361.28	-214.70	19.0	0.00	-2989.89
8	32.5	-134.9	-279.62	203.66	19.0	-45.46	2849.53
9	32.5	-134.9	-279.62	203.66	19.0	-45.46	2849.53
10	150.0	-134.9	0.00	0.00	19.0	-209.82	0.00
11	0.0	-88.9	-998.62	0.00	11.0	0.00	0.00
12	0.0	119.1	-946.44	0.00	11.0	0.00	0.00
13	0.0	0.0	-1045.98	0.00	11.0	0.00	0.00
14	-150.0	165.1	0.00	0.00	19.0	-211.68	0.00
15	-32.5	165.1	-347.41	203.66	19.0	-45.86	-2874.88
16	0.0	165.1	-448.52	214.70	19.0	0.00	-3016.48
17	32.5	165.1	-347.41	-203.66	19.0	45.86	2874.88
18	150.0	165.1	0.00	0.00	19.0	211.68	0.00

Figure 2.23: Dialog box *Stress Points*

After you activate the buttons [c/t-Parts] and [Numbering], the c/t-parts of the cross-section are displayed in the cross-section graphic.

You can display the width c to thickness t ratio of all c/t-parts in a table by clicking the [Details] button. These values can be compared for example with [1] Part 1, Table 12.



c/t-Parts of KB(L) HE B 300-50/30 | DIN 1025-2:1995

c/t-Part No.	A Restrained Shape	B c [mm]	C t [mm]	D c/t [-]	E Coordinates Start y [mm]	F z [mm]	G Coordinates End y [mm]	H z [mm]	I Average Statical Moments Q_y [cm³]	J Q_z [cm³]
1	One Side	117.5	19.0	6.18	-32.5	-134.9	-150.0	-134.9	139.81	123.71
2	One Side	117.5	19.0	6.18	32.5	-134.9	150.0	-134.9	139.81	123.71
3	One Side	117.5	19.0	6.18	-32.5	165.1	-150.0	165.1	173.70	123.71
4	One Side	117.5	19.0	6.18	32.5	165.1	150.0	165.1	173.70	123.71
5	Both Sides	208.0	11.0	18.91	0.0	-88.9	0.0	119.1	1020.72	0.00

Figure 2.24: Dialog box *c/t-Parts*

Additional Designs

Perform fatigue design

In addition, you can perform a fatigue design.

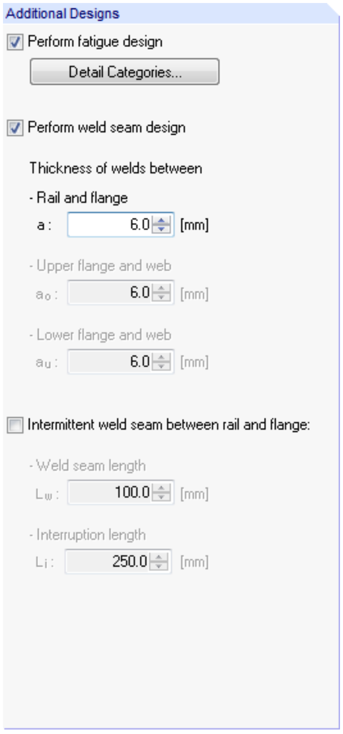


Figure 2.25: Section *Fatigue design* (for EN 1993-6)

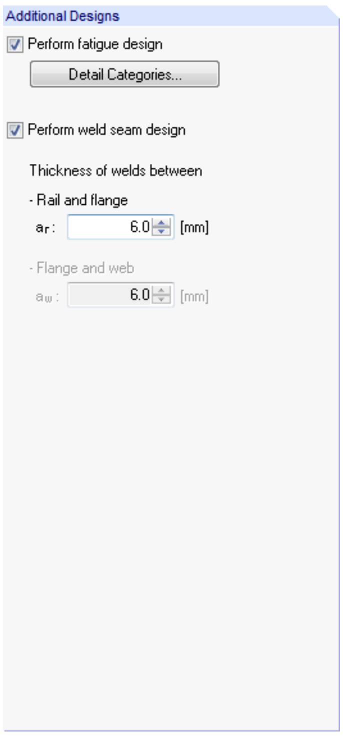
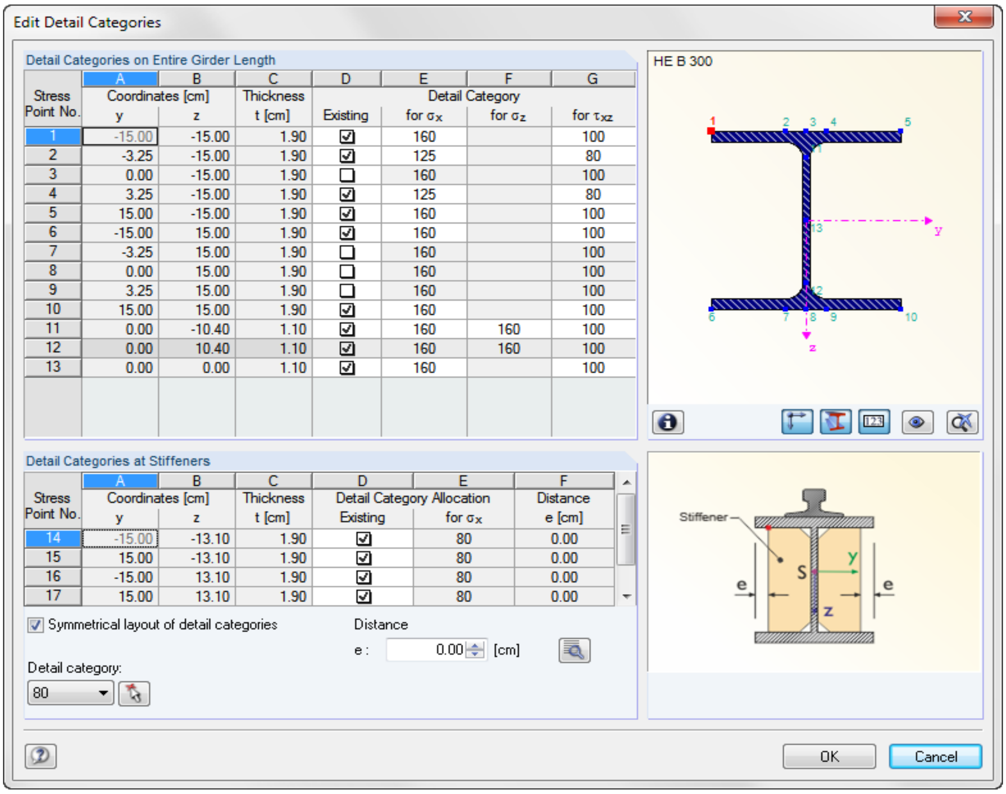


Figure 2.26: Section *Fatigue design* (for DIN 4132)

Detail Categories...

If you select this check box, the [Detail Categories] button becomes available. By clicking it, you open the *Edit Detail Categories* dialog box, where you can specify settings for the relevant stress points.



Stress Point No.	A Coordinates [cm] y	B z	C Thickness t [cm]	D Existing	E Detail Category for σ_x	F for σ_z	G for τ_{xz}
1	-15.00	-15.00	1.90	☑	160		100
2	-3.25	-15.00	1.90	☑	125		80
3	0.00	-15.00	1.90	☐	160		100
4	3.25	-15.00	1.90	☑	125		80
5	15.00	-15.00	1.90	☑	160		100
6	-15.00	15.00	1.90	☑	160		100
7	-3.25	15.00	1.90	☐	160		100
8	0.00	15.00	1.90	☐	160		100
9	3.25	15.00	1.90	☐	160		100
10	15.00	15.00	1.90	☑	160		100
11	0.00	-10.40	1.10	☑	160	160	100
12	0.00	10.40	1.10	☑	160	160	100
13	0.00	0.00	1.10	☑	160		100

Stress Point No.	A Coordinates [cm] y	B z	C Thickness t [cm]	D Detail Category Allocation Existing	E for σ_x	F Distance e [cm]
14	-15.00	-13.10	1.90	☑	80	0.00
15	15.00	-13.10	1.90	☑	80	0.00
16	-15.00	13.10	1.90	☑	80	0.00
17	15.00	13.10	1.90	☑	80	0.00

Figure 2.27: Dialog box *Edit Detail Categories*

The upper table lists the automatically generated stress points including the automatic assignment of the detail categories for the fatigue design. If you select a stress point in column D *Existing*, the appropriate detail category can be assigned.

Due to the great additional normal stresses σ_z, it is necessary (unlike for the upper flange) to specify a detail category for stress in z-direction.

...

If you click in a cell in column E or F to specify the detail category, the buttons [▼] and [...] appear in the cell. [▼] opens a drop-down list in which you can select the desired detail category; [...] opens a dialog box with an abstract from [2] or [8]. This dialog box also allows you to select the appropriate detail category.

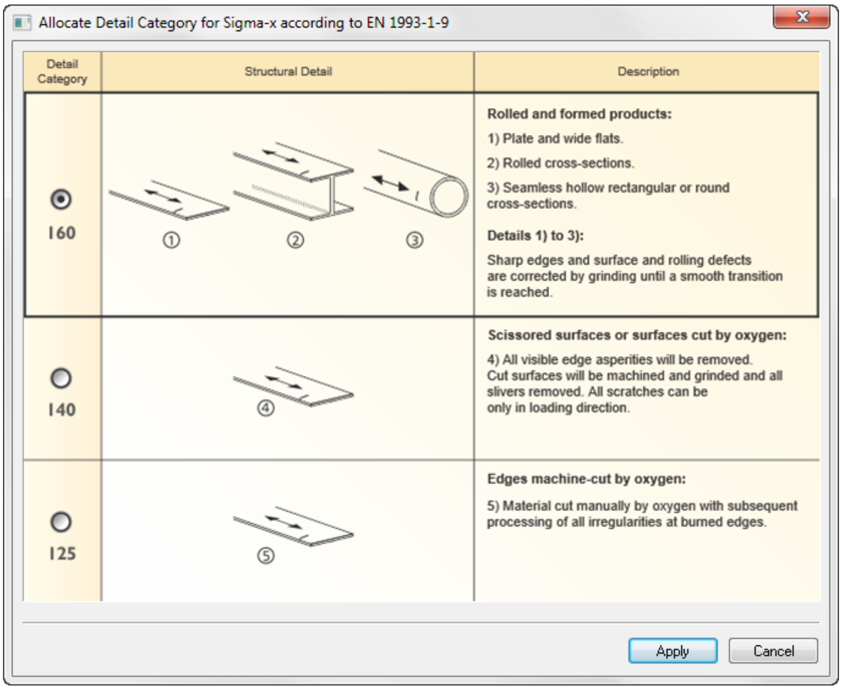


Figure 2.28: Dialog box *Allocate Detail Category according to EN 1993-1-9*

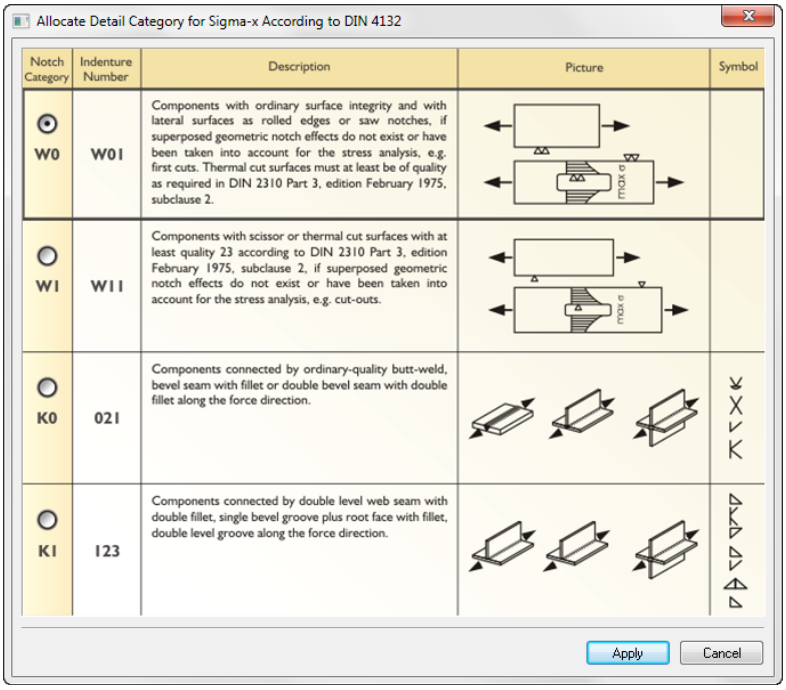


Figure 2.29: Dialog box *Allocate Detail Category according to DIN 4132*

In the lower table of the *Edit Detail Categories* dialog box (see Figure 2.27), you can define the stress points at stiffeners with the corresponding detail categories for fatigue design. Only the stress points at the x-locations of stiffeners are considered. The relevant detail category must also be assigned to these stress points. By clicking [...], you access the abstract from [2] or [8], which can help you with the selection of the detail category.

The stress points and detail categories are preset for the stiffeners; you can, however, edit their coordinates and numbers. If you select the option *Symmetrical layout of detail categories*, the data for the distance *e* and the detail categories for all stress points of the stiffeners is changed. Then, you can use the input field *Distance e* and the *Detail category* drop-down list located below the table with new stress points.

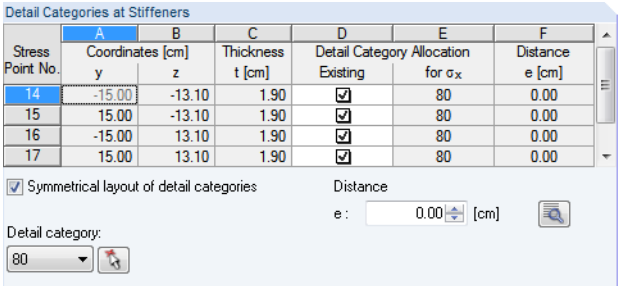


Figure 2.30: Section *Notch Categories at Stiffeners* for *Symmetrical layout of notch categories*

If you clear the selection of the check box *Symmetrical layout of detail categories*, the columns E and F for each stress point of the stiffeners become available. They allow you to define a detail category and a distance *e* for each stress point.

By clicking [Details] in this section, you open a dialog box with the coordinates and static properties of these stress points arranged in a table.

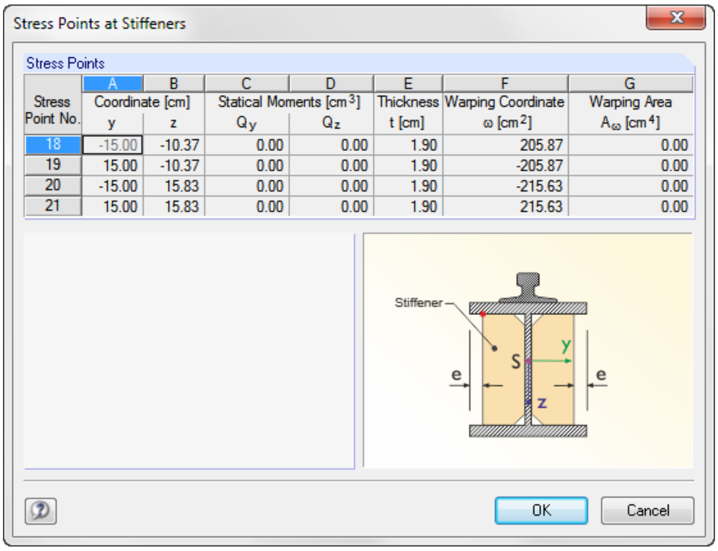


Figure. 2.31: Dialog box *Stress Points at Stiffeners*

Perform weld seam design

If you select the check box *Perform weld seam design*, you can define the thickness of the weld seam between rail and flange. For a welded cross-section, you can also specify the weld thicknesses between rail and flange.

Figure 2.32: Section *Additional Designs*

The *Intermittent weld seam* is appropriate for cases in which the weld seam between the crane rail and flange is not continuous. A parallel opposing arrangement is assumed. After you select the check box, you can specify the length of the weld seam and the interruption. These specifications are considered in the design.

Options

This section provides two check boxes relevant for rail sections.

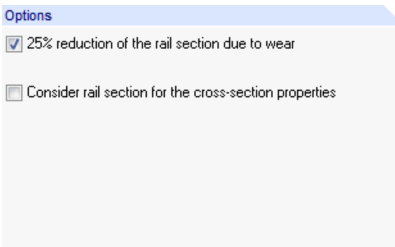


Figure 2.33: Section *Option*

If you select the check box *25% reduction of the rail section due to wear*, a reduced cross-section will be considered for the rail or splice. In this way, the cross-section SA 45 (worn-out) for rail SA 45 or the splice 50/30 for splice 50/40, for example.

If you select the check box *Consider rail section for the cross-section properties*, not only the increased cross-section properties will be considered, but also the crane loads will be related to the upper rail edge.

2.4 Loading

In Window 1.4, you define the loadings applied to the crane runway girders.

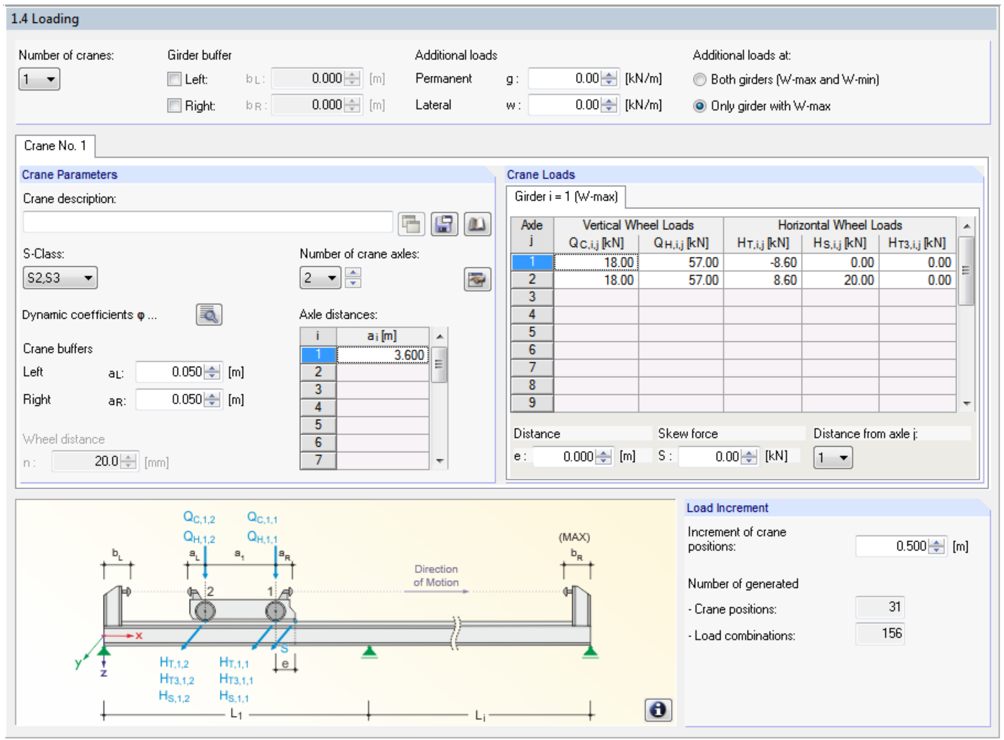


Figure 2.34: Window 1.4 *Loading*

By using the *Number of cranes* drop-down list, you can define how many cranes can travel together on the same crane runway girder (the maximum is three cranes). If there are *Girder buffers* keeping the crane from driving outside the girder on the left or right end, the number of the load combinations is reduced.

In addition to the loading due to crane operation, two *Additional loads* can be defined: permanent load *g* and lateral load *w* (wind). The self-weight need not be defined as permanent load, because it is considered automatically. The lateral load is applied as variable line load in the center of gravity.

The two options in the right upper corner help to differentiate between the loads applied on the crane runway girder: If the design of the crane runway girder with the maximum wheel loads is sufficient, you can select the *Only girder with* W_{max} option. However, if it is not clear, which loads are governing on which girder, the conservative option *Crane loads at both girders* (W_{max} *and* W_{min}) should be selected. Thus, the number of load combinations also increases.

The middle part of this window includes two sections, where you can define the *Crane Parameters* and *Crane Loads*.

By clicking [Copy], you can copy the input parameters of the crane No. 1 to the second or the third crane. You can always switch between the cranes by clicking the respective tab.

You can select a crane by using the [Library] button that opens the according dialog box. For DIN 4132, a *Database* with cranes from the producers DEMAG and KÜHNEZUG is available. The parameters can also be *user-defined* and [Saved] for later usage.

Crane Parameters

The input fields of this section are dependent on the selected standard.

DIN 4231

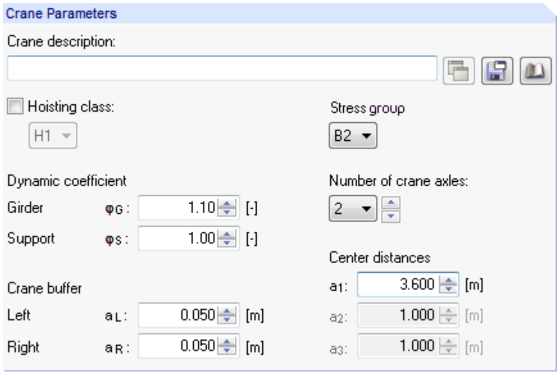


Figure 2.35: Section *Crane Parameters*

The *Hoisting class* (H1 through H4) determines the value of the *Dynamic coefficient*. The selection of the hoisting class becomes available after you select the check box. Otherwise, you enter the *Dynamic coefficient* for the girder and the support manually.

The *Stress group* (B1 through B6) influences the value of the allowable stresses for the fatigue design. If the stress group is B4 to B6, the program considers the eccentric load application at ¼ of the rail head width according to [2].

For one crane, the *Number of crane axles* cannot be higher than four. Furthermore, you can enter the *Axle distances* and the distance of *Crane buffers*.

EN 1993-6

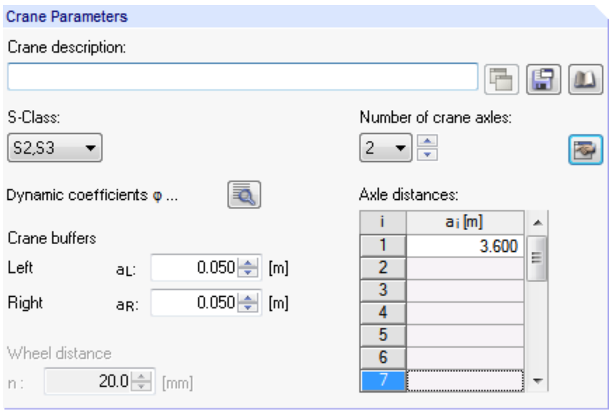


Figure 2.36: Section *Crane Parameters*

In the *S-Class* list, you can select the relevant stress group (damage group). For the stress groups S4 (S3 according to DIN) through S9, CRANEWAY considers the eccentric load application of ¼ of the rail head width according to [5] and [8].

You can specify up to 20 *Crane axles* for each crane. In the table or the input fields below, you can enter the according *Axle distances* and the distances of the *Crane buffers*.

By clicking [Grouping Wheels], you open a dialog box where you can define wheel groups. The dialog box is shown in the following figure.

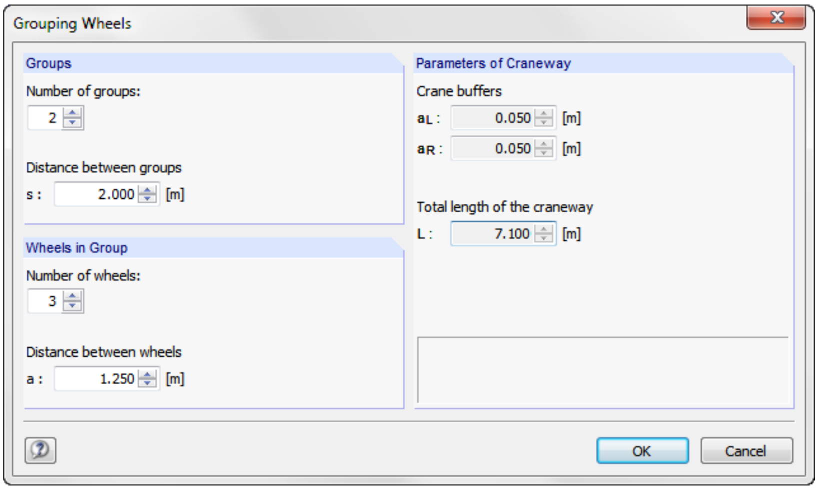


Figure 2.37: Dialog box *Grouping Wheels*

In the *Groups* section, you specify the number and distance between the groups. In the *Wheels in Group* section, you can specify the number of wheels and the distance between them (axle distance). The *Parameters of Craneway* section shows the resulting crane length with the crane buffers used.

By clicking [Edit Dynamic Coefficients] in the *Crane Parameters* section (Figure 2.36), you open a dialog box where you can specify the dynamic coefficients φ of the crane runway beam according to [5].

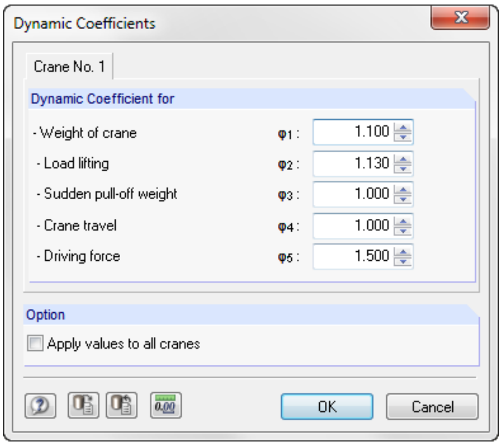


Figure 2.38: Dialog box *Dynamic Coefficients*

Crane Loads

The input of the *Crane Loads* differs depending on the selected standard:

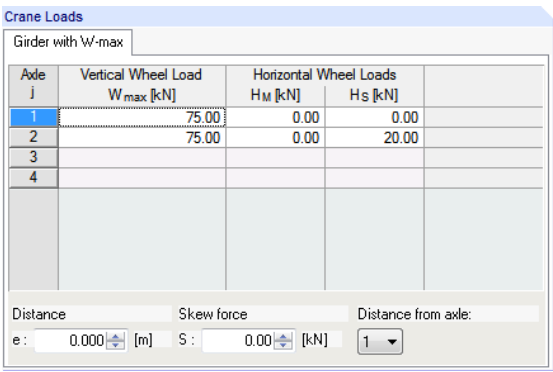


Figure 2.39: Section *Crane Loads* according to DIN 4132

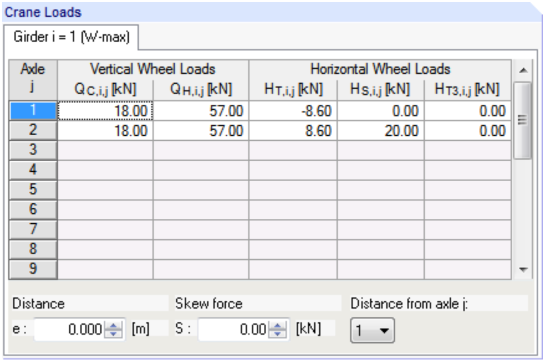
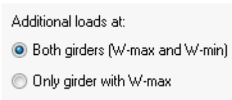


Figure 2.40: Section *Crane Loads* according to EN 1993-6

For each wheel, all applied loads must be specified. For the calculation according to **DIN 4132**, these are the maximum *Vertical Wheel Loads W* and the *Horizontal Wheel Loads* from the inertial forces caused by operation H_M and the *Skew force* H_S and *S*.

For **EN 1993-6**, you must define the maximum *Vertical Wheel Loads* Q_c (due to self-weight of the crane*) and* Q_H *(due to hoist load)*, *the Horizontal Wheel Loads* H_T *(*due to acceleration and braking of the crane bridge*),* H_{T3} *(*due to acceleration and braking of the crane trolley or the hoist*), and the Skew forces* H_S *and* S.

All loads act on the top of the rail: The skew force can be applied independently of other loads (for example for guide rollers) with a different distance from the axle. In such a case, you define the *Distance e* of the load application point of S to the selected *Axle*.



If you activate the option **Additional loads at both girders (**W_{max} **and** W_{min}**)**, a second tab becomes available. There, you can specify the minimum *Vertical* and the according *Horizontal Wheel Loads*.

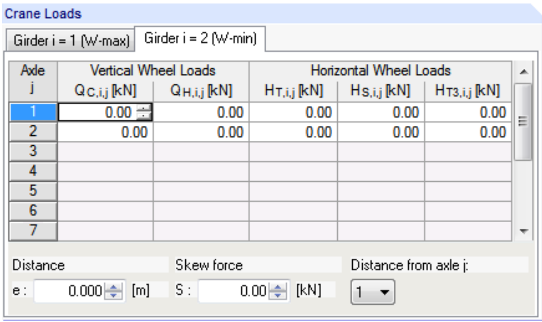


Figure 2.41: Section *Crane Loads* if option *Additional loads at both girders* is selected

Load Increment

This section controls the increment of the crane load positions.

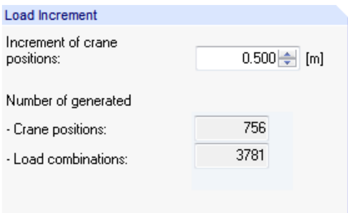


Figure 2.42: Section *Load Increment*

The default distance is 50 cm. When defining the load increment, remember that all generated load combinations must be calculated. The *Number of generated crane positions* and *Load combinations* is dependent on the geometry of the runway beam, the loads to be considered, and the load increment.

2.5 Load Cases

The dynamic 1.5 *Load Cases* window provides an overview of the action situations with all loads and load combinations.

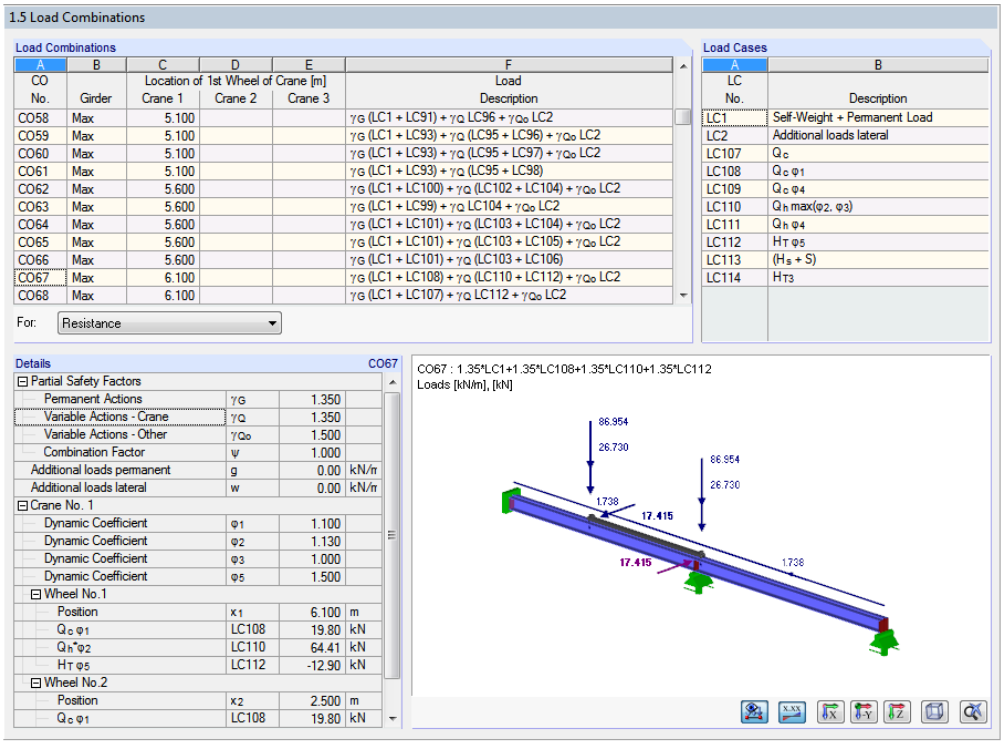
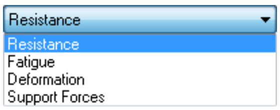


Figure 2.43: Window 1.5 *Load Cases*

Load Combinations

The row selected in this section determines the content of all other sections. The corresponding load cases, details, and load graphic are dynamically displayed for the selected load combination.

Load combination for calculation



From the drop-down list located below the *Load Combinations* table, you can select the design situation whose load combinations you want to be displayed: *Resistance, Fatigue* (EN 1993-6), *Deformation,* and *Support Forces*.

Load Cases

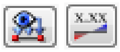
This section lists all load cases which are used in the current load combination (that is, the CO selected in the table to the left).

Details

This section lists the partial safety factors and dynamic coefficients as well as the loads of the current load combination. When you select another load combination or design situation, the graphic is updated.

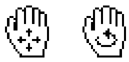
Preview

The graphic shows the current design situation in 3D-rendering.



The load action and load values can be displayed or hidden by using the [Loads] and [Show Value] buttons.

Use the **mouse wheel** to zoom, move, or rotate the view. The position of the pointer is always assumed as center of the zoom area.



Press the wheel button to move the model directly within the workspace, that is, without previously activating the toolbar button [Move, Zoom]. If you additionally press the [Ctrl] key, you can rotate the model. Rotating the model is also possible by moving the mouse while pressing the wheel button the right mouse button at the same time. The mouse pointer symbols are indicating the selected function.

2.6 Imperfections

In this window, you can define the initial imperfections of the girder according to EN 1993-1-1 [7] or DIN 18800 Part 2 [1]. They are needed for the second-order flexural-torsional buckling analysis. The imperfections will be created from the camber rise of the local bow imperfection.

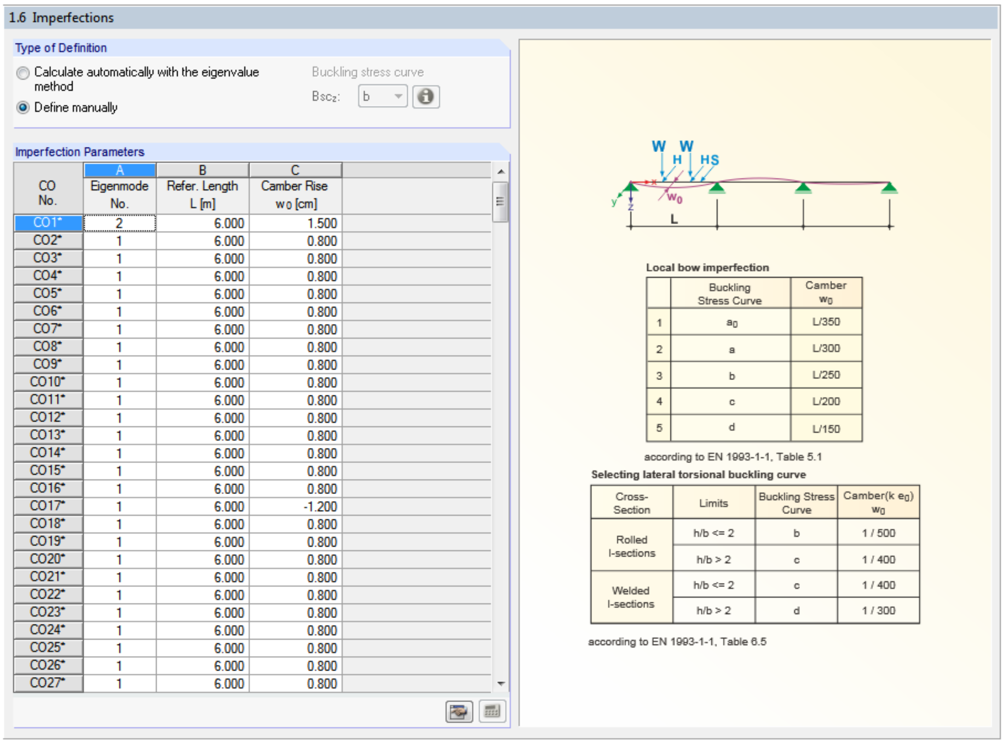


Figure 2.44: Window 1.6 *Imperfections*

Type of Definition

If you select the option *Calculate automatically with the eigenvalue method*, CRANEWAY determines the appropriate imperfection (shape, camber rise, and direction) for each load combination. They are considered in the second-order analysis, always applying the first eigenmode.

If you select the *Define manually* option, you first decide whether the imperfections should be determined automatically first.

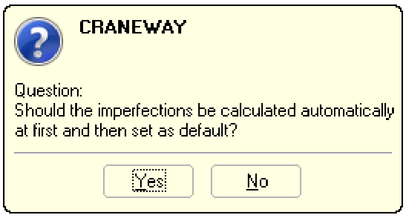


Figure 2.45: Question for option *Define manually*

Then you can manually define or edit the imperfection parameters.

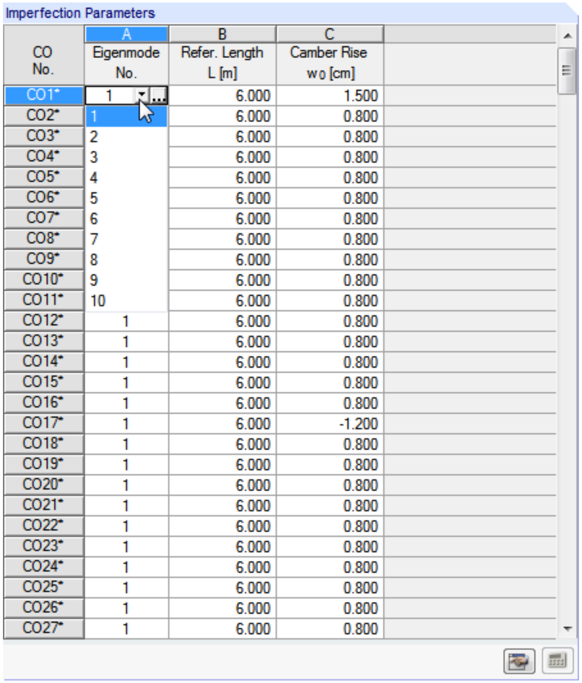
The *Buckling stress curve* Bsc_z is always automatically preset. It is dependent on the selected cross-section with consideration of the rail section. The [Info] button opens the *Info About Cross-Section* dialog box, where the buckling stress curve of the cross-section is also listed (see Figure 2.22, page 19).

Imperfection Parameters

In this section, you can edit the imperfections for all load combinations. For the type of definition *Calculate automatically with the eigenvalue method*, the table is disabled and filled with question marks before the calculation.

After the calculation or by clicking [Calculation], the question marks will be replaced by the determined imperfection parameters.

For the type of definition *Define manually*, the imperfection parameters are available so that the higher eigenmodes can be used. For the selection of the eigenmode, you can use a list, which you open by clicking [▼].



Imperfection Parameters

CO No.	A Eigenmode No.	B Refer. Length L [m]	C Camber Rise w0 [cm]
CO1*	1	6.000	1.500
CO2*	1	6.000	0.800
CO3*	2	6.000	0.800
CO4*	3	6.000	0.800
CO5*	4	6.000	0.800
CO6*	5	6.000	0.800
CO7*	6	6.000	0.800
CO8*	7	6.000	0.800
CO9*	8	6.000	0.800
CO10*	9	6.000	0.800
CO11*	10	6.000	0.800
CO12*	1	6.000	0.800
CO13*	1	6.000	0.800
CO14*	1	6.000	0.800
CO15*	1	6.000	0.800
CO16*	1	6.000	0.800
CO17*	1	6.000	-1.200
CO18*	1	6.000	0.800
CO19*	1	6.000	0.800
CO20*	1	6.000	0.800
CO21*	1	6.000	0.800
CO22*	1	6.000	0.800
CO23*	1	6.000	0.800
CO24*	1	6.000	0.800
CO25*	1	6.000	0.800
CO26*	1	6.000	0.800
CO27*	1	6.000	0.800

Figure 2.46: Selection of *Eigenmode*

Using the manual definition, you also can determine the camber rise according to [7] or [1]: By clicking the [...] button in a cell of the camber rise or the [Edit] button at the end of the table, you open the following dialog box.

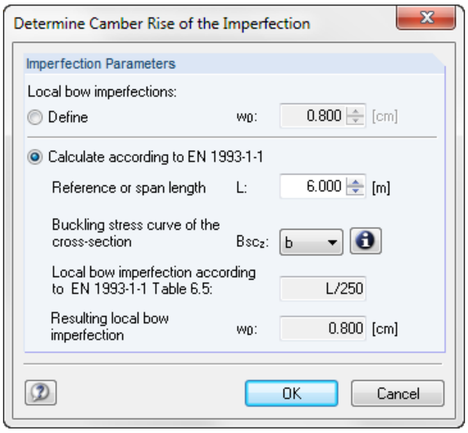


Figure 2.47: Dialog box *Determine Camber Rise of the Imperfection*

If you open the dialog box from a *Camber Rise* cell, the determined value will be assigned only to the current load combination. If you open this dialog box clicking [Edit] at the end of the table, the value will be assigned to all load combinations.

3. Calculation

3.1 Detail Settings

Before you start the [Calculation], check the design details first. To this end, open the according dialog box by clicking [Details]. This button is available in all windows.

The content of this dialog box depends on the Standard selected for design.

3.1.1 EN 1993-6

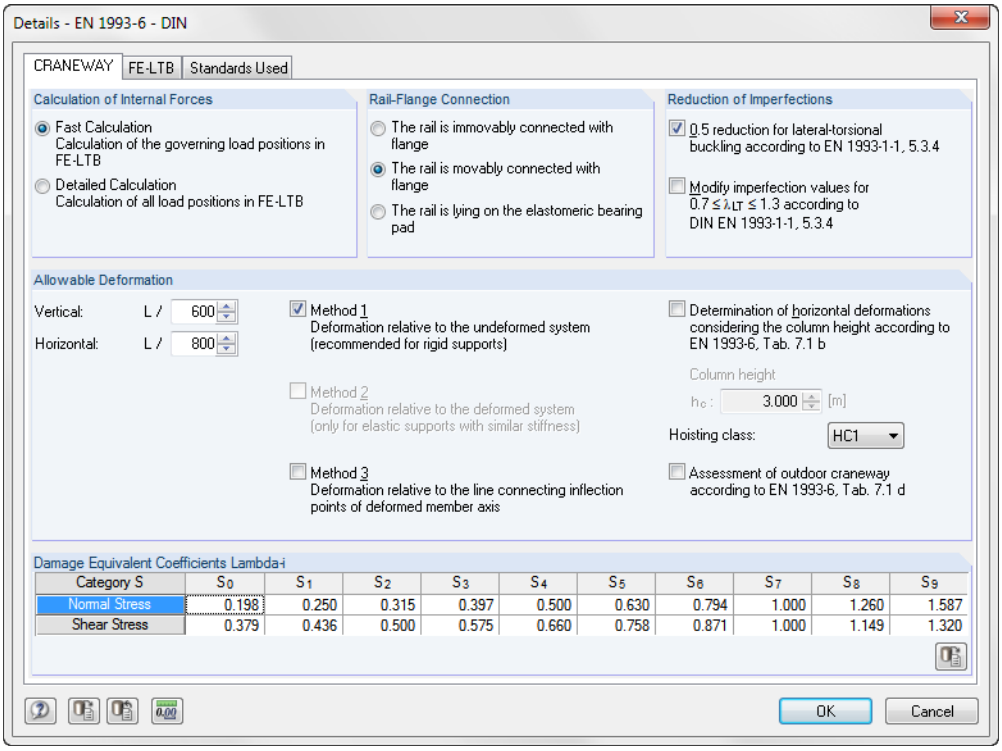


Figure 3.1: Dialog box *Details*, tab *CRANEWAY* for EN 1993-6

Calculation of Internal Forces

You can choose between two calculation methods. The *Detailed Calculation* analyzes all load combinations according to the second-order analysis for warping torsion, while the *Fast Calculation* only according to the linear-static analysis. From these results, the governing load combinations are selected, which are then used for the second-order analysis for warping torsion.

Rail-Flange Connection:

The settings in this section control the effective width of the wheel load distribution on the upper flange according to [6] clause 5.7. The equations implemented for these three options are according to [6] Table 5.1.

Reduction of Imperfections

According to [7] clause 5.3.4, the camber rise of the bow imperfection about the minor axis of the structural component can be reduced by coefficient *k* for lateral-torsional buckling. The recommended value is 0.5.

Allowable Deformation

For the determination of the limit deformations, you can select one of three methods:

Method 1: allowable deformations are relative to the undeformed system and its member axes. This approach is suitable for rigid supports, because the displacements at the support nodes in Z-direction are zero.

Method 2: limit deformations are determined relative to the deformed system. You can select this check box only if you defined spring constants for the supports.

Method 3: inflection points of the deflection curve are calculated and the allowable deformations are relative to the according lengths.

In addition, the allowable deformations can be determined *considering the column height*. Optionally, it is also possible to perform an *Assessment of outdoor craneway* according to [6] Table 7.1 d.

Damage Equivalent Coefficients λ_i

These coefficients are required for the calculation of the damage equivalent stress range in fatigue design and are taken from [5], Table 2.12. The default coefficients can be edited, if necessary.

3.1.2 DIN 4231

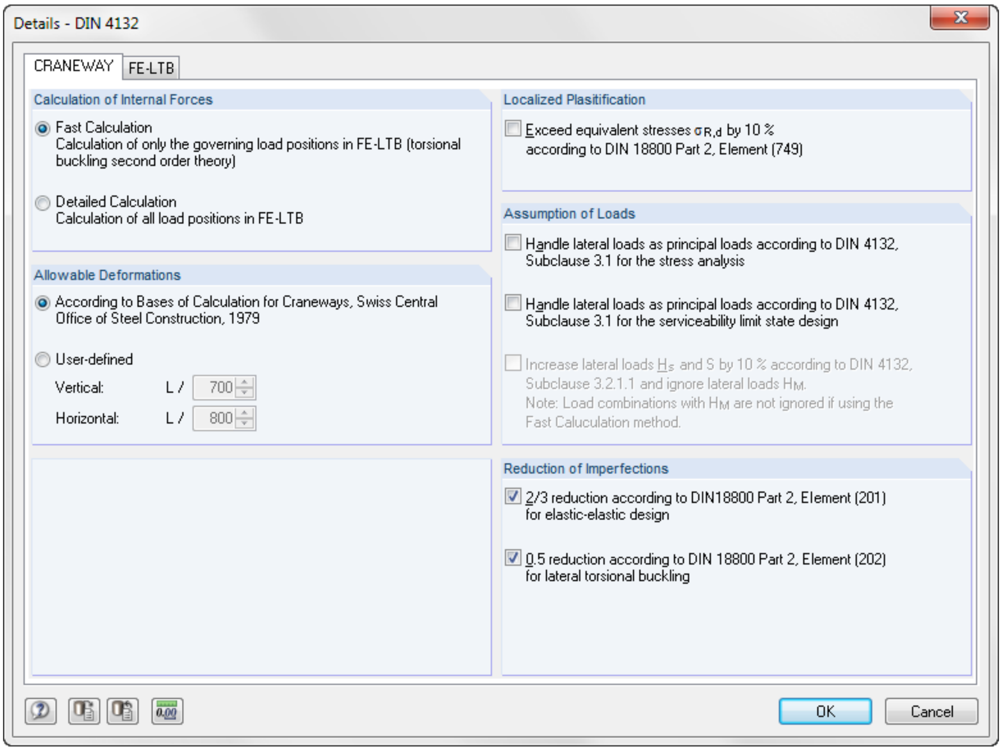


Figure 3.2: Dialog box *Details*, tab *CRANEWAY* for DIN 4132

Calculation of Internal Forces

This section is described in chapter 3.1.1.

Allowable Deformation

The values of limit deformations can be defined *According to Bases of Calculation for Craneways, Swiss Central Office of Steel Construction* [15] or *User-defined* for the vertical and horizontal directions.

Localized Plastification

If you select this check box, the *equivalent stresses $\sigma_{R,d}$ can be exceeded by 10 %*. In the stress analysis, the stresses σ_x and σ_{eqv} are then compared with the increased limit stresses. The stresses σ_z, on the other hand, are compared to the usual (not increased) limit stresses.

Assumption of Loads

The *Calculation of Internal Forces* (see dialog section to the left) controls which check boxes can be accessed here.

The option *Handle lateral loads as principal loads for the stress analysis* specifies that the horizontal inertial forces caused by operation and the wheel loads will be regarded as one load. If they occur simultaneously, these actions will therefore not be multiplied by the combination coefficient ψ in the determination of the internal forces.

The option *Handle lateral loads as principal loads for the serviceability limit state design* specifies that the horizontal inertial forces due to operation will be considered in the fatigue design. Thus, not only the load combination with vertical wheel loads (fundamental combination 1), but also the load combinations with the horizontal inertial forces due to operation (fundamental combination 2) will be analyzed in the fatigue design.

While the first two check boxes need to be selected only rarely, it is always recommended to select the option *Increase lateral loads H_S and S by 10% and ignore lateral loads H_M*. However, this check box is accessible only for the *Detailed Calculation* option (see dialog section to the left).

According to [2], the possible superposition of the lateral forces from operation and from skew forces may be considered in this way. Only the increase of skew forces by 10% is carried out in CRANEWAY. The Fundamental combinations 1 and 2 remain unchanged. Therefore, only the internal forces for fundamental combination 3 will change.

Reduction of Imperfections

The settings in this section have an effect only on the automatic determination of the imperfections. Smaller camber rises of the bow imperfections can be achieved by both options *2/3 reduction for elastic-elastic design* and *0.5 reduction for lateral torsional buckling*.

3.1.3 FE-LTB

The second tab of the *Details* dialog box is independent of the selected design standard. It controls the calculation parameters of the integrated module FE-LTB.

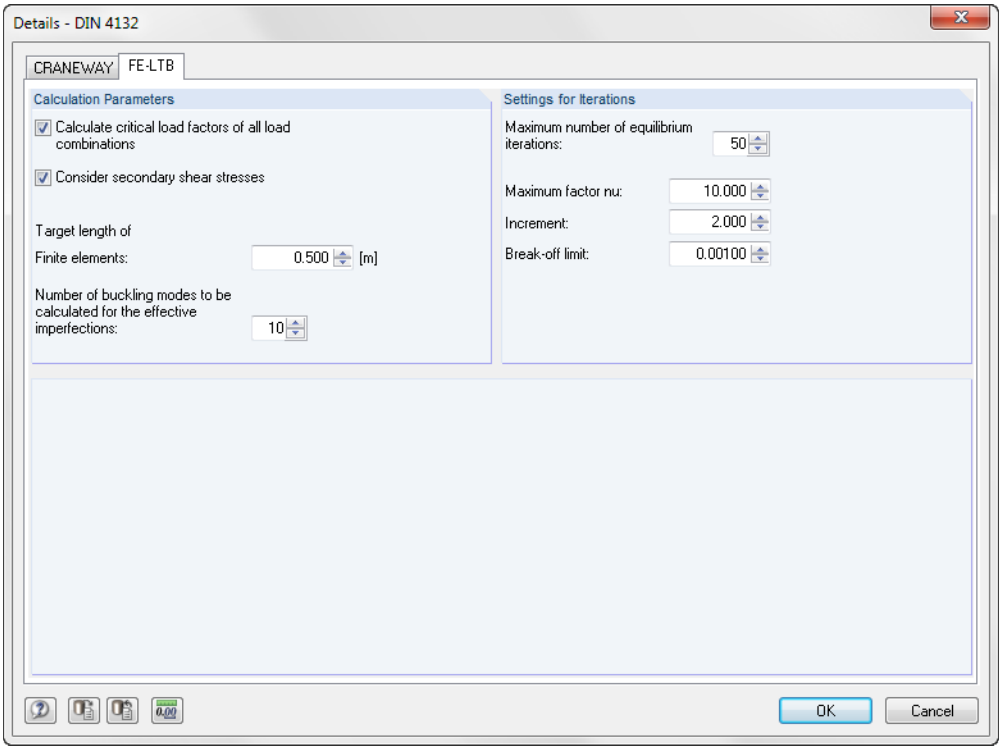


Figure 3.3: Dialog box *Details*, tab *FE-LTB*

FE-LTB is an analysis core that determines the internal forces according to the second-order analysis for warping torsion and therefore is suited for the lateral-torsional analysis of crane runway beams.

Calculation Parameters

You have to select whether or not CRANEWAY should *Calculate critical load factors of all load combinations*. If you select this check box, the program checks whether or not a stability failure occurs under the defined external action: If the critical load factor is less than 1, a warning appears and the calculation is stopped.

The check box *Consider secondary shear stresses* applies for the shear stresses due to the secondary torsional moment $M_{T,s}$. If the check box is not selected, only the shear stresses due to the shear forces and the first torsional moment $M_{T,p}$ are determined.

The *Target Length of Finite Elements* check box controls the length of the finite elements of the crane runway girder. The length of the element should not be greater than $^1/_8$ of the span: Usually, 8 elements for each girder span are enough to calculate the deformations with a deviation of less than 5% relative to the precise solution.

The *Number of buckling modes to be calculated for the effective imperfections* defines how many eigenmodes for the imperfections of the load combinations will be calculated (see Figure 2.46, page 33).

Settings for Iterations

This section controls the calculation of FE-LTB. The iterative determination of the deformations stops when the ratio of the displacement difference to the determined displacement in an iteration is smaller than the *Break-off limit*. At the latest, the calculation stops when the *Maximum number of equilibrium iterations* is reached and shows the result. The recommended values are **50** for the number of iterations and **0.001** for the break-off limit.

The values in the fields *Maximum factor nu* and *Increment* represent additional break-off criteria for the determination of the critical load factors and the increments of the load increase. CRANEWAY proceeds in the following way: First, it performs a calculation with the given loading. Then, in the determination of the critical load factor, the load is incrementally increased until the maximum factor nu is reached. As soon as the stability failure occurs, the program tries to distinguish more accurately between the two last increments of loading to determine the critical load factor as precisely as possible.

The recommended values are **10** for the maximum factor nu and **2** for the Increment.

3.2 Start Calculation

Calculation

To start the calculation, click the [Calculation] button, which is available in all input windows of CRANEWAY.

The process of the calculation is then displayed in a dialog box.

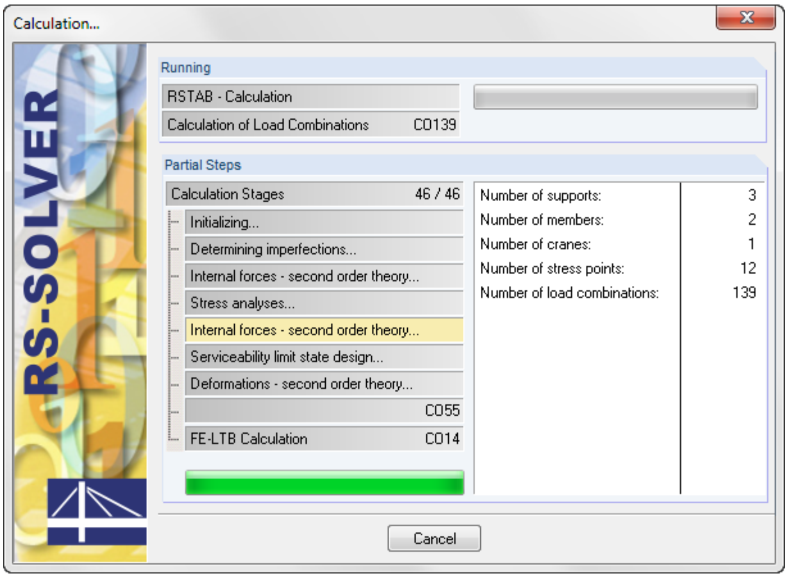


Figure 3.4: Dialog box *Calculation*

4. Results

After the calculation, the 2.1 *Design Summary* window appears.

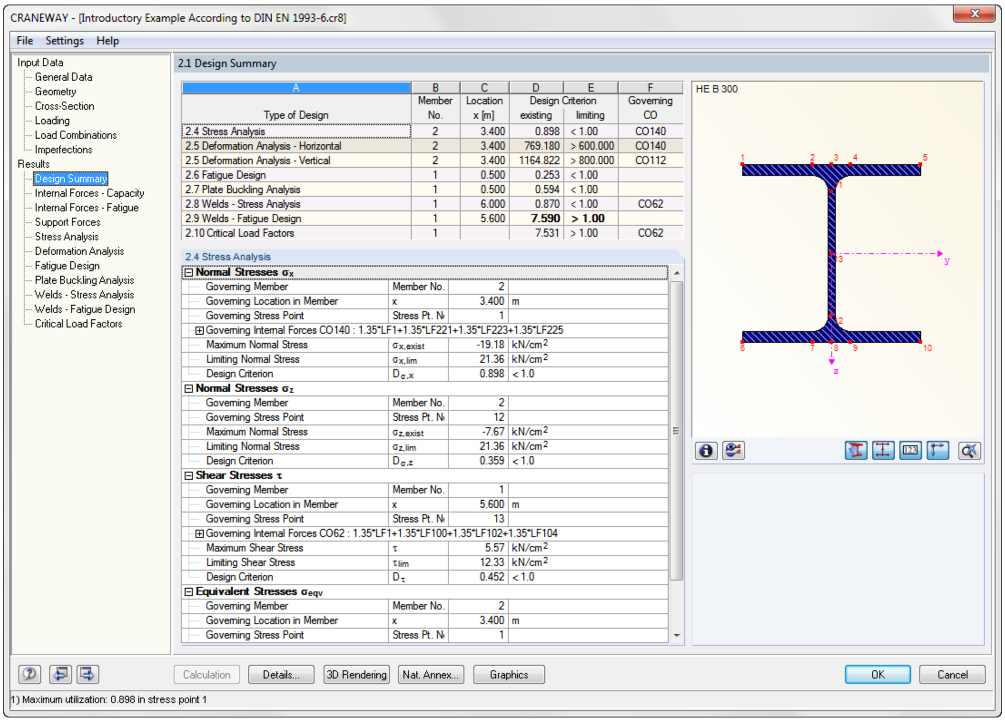
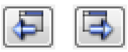


Figure 4.1: Results window with designs and results details

The results of the analysis are sorted by various criteria in the results windows 2.1 through 2.10.



You can select every window by clicking the corresponding entry in the navigator. In addition to that, you can use the buttons shown on the left to set the previous or next window. Alternatively, you can press the function keys [F2] and [F3].

Chapter 4 *Results* presents the results windows in their order. This chapter describes the results obtained according to **EN 1993-6**.

To save the results and exit CRANEWAY, click [OK].

4.1 Design Summary

The upper part of the window shows a summary of designs sorted by the governing design criteria. It provides an overview of all designs: Thus, you can see immediately which checks are satisfactory and which failed.

The lower part contains more detailed data about stresses, deformations, weld seams, etc. for the design selected in the upper part.

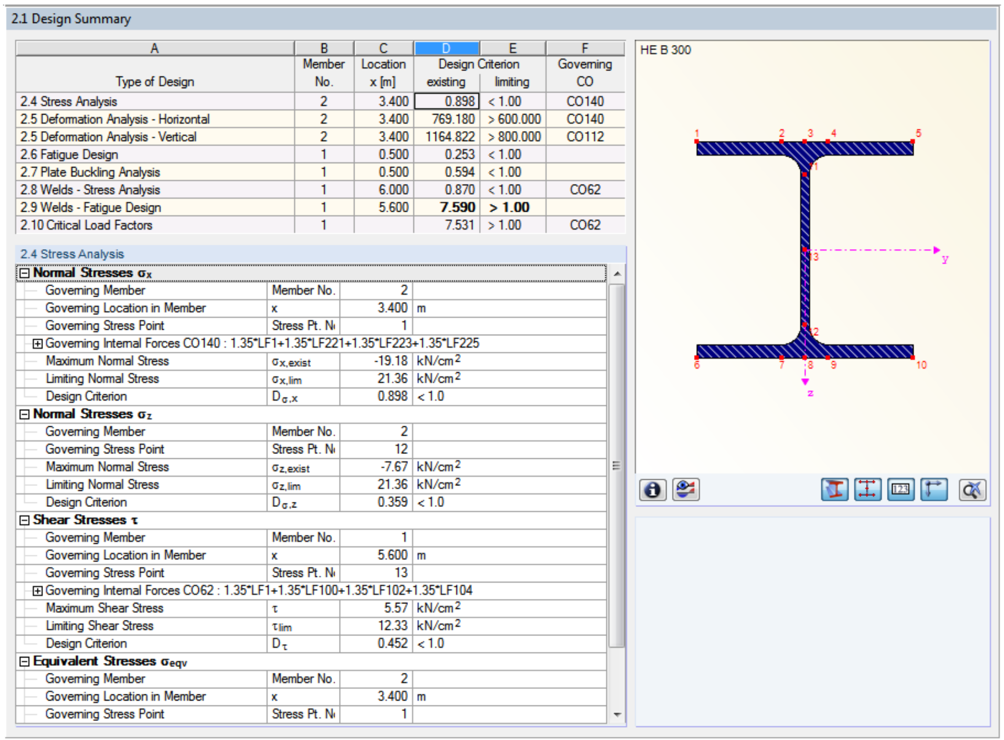


Figure 4.2: Window 2.1 *Design Summary*

Type of Design

The column shows the performed designs.

Member No.

This column displays the number of the member with the highest design criterion.

Location x

At this location of the member (relative to the member start), the maximum value was found.

Design Criterion

In columns D and E, the conditions of the design check are given according to the selected Standard. If the design criterion is not satisfied, the values will be displayed in **bold black** font.

Governing CO

The last column provides information about the load combinations whose internal forces are relevant for the respective designs.

4.2 Internal Forces

The internal forces are shown in two windows for the ultimate limit state (capacity) and fatigue design (if selected in module window 1.3 *Cross-Sections*).

4.2.1 Internal Forces - Capacity

In this window, you specify the internal forces of the calculated load combinations (load positions) that were determined for the ultimate limit state designs. You can show either *All* internal forces or *Only max/min-* values.

2.2.1 Internal Forces - Capacity

A	B	C	D	E	F	G	H	I	J	K
Member	Location	Govern.	Forces [kN]		Moments [kNm]			Moments [kNm², kNm]		
No.	x [m]	CO	V_y	V_z	M_T	M_y	M_z	M_ω	$M_{T,pri}$	$M_{T,sek}$
1	0.000	CO1	0.00	4.03	-0.03	0.00	0.00	0.00	-0.02	-0.01
		CO47	11.71	131.50	2.68	0.01	0.00	0.00	0.26	2.42
		CO57	10.45	92.98	1.70	0.01	0.00	0.00	0.67	1.03
		CO62	9.63	75.56	1.68	0.01	0.00	0.00	0.93	0.75
		CO70	13.32	53.58	2.70	0.01	0.01	0.00	1.76	0.94
		CO75	10.88	40.87	2.24	0.01	0.01	0.00	1.59	0.65
		CO82	5.65	21.80	1.06	0.00	0.00	0.00	0.86	0.21
		CO85	6.47	19.85	1.34	0.00	0.00	0.00	1.06	0.28
		CO107	0.67	-8.22	0.05	0.00	0.00	0.00	0.04	0.01
		CO112	-0.13	-9.48	-0.06	0.00	0.00	0.00	-0.05	-0.01
		CO122	-1.40	-8.38	-0.21	0.00	0.00	0.00	-0.18	-0.03
		CO140	-2.51	-4.85	-0.33	0.00	0.00	0.00	-0.27	-0.05
	0.500 l	CO1	0.00	3.13	-0.03	1.79	0.00	-0.01	-0.02	-0.01
		CO47	11.80	130.60	2.67	65.55	-5.90	1.23	0.13	2.54
		CO57	10.64	92.06	1.70	46.26	-5.32	0.53	0.61	1.09
		CO62	9.86	74.64	1.68	37.55	-4.93	0.38	0.89	0.79
		CO70	13.62	52.61	2.70	26.54	-6.81	0.48	1.71	0.99
		CO75	11.09	39.91	2.24	20.19	-5.54	0.33	1.56	0.68
		CO82	5.71	20.89	1.06	10.67	-2.86	0.11	0.85	0.22
		CO85	6.53	18.93	1.34	9.69	-3.26	0.14	1.04	0.30
		CO107	0.67	-9.12	0.05	-4.34	-0.33	0.00	0.04	0.01
		CO112	-0.12	-10.37	-0.06	-4.96	0.06	0.00	-0.05	-0.01
		CO122	-1.39	-9.27	-0.21	-4.41	0.70	-0.02	-0.18	-0.03
		CO140	-2.50	-5.74	-0.33	-2.65	1.25	-0.03	-0.27	-0.05
	0.500 r	CO1	0.00	3.13	-0.03	1.79	0.00	-0.01	-0.02	-0.01
		CO47	-5.70	16.97	-0.65	65.54	-5.90	1.23	0.13	-0.78
		CO57	10.64	92.06	1.70	46.26	-5.32	0.53	0.61	1.09
		CO62	9.86	74.64	1.68	37.55	-4.93	0.38	0.89	0.79
		CO70	13.62	52.61	2.70	26.54	-6.81	0.48	1.71	0.99
		CO75	11.09	39.91	2.24	20.19	-5.54	0.33	1.56	0.68
		CO82	5.71	20.89	1.06	10.67	-2.86	0.11	0.85	0.22
		CO85	6.53	18.93	1.34	9.69	-3.26	0.14	1.04	0.30
		CO107	0.67	-9.12	0.05	-4.34	-0.33	0.00	0.04	0.01
		CO112	-0.12	-10.37	-0.06	-4.96	0.06	0.00	-0.05	-0.01

Display: (•) All ( ) Max/min only

Figure 4.3: Window 2.2.1 *Internal Forces - Capacity* with option *All* Internal Forces

The internal forces are design values, that is, when determining these internal forces, all relevant partial safety factors, dynamic coefficients, and combination factors were taken into account. These internal forces are used for the stress analysis, the plate-buckling analysis, and the calculation of the critical load factor.

If you select the option *All*, CRANEWAY displays all determined internal forces at all x-locations for the considered load combinations (dependent on the calculation method *Fast Calculation* or *Detailed Calculation*).

If you select the option *Max/min only*, only the internal forces of the x-locations with the extreme values are displayed for each member.

2.2.1 Internal Forces - Capacity

A	B	C	D	E	F	G	H	I	J	K	L
Member No.	max min	Govern. CO	Location x [m]	Forces [kN] V_y	V_z	Moments [kNm] M_T	M_y	M_z	Moments [kNm², kNm] M_ω	$M_{T,pri}$	$M_{T,sek}$
1	max V_y	CO70	2.500 l	**14.36**	48.81	2.91	127.60	-36.01	3.64	0.19	2.72
	min V_y	CO85	4.000 r	**-21.94**	-88.22	-3.89	64.66	-26.89	3.15	-0.65	-3.24
	max V_z	CO47	0.000	11.71	**131.50**	2.68	0.01	0.00	0.00	0.26	2.42
	min V_z	CO62	6.000	9.63	**-162.60**	2.17	-79.08	4.90	-0.20	-0.10	2.27
	max M_T	CO70	2.500 l	14.36	48.81	**2.91**	127.60	-36.01	3.64	0.19	2.72
	min M_T	CO85	4.000 r	-21.94	-88.22	**-3.89**	64.66	-26.89	3.15	-0.65	-3.24
	max M_y	CO62	2.000 l	10.30	71.89	1.89	**147.40**	-20.62	2.05	0.18	1.71
	min M_y	CO82	6.000	-11.76	-102.60	-2.19	**-128.80**	0.92	-0.02	-1.31	-0.88
	max M_z	CO75	6.000	-16.12	-71.13	-2.86	-90.79	**15.75**	-1.90	-0.94	-1.92
	min M_z	CO70	2.500 l	14.36	48.81	2.91	127.60	**-36.01**	3.64	0.19	2.72
	max M_ω	CO70	2.500 l	14.36	48.81	2.91	127.60	-36.01	**3.64**	0.19	2.72
	min M_ω	CO85	6.000	-20.53	-92.14	-3.82	-115.60	15.22	**-2.15**	-1.02	-2.80
	max $M_{T,pri}$	CO70	0.000	13.32	53.58	2.70	0.01	0.01	0.00	**1.76**	0.94
	min $M_{T,pri}$	CO85	5.100 l	-21.22	-90.37	-3.86	-33.45	-3.01	0.15	**-1.39**	-2.47
	max $M_{T,sek}$	CO70	2.500 l	14.36	48.81	2.91	127.60	-36.01	3.64	0.19	**2.72**
	min $M_{T,sek}$	CO85	4.000 r	-21.94	-88.22	-3.89	64.66	-26.89	3.15	-0.65	**-3.24**
2	max V_y	CO140	3.400 l	**15.52**	53.01	2.75	129.70	-36.45	4.06	-0.14	2.89
	min V_y	CO140	3.400 r	**-13.97**	-47.54	-2.86	129.70	-36.45	4.06	-0.14	-2.72
	max V_z	CO107	0.000	9.78	**159.20**	1.76	-81.57	-4.01	0.33	-0.15	1.92
	min V_z	CO122	6.000	11.85	**-135.60**	2.07	-0.01	0.00	0.00	-0.25	2.32
	max M_T	CO140	0.000	14.21	59.47	**2.92**	-61.30	15.06	-2.01	0.96	1.95
	min M_T	CO140	6.000	-12.79	-52.53	**-3.03**	0.01	0.01	0.00	-1.99	-1.04
	max M_y	CO107	4.100 l	-8.07	38.06	-1.41	**146.50**	20.27	-2.45	0.31	-1.72
	min M_y	CO82	0.000	-12.62	110.20	-2.49	**-128.80**	0.92	-0.02	-1.31	-1.18
	max M_z	CO82	1.600 l	-13.84	107.20	-2.54	44.98	**21.63**	-2.33	-0.58	-1.96
	min M_z	CO140	3.400 l	15.52	53.01	2.75	129.70	**-36.45**	4.06	-0.14	2.89
	max M_ω	CO140	3.400 l	15.52	53.01	2.75	129.70	-36.45	**4.06**	-0.14	2.89
	min M_ω	CO107	4.100 l	-8.07	38.06	-1.41	146.50	20.27	**-2.45**	0.31	-1.72
	max $M_{T,pri}$	CO140	1.300 l	14.85	56.97	2.90	14.45	-3.58	0.06	**1.47**	1.43
	min $M_{T,pri}$	CO140	6.000	-12.79	-52.53	-3.03	0.01	0.01	0.00	**-1.99**	-1.04
	max $M_{T,sek}$	CO140	3.400 l	15.52	53.01	2.75	129.70	-36.45	4.06	-0.14	**2.89**
	min $M_{T,sek}$	CO140	3.400 r	-13.97	-47.54	-2.86	129.70	-36.45	4.06	-0.14	**-2.72**

Display: ○ All ◉ Max/min only

Figure 4.4: Window 2.2.1 *Internal Forces - Capacity* with the option *Max/min only*

4.2.2 Internal Forces - Fatigue

The display of the internal forces and the sorting options are identical to the previously described window 2.2.1 *Internal Forces -Capacity*.

The internal forces in this window are also design values: In the calculation of the internal forces, all relevant partial safety factors, dynamic coefficients, and combination factors are taken into account.

These internal forces are used for the fatigue design of the girder as well as the weld designs.

4.3 Support Forces

This results window offers three sorting options for the display.

2.3 Support Forces

A Node No.	B Govern. LC/CO	C LC/CO Description	D Support Forces [kN] P_X	E P_Y	F P_Z	G Support Moments [kNm] M_Y	H M_Z
	LC2	Wind Load					
1	CO1	Self-Weight + Permanent Load	0.00	0.00	2.99	0.00	0.00
	CO2	Total, γ_G (LC1 + LC4) + γ_Q (LC6 + LC8) + γ_{Qo} LC2	0.00	0.00	2.99	0.00	0.00
	CO7	Total, γ_G (LC1 + LC12) + γ_Q (LC14 + LC16) + γ_{Qo} LC2	0.00	-10.78	73.33	0.00	0.00
	CO8	Total, γ_G (LC1 + LC11) + γ_Q LC16 + γ_{Qo} LC2	0.00	-10.79	19.11	0.00	0.00
	CO42	Total, γ_G (LC1 + LC68) + γ_Q (LC70 + LC72) + γ_{Qo} LC2	0.00	-3.62	26.86	0.00	0.00
	CO47	Total, γ_G (LC1 + LC76) + γ_Q (LC78 + LC80) + γ_{Qo} LC2	0.00	8.10	91.04	0.00	0.00
	CO50	Total, γ_G (LC1 + LC77) + γ_Q (LC79 + LC81) + γ_{Qo} LC2	0.00	17.90	87.10	0.00	0.00
	CO52	Total, γ_G (LC1 + LC84) + γ_Q (LC86 + LC88) + γ_{Qo} LC2	0.00	7.70	77.35	0.00	0.00
	CO82	Total, γ_G (LC1 + LC132) + γ_Q (LC134 + LC136) + γ_{Qo} LC2	0.00	3.91	15.25	0.00	0.00
	CO110	Total, γ_G (LC1 + LC173) + γ_Q (LC175 + LC177) + γ_{Qo} LC2	0.00	-0.75	-5.10	0.00	0.00
	CO112	Total, γ_G (LC1 + LC180) + γ_Q (LC182 + LC184) + γ_{Qo} LC2	0.00	-0.09	-6.34	0.00	0.00
	CO122	Total, γ_G (LC1 + LC196) + γ_Q (LC198 + LC200) + γ_{Qo} LC2	0.00	-0.95	-5.58	0.00	0.00
	CO165	Total, γ_G (LC1 + LC261) + γ_Q (LC263 + LC265) + γ_{Qo} LC2	0.00	-0.08	2.67	0.00	0.00
	max		0.00	17.90	91.04	0.00	0.00
	min		0.00	-10.79	-6.34	0.00	0.00
	LC2	Wind Load					
2	CO1	Self-Weight + Permanent Load	0.00	0.00	9.95	0.00	0.00
	CO2	Total, γ_G (LC1 + LC4) + γ_Q (LC6 + LC8) + γ_{Qo} LC2	0.00	0.00	9.95	0.00	0.00
	CO7	Total, γ_G (LC1 + LC12) + γ_Q (LC14 + LC16) + γ_{Qo} LC2	0.00	-1.51	19.74	0.00	0.00
	CO8	Total, γ_G (LC1 + LC11) + γ_Q LC16 + γ_{Qo} LC2	0.00	-1.50	12.19	0.00	0.00
	CO42	Total, γ_G (LC1 + LC68) + γ_Q (LC70 + LC72) + γ_{Qo} LC2	0.00	-9.62	72.12	0.00	0.00
	CO47	Total, γ_G (LC1 + LC76) + γ_Q (LC78 + LC80) + γ_{Qo} LC2	0.00	-8.98	87.68	0.00	0.00
	CO50	Total, γ_G (LC1 + LC77) + γ_Q (LC79 + LC81) + γ_{Qo} LC2	0.00	2.53	84.21	0.00	0.00
	CO52	Total, γ_G (LC1 + LC84) + γ_Q (LC86 + LC88) + γ_{Qo} LC2	0.00	-8.17	102.00	0.00	0.00
	CO82	Total, γ_G (LC1 + LC132) + γ_Q (LC134 + LC136) + γ_{Qo} LC2	0.00	-0.60	147.70	0.00	0.00
	CO110	Total, γ_G (LC1 + LC173) + γ_Q (LC175 + LC177) + γ_{Qo} LC2	0.00	19.83	118.60	0.00	0.00
	CO112	Total, γ_G (LC1 + LC180) + γ_Q (LC182 + LC184) + γ_{Qo} LC2	0.00	7.41	112.30	0.00	0.00
	CO122	Total, γ_G (LC1 + LC196) + γ_Q (LC198 + LC200) + γ_{Qo} LC2	0.00	9.12	84.66	0.00	0.00
	CO165	Total, γ_G (LC1 + LC261) + γ_Q (LC263 + LC265) + γ_{Qo} LC2	0.00	0.50	11.82	0.00	0.00
	max		0.00	19.83	147.70	0.00	0.00
	min		0.00	-9.62	9.95	0.00	0.00
	LC2	Wind Load					
3	CO1	Self-Weight + Permanent Load	0.00	0.00	2.99	0.00	0.00

Display: (•) All ( ) Max/min only ( ) Only max/min advanced

Figure 4.5: Window 2.3 *Support Forces* with option *All* support forces

If you select the first option, the window shows *All* determined support forces of the load combinations. Additionally, the load case 2 *Wind Load* is displayed, so the support forces of the individual components (crane, permanent load, and wind) can be calculated backwards.

2.3 Support Forces

A Node No.	B max min	C Govern. CO	D Horizontal Support Forces P_Y [kN] Total	E Due to Crane	F Due to Wind	G Vertical Support Forces P_Z [kN] Total	H Due to Crane	I Permanent
1	max P_Y	CO50	**17.90**	17.90	0.00	87.10	84.11	2.98
	min P_Y	CO8	**-10.79**	-10.79	0.00	19.11	16.13	2.98
	max P_Z	CO47	8.10	8.10	0.00	**91.04**	88.06	2.98
	min P_Z	CO112	-0.09	-0.09	0.00	**-6.34**	-9.33	2.98
2	max P_Y	CO110	**19.83**	19.83	0.00	118.60	108.65	9.95
	min P_Y	CO42	**-9.62**	-9.62	0.00	72.12	62.17	9.95
	max P_Z	CO82	-0.60	-0.60	0.00	**147.70**	137.75	9.95
	min P_Z	CO1	0.00	0.00	0.00	**9.95**	0.00	9.95
3	max P_Y	CO165	**19.58**	19.58	0.00	76.42	73.43	2.98
	min P_Y	CO122	**-8.17**	-8.17	0.00	93.86	90.88	2.98
	max P_Z	CO122	-8.17	-8.17	0.00	**93.86**	90.88	2.98
	min P_Z	CO52	0.47	0.47	0.00	**-6.40**	-9.38	2.98

Display: ( ) All (•) Max/min only ( ) Only max/min advanced

Figure 4.6: Window 2.3 *Support Forces* with option *Max/min only*

If you select the option *Max/min only*, only the extreme values of the support forces are displayed for the respective directions, that is, the characteristic support forces multiplied by the corresponding dynamic coefficient for supports.

2.3 Support Forces

A	B	C	D	E	F	G	H	I
Node No.	Govern. CO	Horizontal Support Forces P_Y [kN] Total	Due to Crane	Due to Wind	Vertical Support Forces P_Z [kN] Total	Due to Crane	Permanent	Comment
Extreme in Node No.1 - max P_Y								
1	CO50	17.90	17.90	0.00	87.10	84.11	2.98	
2	CO50	2.53	2.53	0.00	84.21	74.26	9.95	
3	CO50	-0.43	-0.43	0.00	-5.39	-8.38	2.98	
Extreme in Node No.1 - min P_Y								
1	CO8	-10.79	-10.79	0.00	19.11	16.13	2.98	
2	CO8	-1.50	-1.50	0.00	12.19	2.24	9.95	
3	CO8	0.25	0.25	0.00	2.61	-0.37	2.98	
Extreme in Node No.1 - max P_Z								
1	CO47	8.10	8.10	0.00	91.04	88.06	2.98	
2	CO47	-8.98	-8.98	0.00	87.68	77.73	9.95	
3	CO47	0.88	0.88	0.00	-5.79	-8.77	2.98	
Extreme in Node No.1 - min P_Z								
1	CO112	-0.09	-0.09	0.00	-6.34	-9.33	2.98	
2	CO112	7.41	7.41	0.00	112.30	102.35	9.95	
3	CO112	-7.32	-7.32	0.00	66.93	63.94	2.98	
Extreme in Node No.2 - max P_Y								
1	CO110	-0.75	-0.75	0.00	-5.10	-8.09	2.98	
2	CO110	19.83	19.83	0.00	118.60	108.65	9.95	
3	CO110	0.92	0.92	0.00	52.40	49.42	2.98	
Extreme in Node No.2 - min P_Y								
1	CO42	-3.62	-3.62	0.00	26.86	23.88	2.98	
2	CO42	-9.62	-9.62	0.00	72.12	62.17	9.95	
3	CO42	1.20	1.20	0.00	-4.55	-7.53	2.98	
Extreme in Node No.2 - max P_Z								
1	CO82	3.91	3.91	0.00	15.25	12.27	2.98	
2	CO82	-0.60	-0.60	0.00	147.70	137.75	9.95	
3	CO82	-3.32	-3.32	0.00	10.02	7.03	2.98	
Extreme in Node No.2 - min P_Z								
1	CO1	0.00	0.00	0.00	2.98	0.00	2.98	
2	CO1	0.00	0.00	0.00	9.95	0.00	9.95	
3	CO1	0.00	0.00	0.00	2.98	0.00	2.98	
Extreme in Node No.3 - max P_Y								
1	CO165	-0.08	-0.08	0.00	2.67	-0.31	2.98	

Display: ○ All ○ Max/min only ◉ Only max/min advanced

Figure 4.7: Window 2.3 *Support Forces* with option *Only max/min advanced*

If you select the display option *Max/min only advanced*, the table shows the extreme values of the horizontal support forces (with components from crane and wind load) and vertical (with components from crane and permanent load).

The support forces will be combined in the same way as the internal forces from the load cases taking into account the dynamic coefficients. Thus, the support forces (except for LC1 and LC2) are multiplied by the ratio of the dynamic coefficient of the girder to the dynamic coefficient of support and added using the LC criterion, since the wheel loads, starting from LC3, already include the dynamic coefficient of the girder.

The support forces are from the calculation according to the second-order analysis for warping torsion. Hence, not all load combinations are available in the *Fast Calculation* method but only those according to second-order analysis for warping torsion.

4.4 Stress Analysis

This window offers three display options controlled in the *Method of Output* section.

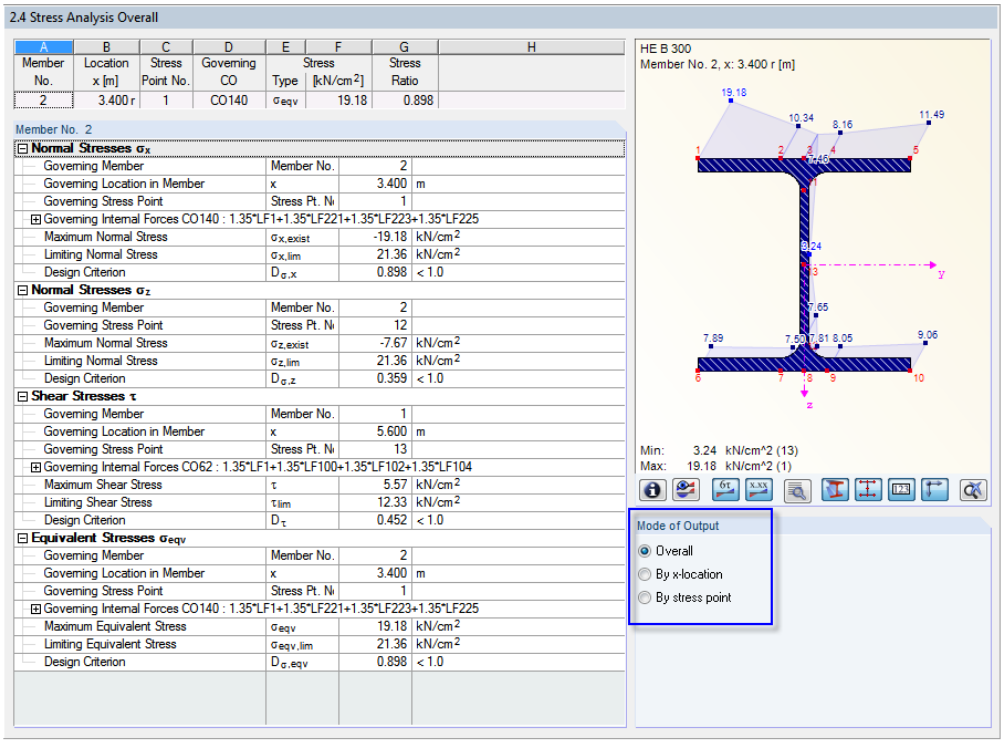


Figure 4.8: Window 2.4 *Stress Analysis Overall*

If you select the *Overall* method of output, the upper table shows only the x-location with the governing ratio. To this end, all x-locations, stress components, stress points, and load combinations are analyzed. Thus, this table displays also the governing stress points, governing load combinations, and the type of stress, which lead to the maximum *Stress Ratio* (represents the ratio of calculated stress to limit stress). The stress analysis is satisfied if the ratio is smaller than one.

For the stress analysis, the internal forces according to the second-order analysis for warping torsion are used, that is, the partial factors γ_F, combination factor ψ, and dynamic coefficient φ are considered.

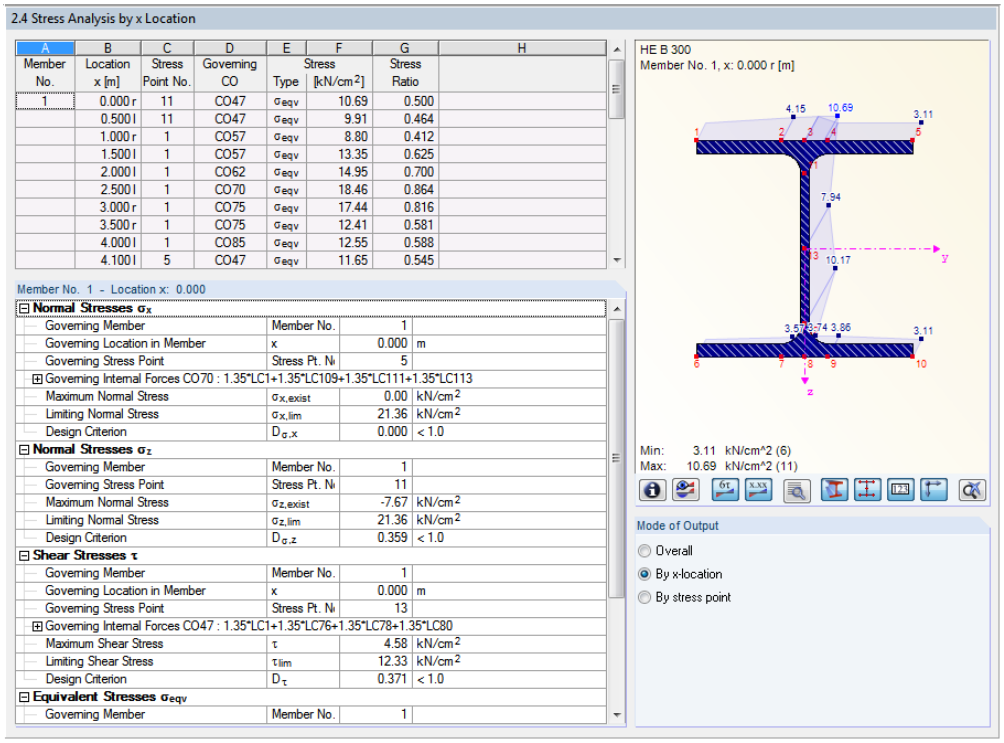
Details - Stresses

Below the table, the detailed intermediate results leading to this ratio are shown. They include the normal stresses σ_x and σ_z, shear stress τ, and the equivalent stresses σ_{eqv}. For each stress component, you can see the maximum stress at this x-location and the underlying governing internal forces.

If you click [+] at the beginning of a row with the load combination, you can see the internal forces of this CO. The exception is the normal stress σ_z, which is determined according to the standard directly from the wheel pressure. The last row of each stress component shows the design, which is compared with the value 1.

Stress graphic

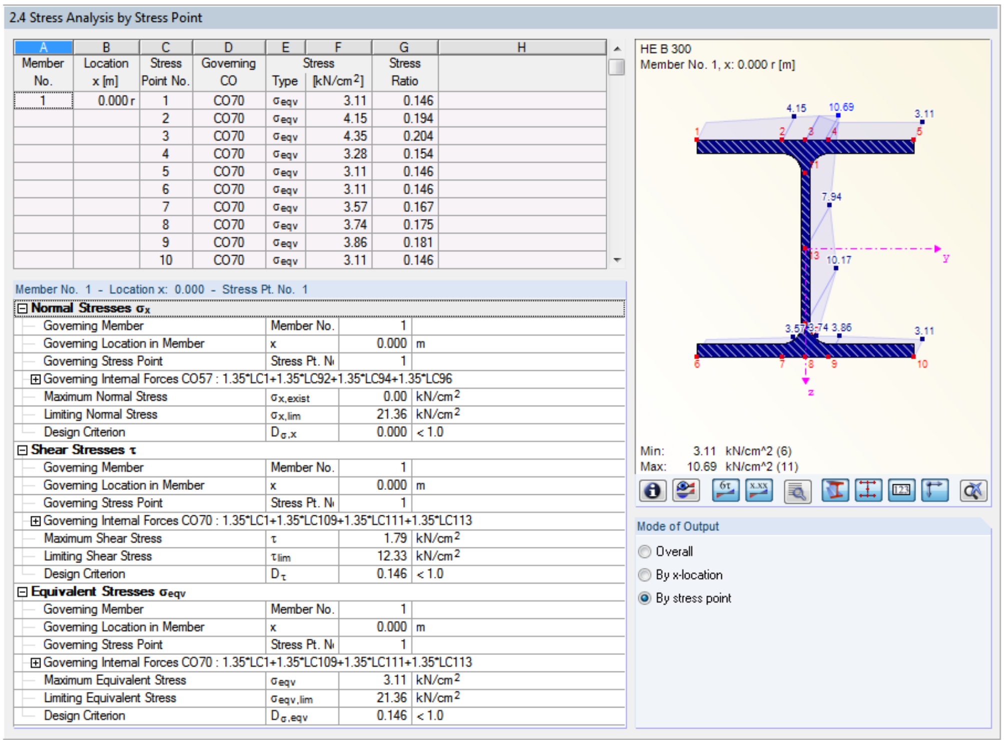
On the right, you can find a graphic with the stress diagram for the cross-section. The graphic depends on the selected design in the table. Thus, you can visualize the governing normal, shear, and equivalent stresses at the current x-location.



Member No.	Location x [m]	Stress Point No.	Governing CO	Stress Type	Stress [kN/cm2]	Stress Ratio
1	0.000 r	11	CO47	σeqv	10.69	0.500
	0.500 l	11	CO47	σeqv	9.91	0.464
	1.000 r	1	CO57	σeqv	8.80	0.412
	1.500 l	1	CO57	σeqv	13.35	0.625
	2.000 l	1	CO62	σeqv	14.95	0.700
	2.500 l	1	CO70	σeqv	18.46	0.864
	3.000 r	1	CO75	σeqv	17.44	0.816
	3.500 r	1	CO75	σeqv	12.41	0.581
	4.000 l	1	CO85	σeqv	12.55	0.588
	4.100 l	5	CO47	σeqv	11.65	0.545

Figure 4.9: Window 2.4 *Stress Analysis by x-Location*

If you select the *By x-location* mode of output, the maximum ratios are shown at each x-location.



Member No.	Location x [m]	Stress Point No.	Governing CO	Stress Type	Stress [kN/cm2]	Stress Ratio
1	0.000 r	1	CO70	σeqv	3.11	0.146
		2	CO70	σeqv	4.15	0.194
		3	CO70	σeqv	4.35	0.204
		4	CO70	σeqv	3.28	0.154
		5	CO70	σeqv	3.11	0.146
		6	CO70	σeqv	3.11	0.146
		7	CO70	σeqv	3.57	0.167
		8	CO70	σeqv	3.74	0.175
		9	CO70	σeqv	3.86	0.181
		10	CO70	σeqv	3.11	0.146

Figure 4.10: Window 2.4 *Stress Analysis by Stress Point*

If the output is set as *By stress point*, then the results in the upper table are listed for each stress point and for each x-location.

4.4.1 Theoretical Background on Stress Calculation

CRANEWAY calculates the normal stresses σ_x, shear stresses τ, and the equivalent stresses σ_{eqv} at all cross-section points. At the top edge of the web plate, the normal stresses σ_z from the applied wheel load are also taken into account.

The calculation is carried out along the crane runway girder in so-called x-locations. These x-locations can be found at the nodes of the finite elements into which the girder was subdivided and also at the load application locations of the crane in the individual load combinations.

In the following, the stress points are indicated by the coordinates (y_i, z_i). The normal stresses σ_x and the shear stresses τ are calculated from the internal forces which were computed according to the second-order analysis subjected to γ_F times the loading.

Normal Stresses

Because the warping torsion is taken into account, not only parts from axial force and bending, but also from the warping torsional moment occur for the normal stresses σ_x. In all, we obtain for the normal stress σ_x in a point i of the cross-section:

$$\sigma_{x,i} = \frac{N}{A} + \frac{M_y}{S_y(y_i,z_i)} - \frac{M_z}{S_z(y_i,z_i)} - \frac{M_\omega}{C_w}\omega_M(y_i,z_i)$$

The symbols mean:

N	Axial force
M_y	Bending moment about y-axis
M_z	Bending moment about z-axis
M_ω	Warping torsional moment
A	Cross-section surface
$S_y(y_i,z_i)$	Section modulus about y-axis for point (y_i,z_i)
$S_z(y_i,z_i)$	Section modulus about z-axis for point (y_i,z_i)
C_w	Warping constant relative to the shear center M
ω_M	Principal warping at point (y_i,z_i)

Shear stresses

The shear stresses consist of shear force components and torsional components. The relation to the determination of the primary shear stresses is:

$$\tau_{p,i} = \frac{V_y \cdot Q_z(y_i,z_i)}{I_z \cdot t(y_i,z_i)} + \frac{V_z \cdot Q_y(y_i,z_i)}{I_y \cdot s(y_i,z_i)} + \left|\frac{M_{T,p}}{S_T(y_i,z_i)}\right|$$

The descriptions mean:

V_y	Shear force in y-axis direction
V_z	Shear force in z-axis direction
$M_{T,p}$	Primary torsional moment
I_y	Second moment of area relative to y-axis
I_z	Second moment of area relative to z-axis
$Q_y(y_i,z_i)$	First moment of area relative to y-axis for point (y_i,z_i)
$Q_z(y_i,z_i)$	First moment of area relative to z-axis for point (y_i,z_i)
$t(y_i,z_i)$	Thickness of cross-section part in point (y_i,z_i)
$s(y_i,z_i)$	Thickness of cross-section part in point(y_i,z_i)
$S_T(y_i,z_i)$	Torsional section modulus for point (y_i,z_i)

Secondary shear stresses

Furthermore, the secondary shear stress due to the secondary torsional moment $M_{T,s}$ is computed.

$$\tau_{s,i} = \frac{M_{T,s} \cdot Q_{\omega}(y_i, z_i)}{C_w \cdot t(y_i, z_i)}$$

The descriptions mean:

$M_{T,s}$	Secondary torsional moment
$Q_{\omega}(y_i,z_i)$	Warping surface in point (y_i,z_i)
C_w	Warping constant
$t(y_i,z_i)$	Cross-section thickness in point (y_i,z_i)

In CRANEWAY, you can choose whether to take into account the secondary shear stresses in the stress calculation (see Figure 3.3, page 37). If they are considered in the stress calculation, they are directly added to the primary shear stresses.

Normal stresses from applied wheel loads

The normal stresses σ_z are, in contrast to the normal stresses σ_x and shear stresses τ, not calculated according to the second-order analysis but according to the following equations:

- **DIN 4231**

$$\sigma_{z,i} = \frac{W}{c(y_i, z_i) \cdot t(y_i, z_i)}$$

The descriptions mean:

W	Wheel load multiplied by the partial safety factor γ_F, and dynamic coefficient φ
$c(y_i,z_i)$	Load application length of the wheel load
$t(y_i,z_i)$	Thickness of the governing cross-section parts in point (y_i,z_i)

The length $c(y_i,z_i)$ is calculated according to [2] section 4.1.2. The following figure illustrates the principle of the determination of the load application length *c*.

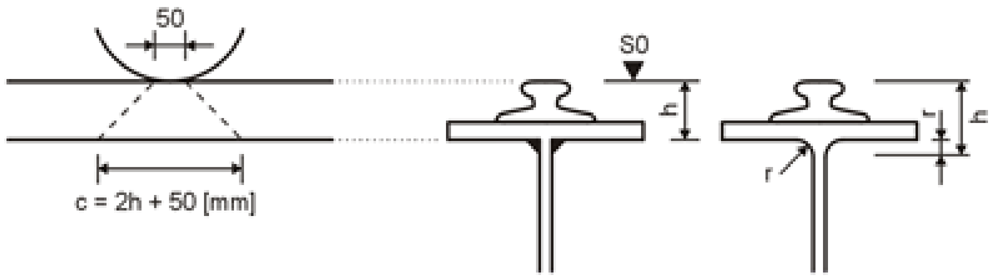


Figure 4.11: Length of the uniformly distributed wheel load

- **EN 1993-6**

$$\sigma_{z,i} = \frac{F_{z,Ed}}{l_{eff} \cdot t_w} \quad \text{or for rolled cross-sections} \quad \sigma_{z,i} = \frac{F_{z,Ed}}{(l_{eff} + 2 \cdot r) \cdot t_w}$$

The descriptions mean:

$F_{z,Ed}$	Design value of the wheel load
l_{eff}	Effective loaded length of wheel load acc. to [6], Table 5.1
t_w	Thickness of the web plate

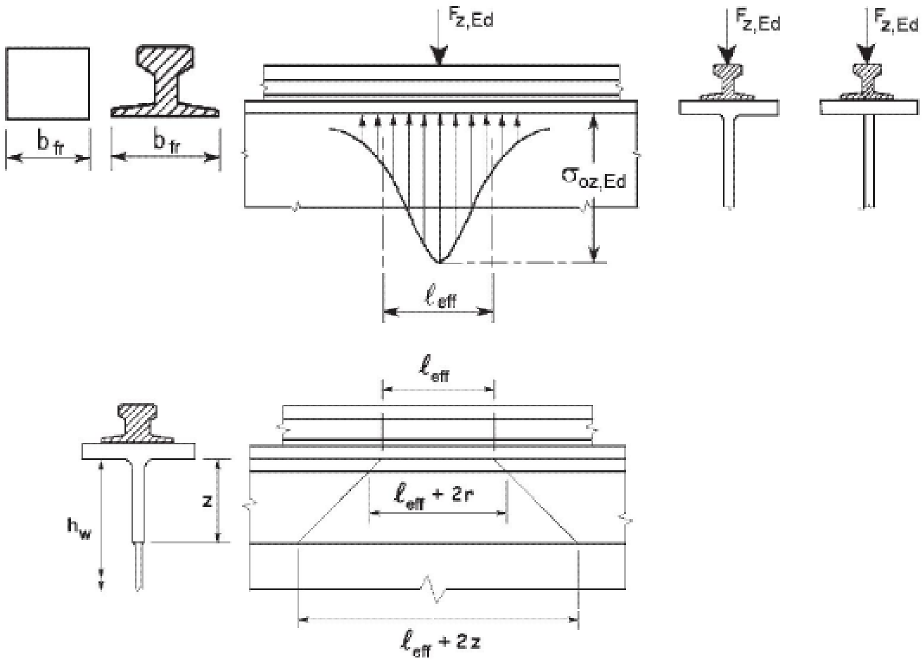


Figure 4.12: Effective loaded length

Table 5.1: Effective loaded length ℓ_{eff}

Case	Description	Effective loaded length ℓ_{eff}
(a)	Crane rail rigidly fixed to the flange	$\ell_{eff} = 3{,}25\,[I_{rf} / t_w]^{1/3}$
(b)	Crane rail not rigidly fixed to flange	$\ell_{eff} = 3{,}25\,[(I_r + I_{f,eff}) / t_w]^{1/3}$
(c)	Crane rail mounted on a suitable resilient elastomeric bearing pad at least 6mm thick.	$\ell_{eff} = 4{,}25\,[(I_r + I_{f,eff}) / t_w]^{1/3}$

$I_{f,eff}$ is the second moment of area, about its horizontal centroidal axis, of a flange with an effective width of b_{eff}

I_r is the second moment of area, about its horizontal centroidal axis, of the rail

I_{rf} is the second moment of area, about its horizontal centroidal axis, of the combined cross-section comprising the rail and a flange with an effective width of b_{eff}

t_w is the web thickness.

$b_{eff} = b_{fr} + h_r + t_f$ but $b_{eff} \leq b$

where: b is the overall width of the top flange;

b_{fr} is the width of the foot of the rail, see figure 5.2;

h_r is the height of the rail, see figure 5.1;

t_f is the flange thickness.

Note: Allow for crane rail wear, see **5.6.2(2)** and **5.6.2(3)** in determining I_r, I_{rf} and h_r.

Figure 4.13: Effective loaded length

Designs

In the elastic-elastic design method, you have to verify that under the design actions (γ_F times the loads) the following applies:

$$\max \sigma_x \le f_{y,d}$$

$$\max \sigma_z \le f_{y,d}$$

$$\max \tau \le \frac{1}{\sqrt{3}} \cdot f_{y,d}$$

$$\max \sigma_{eqv} \le f_{y,d} = \frac{f_{y,k}}{\gamma_M}$$

The equivalent stress σ_{eqv} according to VON MISES is determined from the normal and shear stresses as follows:

$$\sigma_{eqv} = \sqrt{\sigma_x^2 + \sigma_z^2 - \sigma_x \cdot \sigma_z + 3\tau^2}$$

In this formula, the sign must be considered in the calculation of the stresses. Due to the distribution of the compression stress, the stress σ_z under the wheel is always negative.

Since the stress σ_z exists only at the top edge of the web plate or does not have any influence further down in the beam, the following simplified formula is used for the other stress points.

$$\sigma_{eqv} = \sqrt{\sigma_x^2 + 3\tau^2}$$

The stress analysis is carried out in every stress point at all x-locations of the crane runway girder with the according design internal forces according to the second-order analysis for warping torsion.

In the stress analysis, the normal stresses σ_x have the greatest influence. The greatest normal stress σ_x occurs on the edge of the flange, where the normal stress components from the bending moments about both principal axes and from the warping torsional moment superimpose each other. The superposition is shown in the following figure.

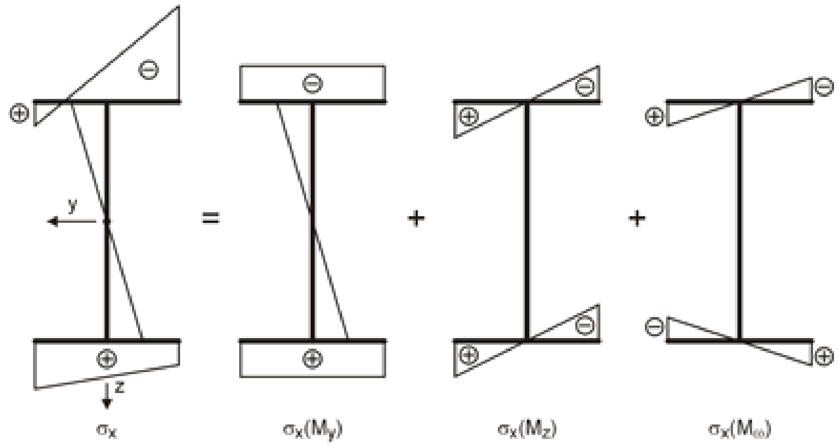
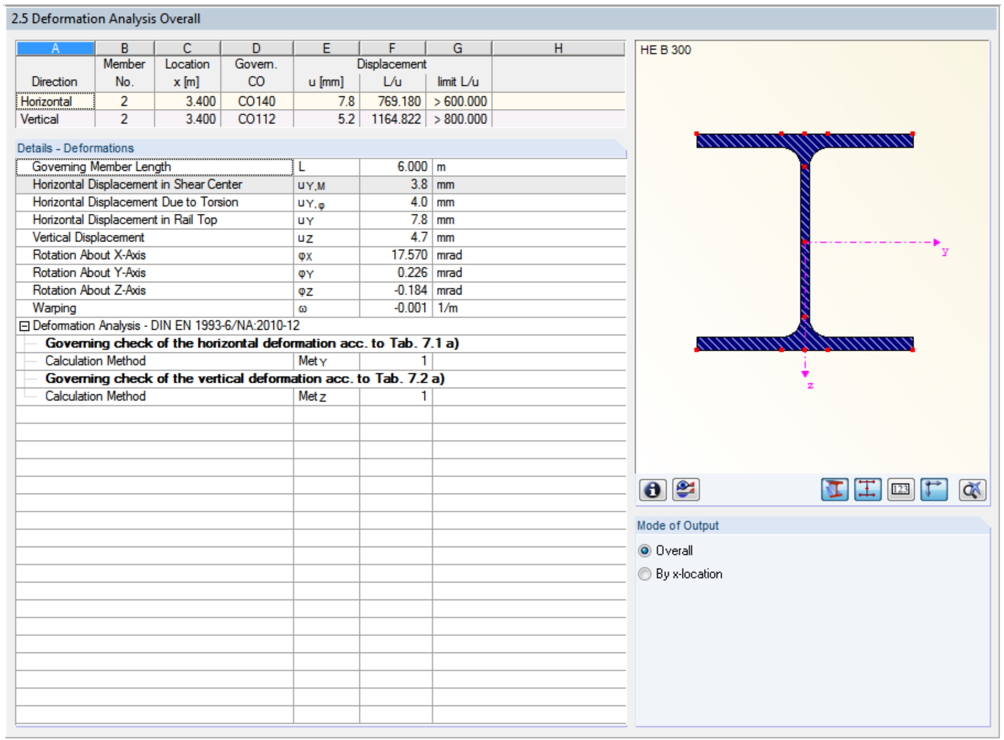


Figure 4.14: Normal stress components for biaxial bending with warping torsion

4.5 Deformation Analysis

This window contains two display options that you can control by selecting the *Mode of Output*.



A	B	C	D	E	F	G	H
Direction	Member No.	Location x [m]	Govern. CO	Displacement u [mm]	L/u	limit L/u	
Horizontal	2	3.400	CO140	7.8	769.180	> 600.000	
Vertical	2	3.400	CO112	5.2	1164.822	> 800.000	

Details - Deformations

Governing Member Length	L	6.000	m
Horizontal Displacement in Shear Center	$u_{Y,M}$	3.8	mm
Horizontal Displacement Due to Torsion	$u_{Y,\varphi}$	4.0	mm
Horizontal Displacement in Rail Top	u_Y	7.8	mm
Vertical Displacement	u_Z	4.7	mm
Rotation About X-Axis	φ_X	17.570	mrad
Rotation About Y-Axis	φ_Y	0.226	mrad
Rotation About Z-Axis	φ_Z	-0.184	mrad
Warping	ω	-0.001	1/m
Deformation Analysis - DIN EN 1993-6/NA:2010-12			
Governing check of the horizontal deformation acc. to Tab. 7.1 a)			
Calculation Method	Met_Y	1	
Governing check of the vertical deformation acc. to Tab. 7.2 a)			
Calculation Method	Met_Z	1	

Figure 4.15: Window 2.5 *Deformation Analysis Overall*

The deformations of the relevant load combinations are analyzed for each x-location. If you select the *Overall* option, the table shows only the x-locations with the CO numbers at which the governing displacement occurs in the horizontal and vertical direction.

In the analysis, the ratio of field length to greatest displacement in the field is compared with the allowable ratio L/u. The design is satisfied if the existing ratio L/u is greater than the allowable quotient.

The deformations are calculated according to the second-order analysis for warping torsion with the characteristic values, that is, the partial safety factor $\gamma_F = 1.0$, combination factor $\psi = 1.0$, and dynamic coefficient $\varphi = 1.0$.

Details - Deformations

The intermediate results of the governing displacements u_y and u_z are listed below the table. There, you can also see the parts of the rotations ϕ_x, ϕ_y, and ϕ_z and the warping ω. All deformation components are relative to the shear center M. The only exception is the displacement u_y: this component is related to the upper edge of the rail.

In the mode of output *By x-location* (see Figure 4.16), all performed deformation analyses are listed at each x-location and for each load combination. If you click in a row of the upper table, the corresponding *Details* of the current displacement are set in the table below. This mode of output also includes the calculation method for the horizontal and vertical deformations (see chapter 3.1.1, page 34).

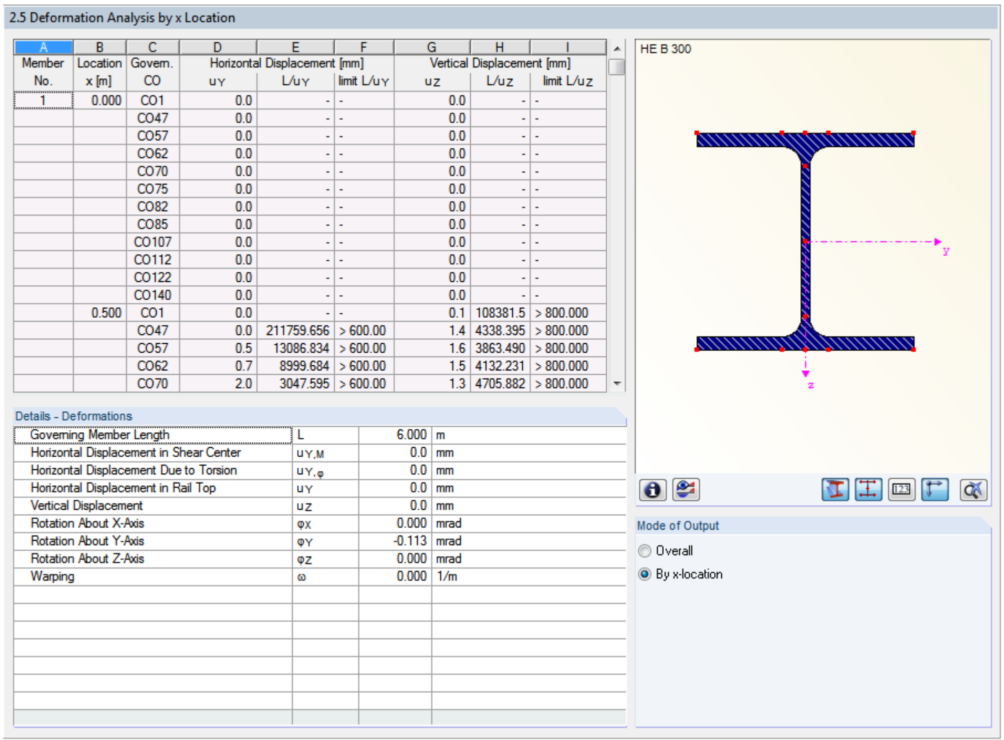


Figure 4.16: Window 2.5 *Deformation Analysis by x-Location*

4.5.1 Theoretical Background on Deformation Analysis

In addition to the internal forces and stresses, CRANEWAY determines the according deformations. These are the displacements u_y, $u_{y,M}$, u_z, the rotations ϕ_x, ϕ_y, ϕ_z, and the warping ω.

The deformation analysis is performed for the displacements in horizontal direction u_y and for the displacements in vertical direction u_z. CRANEWAY allows you to compare them with guide values, which can be defined manually.

- Vertical deflection of the crane runway beam
- Horizontal deformation of the crane runway beam

In the calculation of the deformation, the partial safety factor $\gamma_F = 1.0$ and the combination coefficient $\psi = 1.0$ is used.

The deformation analysis of the lateral displacement is of great importance: The analysis of the horizontal deformation is often the governing design and therefore determines the dimensions of the runway beam.

4.6 Fatigue Design

This window provides two display options that are controlled by means of the *Mode of Output*.

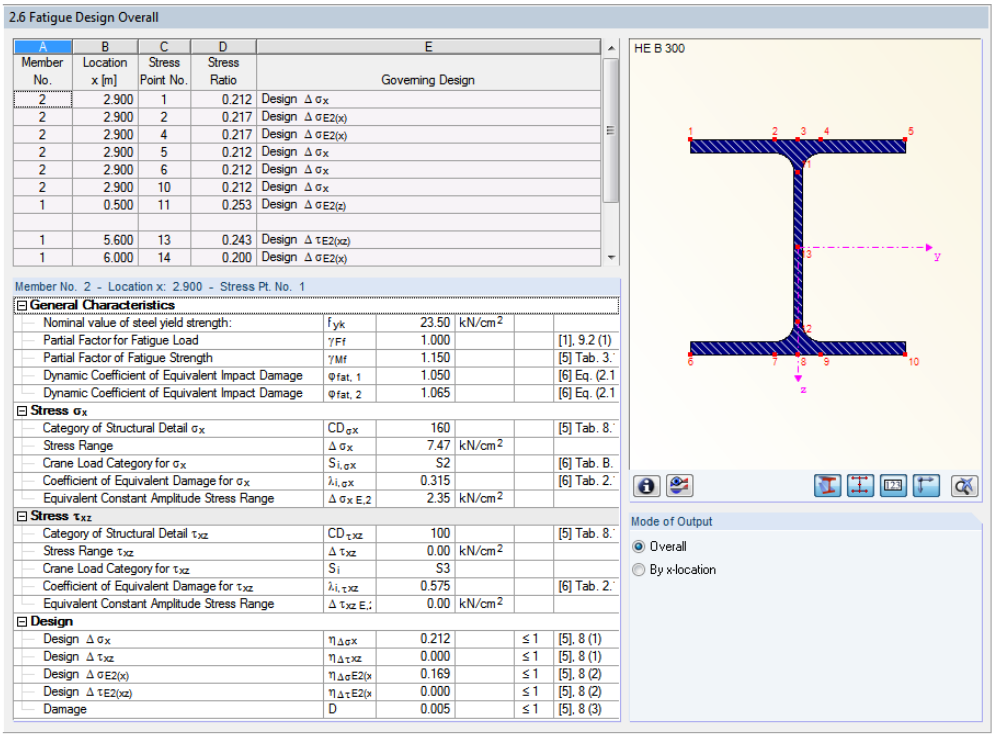


Figure 4.17: Window 2.6 *Fatigue Design Overall*

If you select the *Overall* mode of output, the upper table shows for the stress points, to which detail categories were assigned (see chapter 2.3, page 22), the respective x-locations with the greatest stress ratio. Column E shows the governing types of stress.

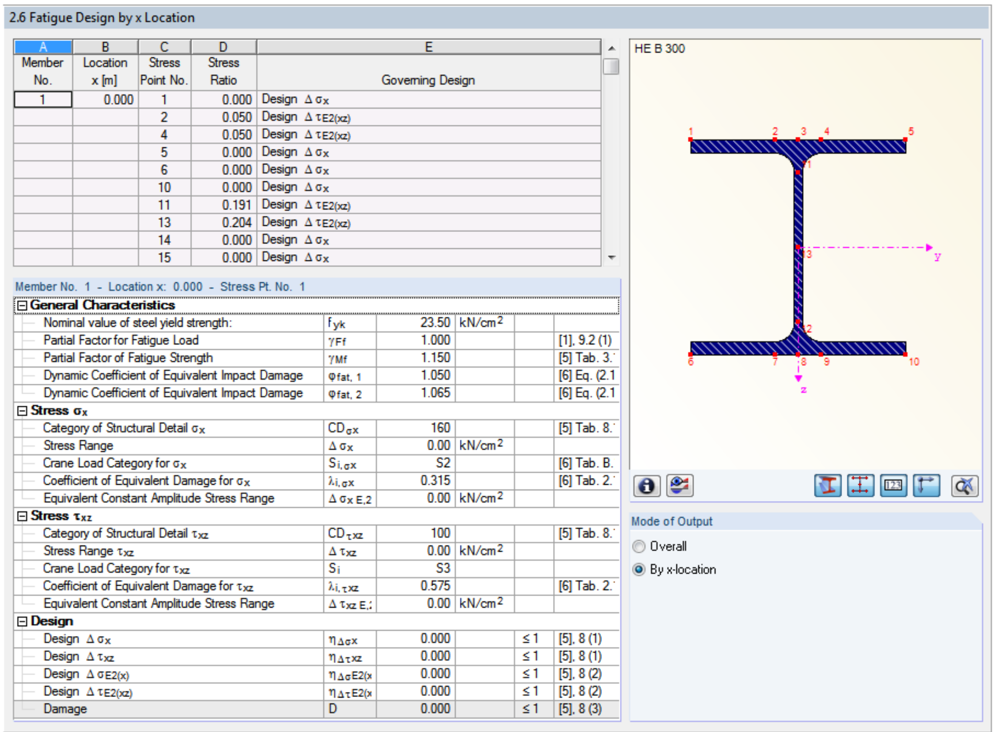


Figure 4.18: Window 2.6 *Fatigue Design by x-Location*

For the mode of output *By x-Location*, the designs are listed for each member location x and each stress point, to which a detail category was assigned.

Design Details

The lower part of the window lists all intermediate results that apply for the ratio at the stress point selected above. In addition to the general parameters, you can also check the components of the normal and shear stresses as well as the equivalent constant amplitude stress ranges.

4.6.1 Theoretical Background on Fatigue Designs

DIN 4132

In contrast to the stress analysis, the fatigue design uses the partial safety factors $\gamma_F = 1$. Therefore, the provided stresses in the fatigue design cannot be set in relation to the design values of the general stress analysis but must be compared with the according allowable stresses for the fatigue design. They depend on the used steel grade, the detail category, the stress relation of minimum stress to maximum stress ($\chi = \sigma_{min}/\sigma_{max}$) and the number of crane travels defined in the stress group of the crane.

Fatigue damage accumulation is characteristic for the material steel. Each single stress amplitude can be of great importance. Therefore, the following condition is to be satisfied.

$$\sum\left(\frac{\max{}^{\sigma}_{\tau\,i}}{\text{allow}^{\sigma}_{\tau}S_i}\right)^k + \left(\frac{\max{}^{\sigma}_{\tau}}{\text{allow}^{\sigma}_{\tau}S}\right)^k \leq 1$$

The following values are to be included in the combination formula:

$\max^{\sigma}_{\tau}$	Maximum stress due to single crane i
$\text{allow}^{\sigma}_{\tau}S$	Allowable stress for the corresponding stress group
$\max^{\sigma}_{\tau}$	Maximum stress from several cranes together
$\text{allow}^{\sigma}_{\tau}S$	Allowable stress for the according stress group of several cranes

Exponent k:

k = 6.635	for detail categories W0 through W2 for St 37
k = 5.336	for detail categories W0 through W2 for St 52
k = 3.323	for detail categories K0 through K4

In determining the allowable stresses for two cranes, the program uses a stress group lower by two levels than the stress group of the crane with the lowest stress group. If there are three cranes, the program uses a stress group lower by three levels than the stress group of the crane with the lowest stress group.

If during the traveling of a crane the maximum stress values σ or τ are already induced by individual crane wheels or wheel groups, they have to be considered for themselves as actions with the allowable stress in the design by using the previous formula.

For complicated stress distributions, the assessment of the amplitudes and the values σ_o and σ_u is difficult. This problem can be solved by using the rainflow method: In this method, the amplitudes and the corresponding top σ_t and bottom σ_b stresses are determined from the stress diagrams. Furthermore, this method can consider all forms of stress diagrams. The determined stresses σ_t and σ_b are then used as input parameters for the actual fatigue design.

The rainflow method gives the resulting stress couples σ_t and σ_b for each period (amplitude). Next, the fatigue design is carried out for these stress couples. Furthermore, it is important to consider if these are full or half periods. In the following combination formulas, the influence of the periods (amplitudes) was added.

$$\sum s_i \left(\frac{\max{}^{\sigma}_{\tau\, i}}{\text{allow}{}^{\sigma}_{\tau} R_i} \right)^k + \left(\frac{\max{}^{\sigma}_{\tau}}{\text{allow}{}^{\sigma}_{\tau} R} \right)^k \le 1$$

s_i means:

$s_i = 1.0$ for full period

$s_i = 0.5$ for half period

For the normal stress σ_z, in contrast to the stresses σ_x and τ, the top stress σ_t and the bottom stress σ_b are not determined by means of the rainflow methods from the stress diagrams. It is assumed that each vertical wheel load travels over the location to be examined and induces the corresponding top stresses σ_t:

$$\sigma_{o,i} = \frac{\varphi \cdot W_i}{c \cdot t}$$

where

φ	Dynamic coefficient
W_i	Wheel load
c	Load application length of wheel load
t	Thickness of web plate

CRANEWAY also takes into account eccentrically acting wheel loads that induce a torsional moment. For the stress group B4 - B6, an eccentric load application of $\pm {}^1/_4$ of the rail head width is taken into account. This is done by adding stresses of the according torsional moment $M_{T,i}$ to the centric wheel load application, see Figure 4.19a).

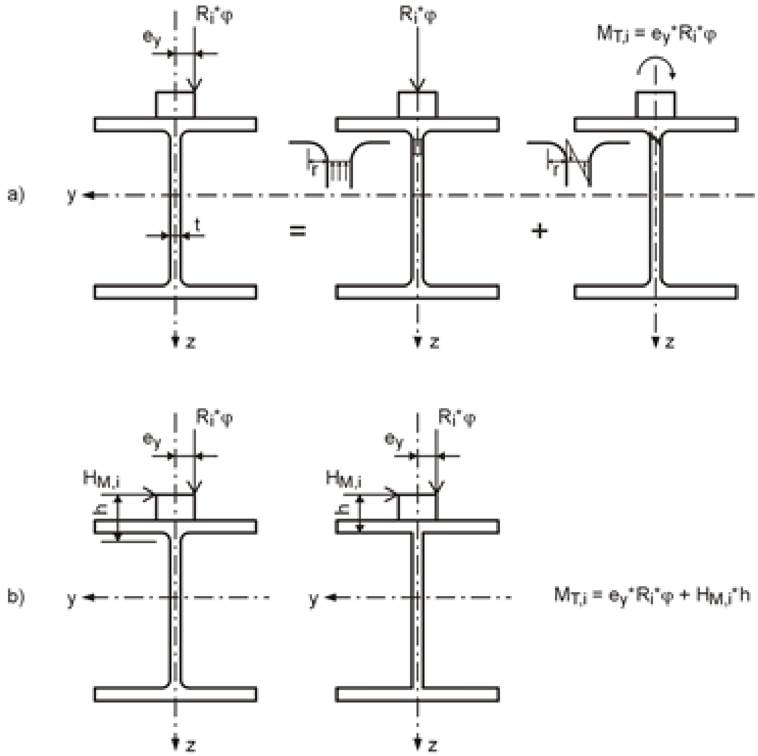


Figure 4.19: Stress at the upper edge of the web due to eccentric wheel load

If the horizontal inertial forces H_M are considered in the fatigue design, we obtain the torsional moment $M_{T,i}$ according to Figure 4.19 b).

The composed normal stress $\sigma_{z,i,}$ is thus:

$$\sigma_{z,i} = \sigma_{z,i,V} + \sigma_{z,i,M}$$

where

$$\sigma_{z,i,V} = \sigma_{o,i}$$

$$\sigma_{z,i,M} = \frac{6}{t^2} \cdot M_{T,i} \cdot \frac{\lambda}{2} \cdot \tanh\left(\frac{\lambda \cdot a}{2}\right)$$

where

$$\lambda = \sqrt{\frac{m_d}{G \cdot I_T}}$$

$$m_d = 1.15 \cdot \frac{E \cdot t^3}{a} \cdot \frac{\left(\sinh\left(\frac{\pi \cdot b}{a}\right)\right)^2}{\sinh\left(\frac{2 \cdot \pi \cdot b}{s}\right) - 2 \cdot \frac{\pi \cdot b}{a}}$$

The descriptions mean:

t	Thickness of the web plate
G	Shear module (steel G = 8100 kN/cm^2)
E	Modulus of elasticity (steel G = 21000 kN/cm^2)
I_T	Torsion constant
a	Spacing of the transverse web stiffeners
b	Depth of the transverse web stiffener (is usually equal to the depth of the web plate)

In the fatigue design, the stress σ_z from the wheel load has an influence, according to [2] clause 4.1.2τ, on the shear stresses at the loaded upper edge of the web plate. The stress σ_z from the wheel load induces the sheer stress τ_{xz} in the web plate. In CRANEWAY, this is taken into account by the following formula:

$$\tau_{xz} = 0.2 \cdot \sigma_z$$

EN 1993-6 (EN 1993-1-9)

The fatigue design according to EN 1993-1-9 is based on the nominal stress concept. The internal forces are determined according to the structural analysis for members; the stresses are calculated at the location of the expected crack formation according to the mechanics of materials. In the fatigue design, the nominal stress ranges Δσ and Δτ due to actions are compared to the design values of the fatigue strength $\Delta\sigma_R$ and $\Delta\tau_R$. Furthermore, the concept of the partial safety values applies in EN 1993-1-9.

The standard procedure according to EN 1993-1-9 is the design by means of the damage equivalent factors: Here, the equivalent constant amplitude stress ranges $\Delta\sigma_{E,2}$ and $\Delta\tau_{E,2}$ relative to n = $2*10^6$ stress cycles under consideration of the partial safety factors are to be set in relation to the limit values of the fatigue strength $\Delta\sigma_C$ or $\Delta\tau_C$ for n = $2*10^6$ stress cycles of the detail category. This leads to the following design requirements:

$$\frac{\gamma_{Ff} \cdot \Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}} \leq 1.0 \qquad \text{and}$$

$$\frac{\gamma_{Ff} \cdot \Delta\tau_{E,2}}{\Delta\tau_C / \gamma_{Mf}} \leq 1.0$$

where

$$\gamma_{Ff} \cdot \Delta\sigma_{E,2} = \lambda \cdot \Delta\sigma$$

EN 1993-1-9, chapter 8, Eq. 8.2

For simultaneous occurrence of direct and shear stress ranges, the following is valid:

$$\left(\frac{\gamma_{Ff} \cdot \Delta\sigma_{E,2}}{\Delta\sigma_C / \gamma_{Mf}}\right)^3 + \left(\frac{\gamma_{Ff} \cdot \Delta\tau_{E,2}}{\Delta\tau_C / \gamma_{Mf}}\right)^5 \leq 1.0$$

EN 1993-1-9, chapter 8, Eq. 8.3

To determine the equivalent constant amplitude stress range, EN 1991-3 gives the damage equivalent factors λ_i for the respective damage classes. The following table is implemented in CRANEWAY.

Table 2.12 — λ_i-values according to the classification of cranes

Classes S	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
normal stresses	0,198	0,250	0,315	0,397	0,500	0,630	0,794	1,00	1,260	1,587
shear stresses	0,379	0,436	0,500	0,575	0,660	0,758	0,871	1,00	1,149	1,320

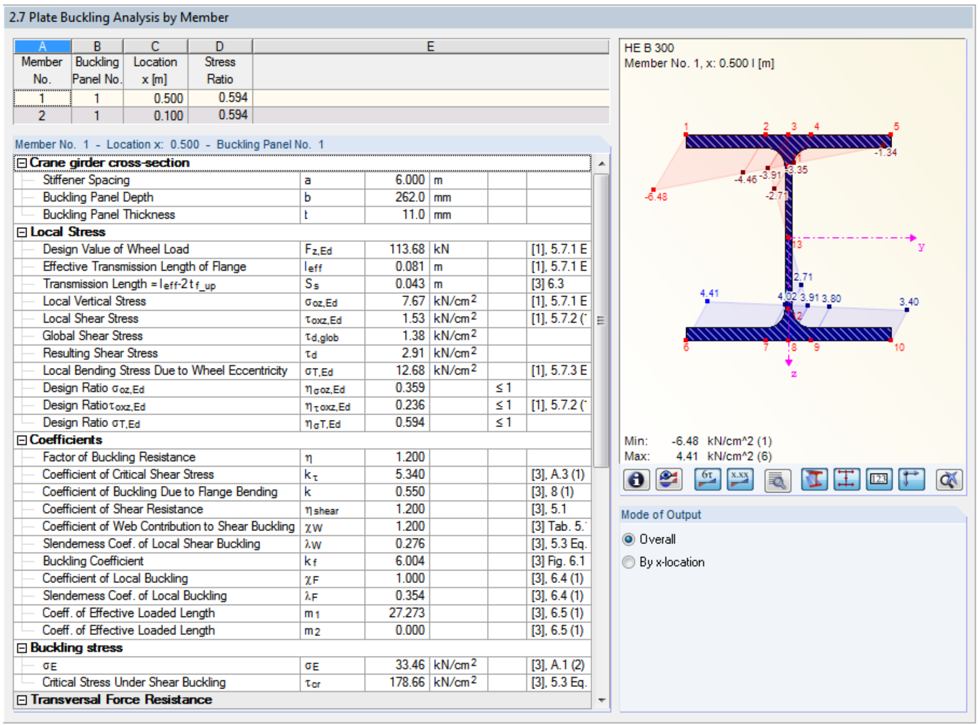
NOTE 1: In determining the λ-values standardized spectra with a gaussian distribution of the load effects, the Miner rule and fatigue strength S-N lines with a slope $m = 3$ for normal stresses and $m = 5$ for shear stress have been used.

NOTE 2: In case the crane classification is not included in the specification documents of the crane indications are given in Annex B.

Figure 4.20: Damage equivalent factors according to EN 1991-3, Table 2.12

4.7 Plate Buckling Analysis

For the *Overall* mode of output, the upper table shows the member with the x-location where the maximum ratio occurs for each panel of the crane runway beam. In the table below, you can see detailed characteristics of the buckling panel, local stresses, coefficients, etc. for the row selected in the table above.



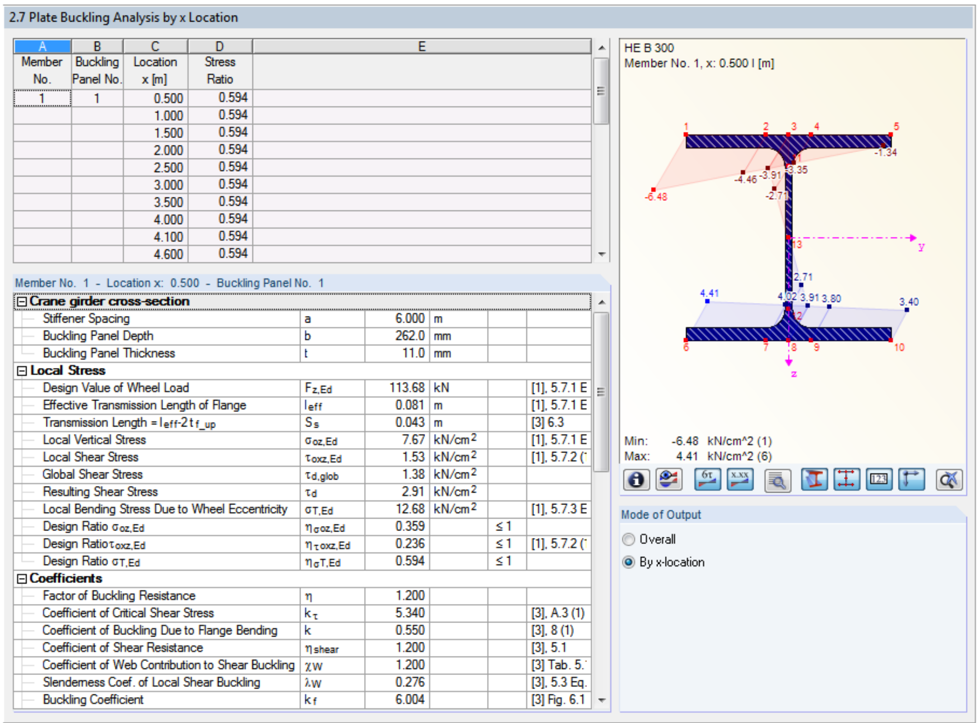
A Member No.	B Buckling Panel No.	C Location x [m]	D Stress Ratio	E
1	1	0.500	0.594	
2	1	0.100	0.594	

Member No. 1 - Location x: 0.500 - Buckling Panel No. 1

Crane girder cross-section					
Stiffener Spacing	a	6.000	m		
Buckling Panel Depth	b	262.0	mm		
Buckling Panel Thickness	t	11.0	mm		
Local Stress					
Design Value of Wheel Load	$F_{z,Ed}$	113.68	kN		[1], 5.7.1 E
Effective Transmission Length of Flange	l_{eff}	0.081	m		[1], 5.7.1 E
Transmission Length = l_{eff}-2 t_{f_up}	S_s	0.043	m		[3] 6.3
Local Vertical Stress	$\sigma_{oz,Ed}$	7.67	kN/cm²		[1], 5.7.1 E
Local Shear Stress	$\tau_{oxz,Ed}$	1.53	kN/cm²		[1], 5.7.2 (
Global Shear Stress	$\tau_{d,glob}$	1.38	kN/cm²		
Resulting Shear Stress	τ_d	2.91	kN/cm²		
Local Bending Stress Due to Wheel Eccentricity	$\sigma_{T,Ed}$	12.68	kN/cm²		[1], 5.7.3 E
Design Ratio $\sigma_{oz,Ed}$	$\eta_{\sigma oz,Ed}$	0.359		≤ 1	
Design Ratio $\tau_{oxz,Ed}$	$\eta_{\tau oxz,Ed}$	0.236		≤ 1	[1], 5.7.2 (
Design Ratio $\sigma_{T,Ed}$	$\eta_{\sigma T,Ed}$	0.594		≤ 1	
Coefficients					
Factor of Buckling Resistance	η	1.200			
Coefficient of Critical Shear Stress	k_τ	5.340			[3], A.3 (1)
Coefficient of Buckling Due to Flange Bending	k	0.550			[3], 8 (1)
Coefficient of Shear Resistance	η_{shear}	1.200			[3], 5.1
Coefficient of Web Contribution to Shear Buckling	χ_W	1.200			[3] Tab. 5.
Slenderness Coef. of Local Shear Buckling	λ_W	0.276			[3], 5.3 Eq.
Buckling Coefficient	k_f	6.004			[3] Fig. 6.1
Coefficient of Local Buckling	χ_F	1.000			[3], 6.4 (1)
Slenderness Coef. of Local Buckling	λ_F	0.354			[3], 6.4 (1)
Coeff. of Effective Loaded Length	m_1	27.273			[3], 6.5 (1)
Coeff. of Effective Loaded Length	m_2	0.000			[3], 6.5 (1)
Buckling stress					
σ_E	σ_E	33.46	kN/cm²		[3], A.1 (2)
Critical Stress Under Shear Buckling	τ_{cr}	178.66	kN/cm²		[3], 5.3 Eq.
Transversal Force Resistance					

Figure 4.21: Window 2.7 *Plate Buckling Analysis - Overall*

You can display the governing designs also *By x-location*.



A Member No.	B Buckling Panel No.	C Location x [m]	D Stress Ratio	E
1	1	0.500	0.594	
		1.000	0.594	
		1.500	0.594	
		2.000	0.594	
		2.500	0.594	
		3.000	0.594	
		3.500	0.594	
		4.000	0.594	
		4.100	0.594	
		4.600	0.594	

Member No. 1 - Location x: 0.500 - Buckling Panel No. 1

Crane girder cross-section					
Stiffener Spacing	a	6.000	m		
Buckling Panel Depth	b	262.0	mm		
Buckling Panel Thickness	t	11.0	mm		
Local Stress					
Design Value of Wheel Load	$F_{z,Ed}$	113.68	kN		[1], 5.7.1 E
Effective Transmission Length of Flange	l_{eff}	0.081	m		[1], 5.7.1 E
Transmission Length = l_{eff}-2 t_{f_up}	S_s	0.043	m		[3] 6.3
Local Vertical Stress	$\sigma_{oz,Ed}$	7.67	kN/cm²		[1], 5.7.1 E
Local Shear Stress	$\tau_{oxz,Ed}$	1.53	kN/cm²		[1], 5.7.2 (
Global Shear Stress	$\tau_{d,glob}$	1.38	kN/cm²		
Resulting Shear Stress	τ_d	2.91	kN/cm²		
Local Bending Stress Due to Wheel Eccentricity	$\sigma_{T,Ed}$	12.68	kN/cm²		[1], 5.7.3 E
Design Ratio $\sigma_{oz,Ed}$	$\eta_{\sigma oz,Ed}$	0.359		≤ 1	
Design Ratio $\tau_{oxz,Ed}$	$\eta_{\tau oxz,Ed}$	0.236		≤ 1	[1], 5.7.2 (
Design Ratio $\sigma_{T,Ed}$	$\eta_{\sigma T,Ed}$	0.594		≤ 1	
Coefficients					
Factor of Buckling Resistance	η	1.200			
Coefficient of Critical Shear Stress	k_τ	5.340			[3], A.3 (1)
Coefficient of Buckling Due to Flange Bending	k	0.550			[3], 8 (1)
Coefficient of Shear Resistance	η_{shear}	1.200			[3], 5.1
Coefficient of Web Contribution to Shear Buckling	χ_W	1.200			[3] Tab. 5.
Slenderness Coef. of Local Shear Buckling	λ_W	0.276			[3], 5.3 Eq.
Buckling Coefficient	k_f	6.004			[3] Fig. 6.1

Figure 4.22: Window 2.7 *Plate Buckling Analysis by x-Location*

4.8 Welds - Stress Analysis

This window is displayed only if you selected the weld seam design in the 1.3 *Cross-Section* window (see chapter 2.3, page 15). The stresses of the weld seams can also be displayed *Overall* or *By x-location*.

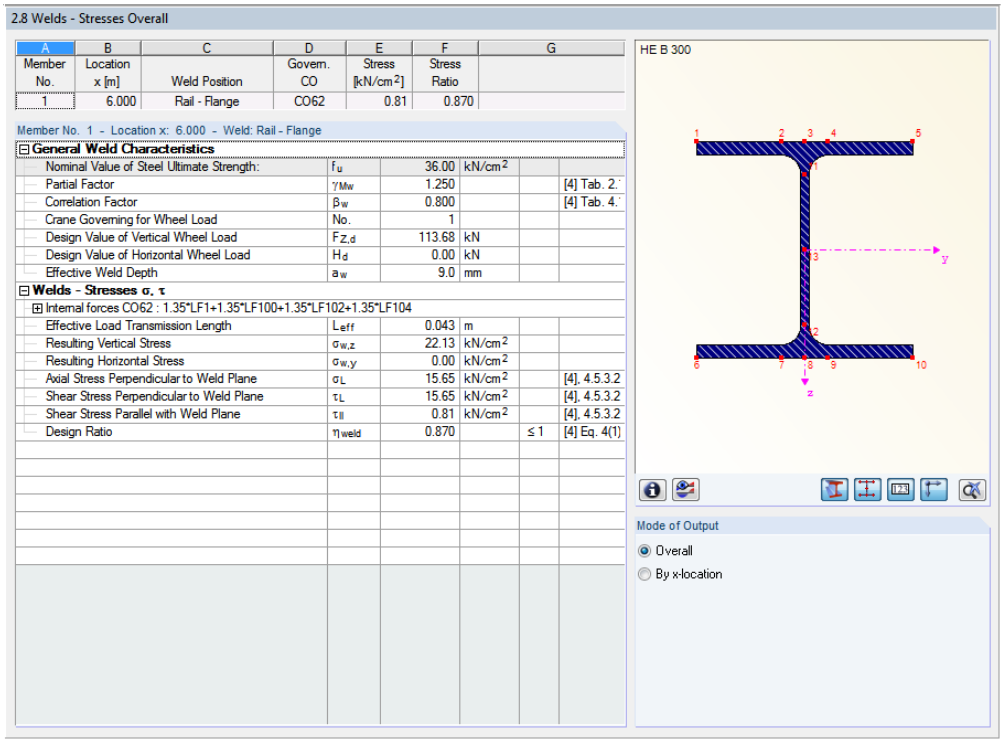


Figure 4.23: Window 2.8 *Welds - Stresses Overall*

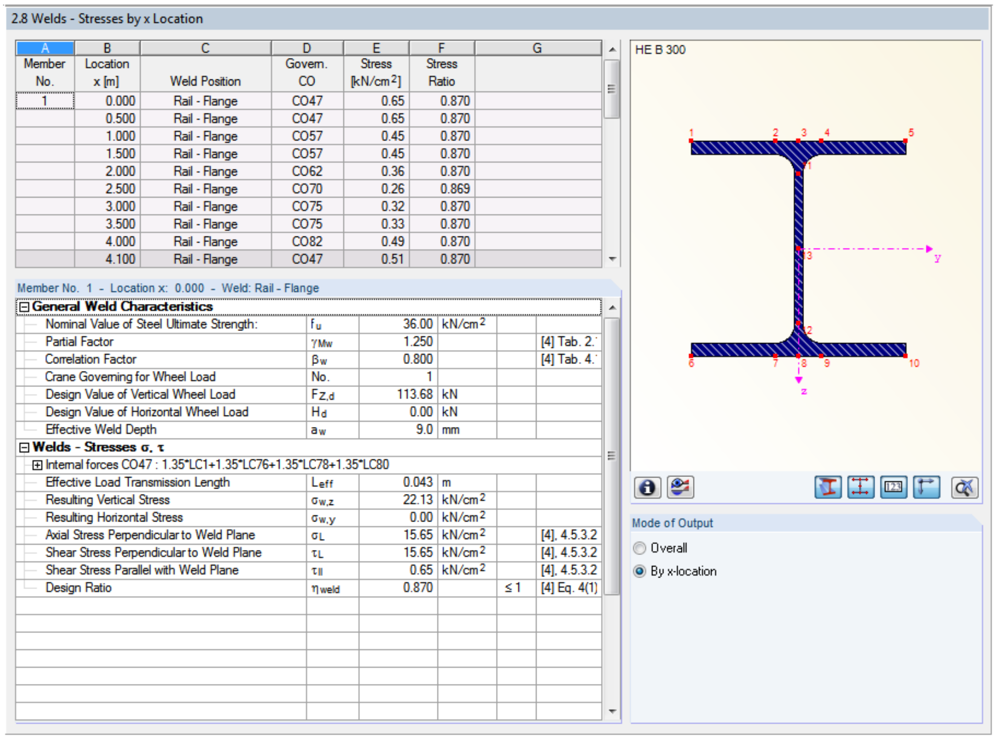
For the *Overall* mode of output, the upper table shows only those x-locations of each weld seam (rail-flange and flange-web) that result in a maximum ratio. It also shows for which load combination this design criterion is relevant.

The design criterion is met if the ratio is smaller than 1. The stress ratio is the ratio of determined equivalent stress to the limit equivalent stress of the weld seam.

Details of weld seams

The lower table of this window lists the intermediate results for the design criterion of the location selected in the table above. In addition to the general weld characteristics, the table shows the internal forces, normal stresses σ, and shear stresses τ of the weld seam.

If you select the mode of output *By x-location*, the table shows the governing stress analyses for the weld seams at every x-location.


2.8 Welds - Stresses by x Location

A Member No.	B Location x [m]	C Weld Position	D Govern. CO	E Stress [kN/cm²]	F Stress Ratio	G
1	0.000	Rail - Flange	CO47	0.65	0.870	
	0.500	Rail - Flange	CO47	0.65	0.870	
	1.000	Rail - Flange	CO57	0.45	0.870	
	1.500	Rail - Flange	CO57	0.45	0.870	
	2.000	Rail - Flange	CO62	0.36	0.870	
	2.500	Rail - Flange	CO70	0.26	0.869	
	3.000	Rail - Flange	CO75	0.32	0.870	
	3.500	Rail - Flange	CO75	0.33	0.870	
	4.000	Rail - Flange	CO82	0.49	0.870	
	4.100	Rail - Flange	CO47	0.51	0.870	

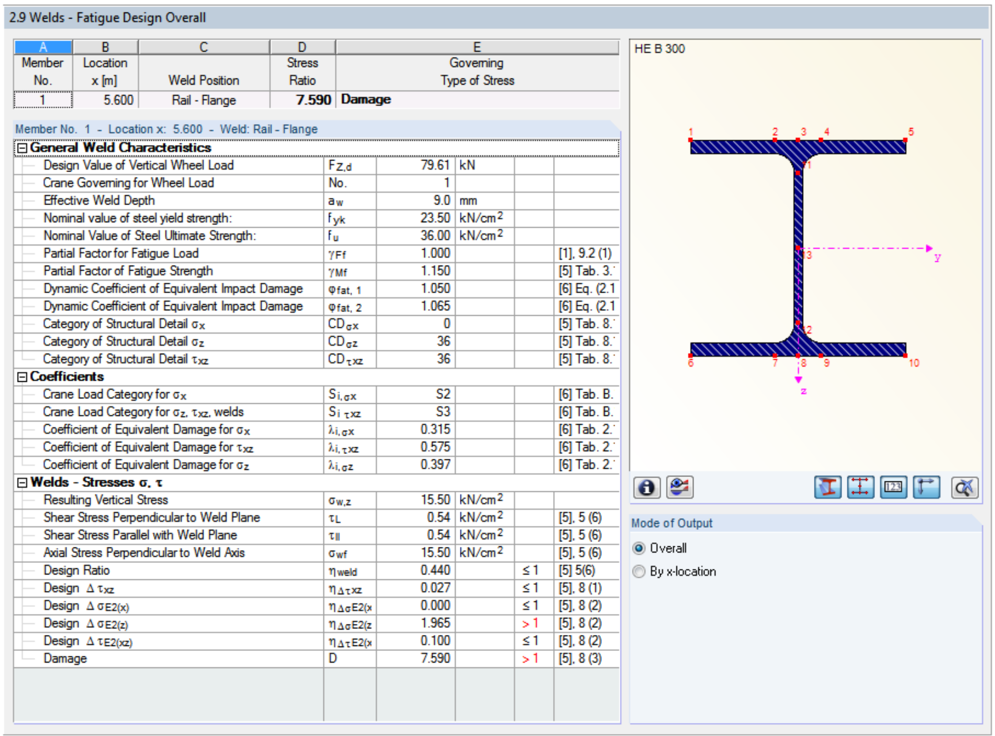
Member No. 1 - Location x: 0.000 - Weld: Rail - Flange

General Weld Characteristics					
Nominal Value of Steel Ultimate Strength:	f_u	36.00	kN/cm²		
Partial Factor	γ_{Mw}	1.250			[4] Tab. 2.
Correlation Factor	β_w	0.800			[4] Tab. 4.
Crane Governing for Wheel Load	No.	1			
Design Value of Vertical Wheel Load	$F_{z,d}$	113.68	kN		
Design Value of Horizontal Wheel Load	H_d	0.00	kN		
Effective Weld Depth	a_w	9.0	mm		
Welds - Stresses σ, τ					
Internal forces CO47 : 1.35*LC1+1.35*LC76+1.35*LC78+1.35*LC80					
Effective Load Transmission Length	L_{eff}	0.043	m		
Resulting Vertical Stress	$\sigma_{w,z}$	22.13	kN/cm²		
Resulting Horizontal Stress	$\sigma_{w,y}$	0.00	kN/cm²		
Axial Stress Perpendicular to Weld Plane	$\sigma_\perp$	15.65	kN/cm²		[4], 4.5.3.2
Shear Stress Perpendicular to Weld Plane	$\tau_\perp$	15.65	kN/cm²		[4], 4.5.3.2
Shear Stress Parallel with Weld Plane	$\tau_\parallel$	0.65	kN/cm²		[4], 4.5.3.2
Design Ratio	η_{weld}	0.870		≤ 1	[4] Eq. 4(1)

Figure 4.24: Window 2.8 *Welds - Stresses by x-Location*

4.9 Welds - Fatigue Design

This window shows the weld seam ratios for the fatigue design. As in the other output windows, you can select between the modes of output *Overall* and *By x-Location*.


2.9 Welds - Fatigue Design Overall

A Member No.	B Location x [m]	C Weld Position	D Stress Ratio	E Governing Type of Stress
1	5.600	Rail - Flange	**7.590**	**Damage**

Member No. 1 - Location x: 5.600 - Weld: Rail - Flange

General Weld Characteristics					
Design Value of Vertical Wheel Load	$F_{z,d}$	79.61	kN		
Crane Governing for Wheel Load	No.	1			
Effective Weld Depth	a_w	9.0	mm		
Nominal value of steel yield strength:	f_{yk}	23.50	kN/cm²		
Nominal Value of Steel Ultimate Strength:	f_u	36.00	kN/cm²		
Partial Factor for Fatigue Load	γ_{Ff}	1.000			[1], 9.2 (1)
Partial Factor of Fatigue Strength	γ_{Mf}	1.150			[5] Tab. 3.
Dynamic Coefficient of Equivalent Impact Damage	$\varphi_{fat,1}$	1.050			[6] Eq. (2.1
Dynamic Coefficient of Equivalent Impact Damage	$\varphi_{fat,2}$	1.065			[6] Eq. (2.1
Category of Structural Detail σ_x	$CD_{\sigma x}$	0			[5] Tab. 8.
Category of Structural Detail σ_z	$CD_{\sigma z}$	36			[5] Tab. 8.
Category of Structural Detail τ_{xz}	$CD_{\tau xz}$	36			[5] Tab. 8.
Coefficients					
Crane Load Category for σ_x	$S_{i,\sigma x}$	S2			[6] Tab. B.
Crane Load Category for σ_z, τ_{xz}, welds	$S_{i,\tau xz}$	S3			[6] Tab. B.
Coefficient of Equivalent Damage for σ_x	$\lambda_{i,\sigma x}$	0.315			[6] Tab. 2.
Coefficient of Equivalent Damage for τ_{xz}	$\lambda_{i,\tau xz}$	0.575			[6] Tab. 2.
Coefficient of Equivalent Damage for σ_z	$\lambda_{i,\sigma z}$	0.397			[6] Tab. 2.
Welds - Stresses σ, τ					
Resulting Vertical Stress	$\sigma_{w,z}$	15.50	kN/cm²		
Shear Stress Perpendicular to Weld Plane	$\tau_\perp$	0.54	kN/cm²		[5], 5 (6)
Shear Stress Parallel with Weld Plane	$\tau_\parallel$	0.54	kN/cm²		[5], 5 (6)
Axial Stress Perpendicular to Weld Axis	σ_{wf}	15.50	kN/cm²		[5], 5 (6)
Design Ratio	η_{weld}	0.440		≤ 1	[5] 5(6)
Design Δ τ_{xz}	$\eta_{\Delta\tau xz}$	0.027		≤ 1	[5], 8 (1)
Design Δ $\sigma_{E2(x)}$	$\eta_{\Delta\sigma E2(x}$	0.000		≤ 1	[5], 8 (2)
Design Δ $\sigma_{E2(z)}$	$\eta_{\Delta\sigma E2(z}$	1.965		> 1	[5], 8 (2)
Design Δ $\tau_{E2(xz)}$	$\eta_{\Delta\tau E2(x}$	0.100		≤ 1	[5], 8 (2)
Damage	D	7.590		> 1	[5], 8 (3)

Figure 4.25: Window 2.9 *Welds - Fatigue Design Overall*

4.10 Critical Load Factors

The last results window appears if you select the check box *Calculate critical load factors of all load combinations* in the *FE-LTB* tab of the *Details* dialog box (see Figure 3.3, page 37). It provides an overview of the critical load factors determined for the relevant load combinations (load positions).

2.10 Critical Load Factors

A CO	B Critical Load Factor	C Reason for Ending Calculation
CO1	9.000	9) Maximum nu factor has been reached -> no stability problem
CO47	8.969	2) Diagonal coefficient in matrix is less than zero
CO57	8.453	3) Maximum number of 50 equilibrium iterations has been reached
CO62	7.531	3) Maximum number of 50 equilibrium iterations has been reached
CO70	7.781	3) Maximum number of 50 equilibrium iterations has been reached
CO75	7.969	2) Diagonal coefficient in matrix is less than zero
CO82	8.531	2) Diagonal coefficient in matrix is less than zero
CO85	9.564	2) Diagonal coefficient in matrix is less than zero
CO107	7.656	3) Maximum number of 50 equilibrium iterations has been reached
CO112	8.656	3) Maximum number of 50 equilibrium iterations has been reached
CO122	8.719	3) Maximum number of 50 equilibrium iterations has been reached
CO140	7.656	3) Maximum number of 50 equilibrium iterations has been reached

Figure 4.26: Window 2.10 *Critical Load Factors*

Critical Load Factor

The value is an indicator for the stability of the structural system. A critical load factor of, for example, 7.969 for the load combination CO75 (see figure above) means that the loading of this load combination can be increased only by the factor 7.969 until the system becomes unstable (comment *Diagonal coefficient in matrix is less than zero*). An elastic material behavior is assumed.

Reason for Ending Calculation

In most cases, column C shows the comments *Diagonal coefficient in matrix is less than zero* or *Maximum number of x equilibrium iterations has been reached*. The first comment indicates that the loss of stability could be confirmed mathematically. The second comment means that it was not possible to reach the break-off limit in the allowed number of iterations. The *Maximum number of equilibrium iterations* and the *Break-off limit* are set in the *FE-LTB* tab of the *Details* dialog box (see Figure 3.3, page 37).

If the critical load factor is smaller than 1, the model becomes unstable already before reaching the design load.

If the critical load factor is 0, the calculation could not be carried out. The model is probably kinematic so that you have to check the support conditions.

5. Printout Report

The CRANEWAY input and output data is not automatically sent to a printer. Instead, the printout report is first generated from the data. You can add graphics, descriptions or comments, scans, etc. to the printout report (see Figure 5.5, page 66).

5.1 Create Printout Report

Since the printout report has not been created in RSTAB or RFEM yet, you must first exit CRANEWAY by clicking [OK] or [Graphics]. The printout report can then be started in RSTAB or RFEM by selecting from the menu

File → Open Printout Report

or clicking the corresponding button.

If a printout report does not exist yet, the *New Printout Report* dialog box appears.

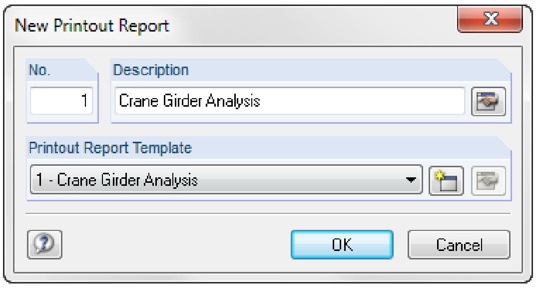


Figure 5.1: Dialog box *New Printout Report*

The *number* of the report is set by default but can also be changed. You can add a *Description* for the report, which makes it easier to select it from the list of other reports later. The description does not appear in the printout.

Furthermore, you can select a particular report template from the list in the dialog section *Printout Report Template*.

The buttons in the dialog box have the following functions:

	A new report template can be created.
	The selection of the report can be edited (➔ chapter 5.2, page 63).

Table 5.1: Buttons in dialog box *New Printout Report*

5.2 Selection in Printout Report

You can select the chapters to be displayed in the printout report in a dialog box. To open this dialog box, select in the printout report menu

Edit → Selection

or click [Select Topics for Printout Report].

The *Printout Report Selection* dialog box appears.

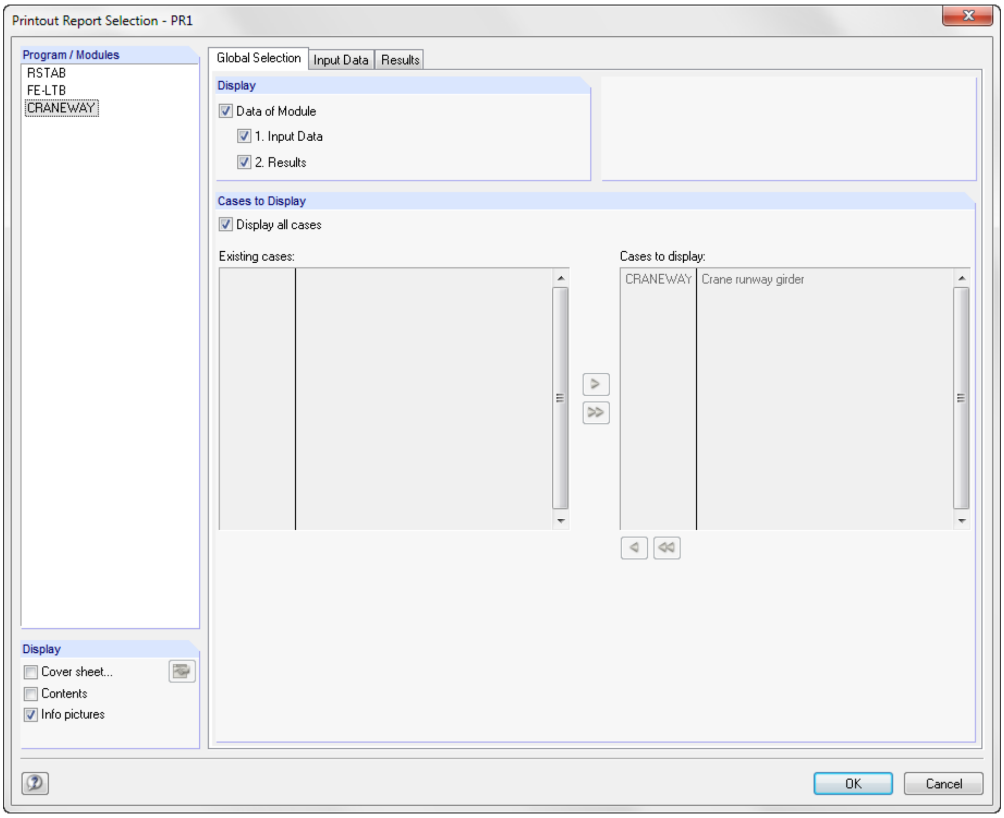


Figure 5.2: Dialog box *Printout Report Selection*, tab *Global Selection*

The list in the *Program / Modules* section contains the modules, for which input data is available. After you select the program in this list, you can continue with the tabs to the right to select the chapters that you want to print.

Global Selection

The first tab manages the main chapters of the report. If you clear the selection of a check box, the corresponding detail tab disappears as well. To display only the input data and results from CRANEWAY, you can clear the selection of the *RSTAB Data* or *RFEM Data* in the global selection of these programs.

Use the three check boxes in the lower-left section *Display* to decide if you want to display the *Cover sheet*, *Contents*, or small *Info pictures* in the report margin.

Input Data

The second tab controls which input data should appear in the report.

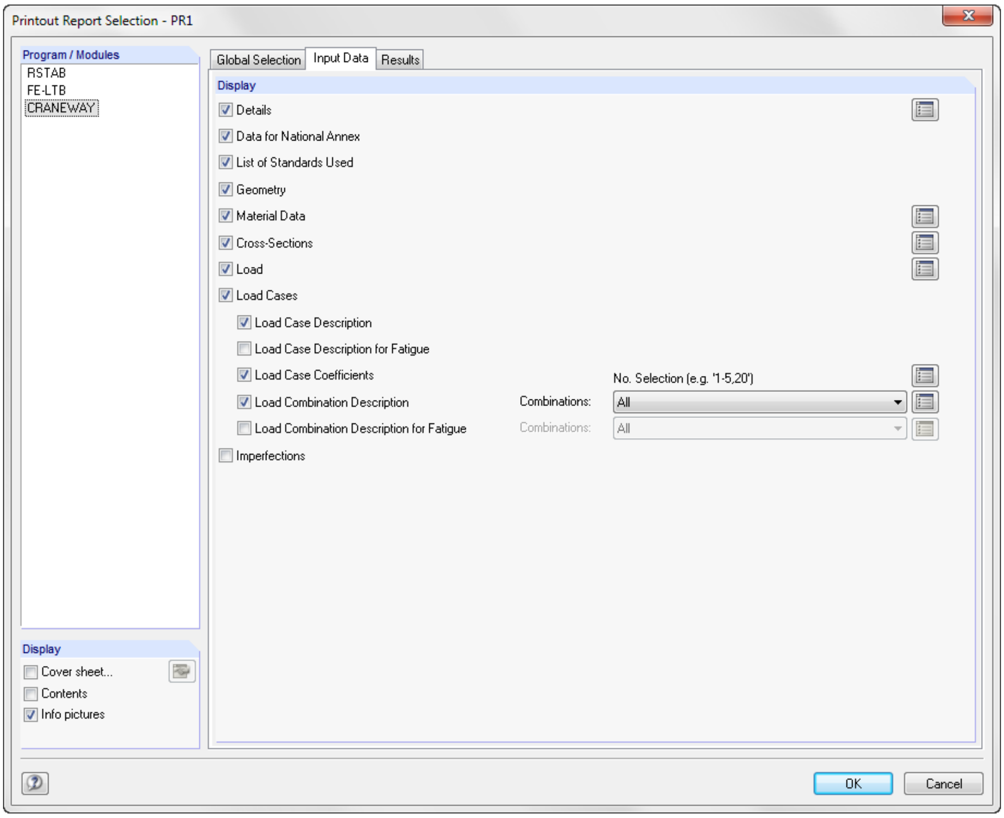


Figure 5.3: Dialog box *Printout Report Selection*, tab *Input Data*

For many of the listed categories, you can specifically define the scope of the data to be printed by clicking [Details].

Results

In this tab, you can also define which results should be included in the printout report and how detailed the output should be by using the check boxes and option buttons.

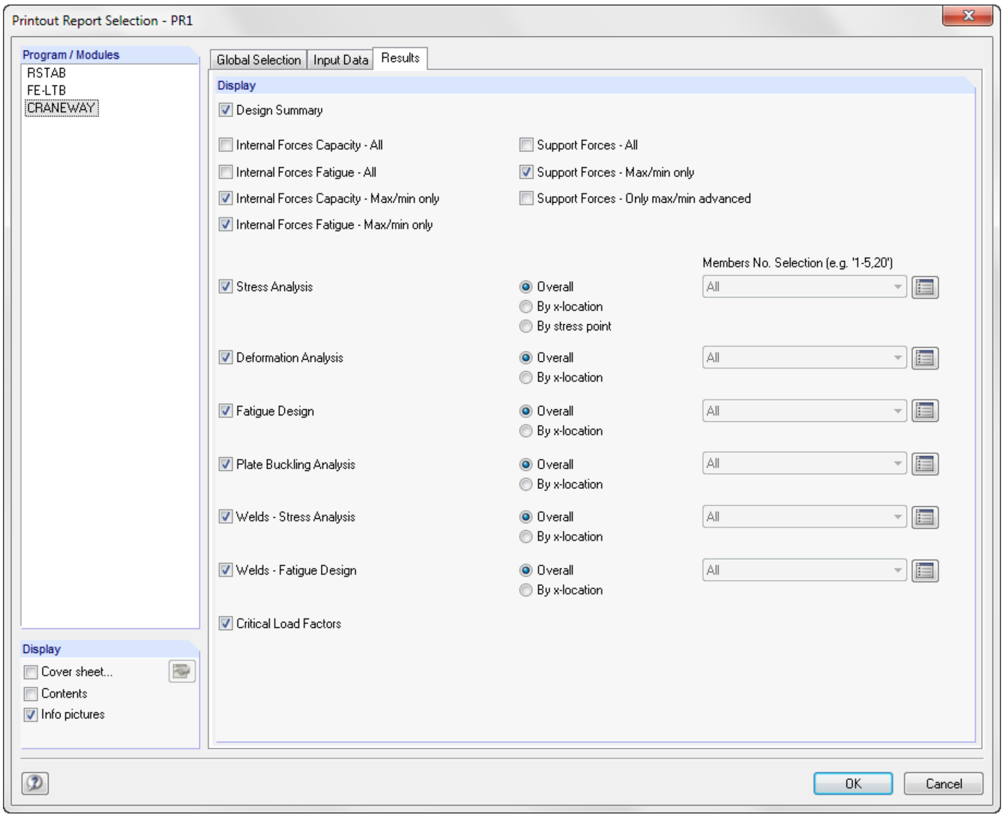


Figure 5.4: Dialog box *Printout Report Selection*, tab *Results*

Like the CRANEWAY results windows, the printable results are sorted by designs. To specify the scope of the printed results, click [Details].

5.3 Printout Report Navigator

The generated printout report shows a Navigator on the left and a preview of the printout report in the main window on the right.

The individual chapters of the report can be moved anywhere in the Navigator by using the drag-and-drop function.

The context menu in the Navigator provides further options for adjusting the printout report. To open the context menu, right-click the relevant chapter. As common for Windows applications, you can use multiple selections by pressing [Ctrl] or [⇧].

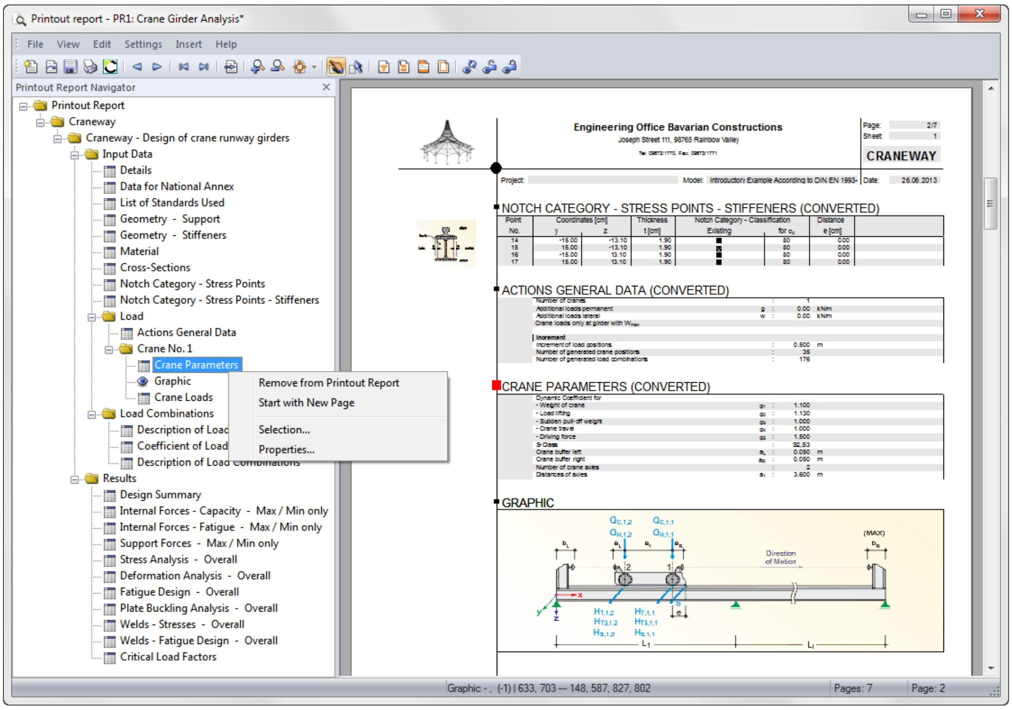
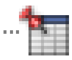


Figure 5.5: Context menu in navigator and preview

Remove from Printout Report

The selected chapter will be deleted. If you want to reinsert it, select menu *Edit* → *Selection*.

Start with New Page



The selected chapter starts on a new page and is marked by a red pin in the navigator.

Selection

You have access to the global selection that is described on the following pages. The selected chapter is preset.

Properties

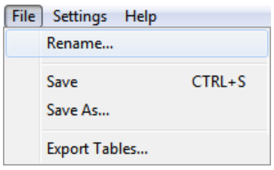
Some general properties of a chapter can be modified; for example, you can change the title or enter an additional description.

6. General Functions

This chapter describes useful menu functions and graphical options for input and evaluation.

6.1 Menu *File*

With these menu functions, you can change the description of the CRANEWAY case and export the windows as tables.



Rename

This function allows you to enter a new *Description* for the CRANEWAY case.

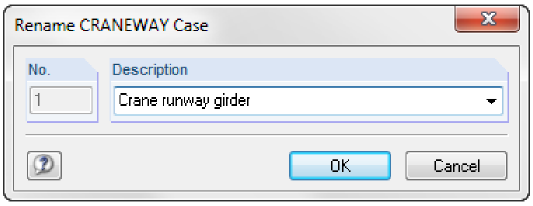


Figure 6.1: Dialog box *Rename CRANEWAY Case*

Export Tables

CRANEWAY allows you to directly export data to *MS Excel*, *OpenOffice.org Calc*, or the *CSV* file format. The following export dialog box appears.

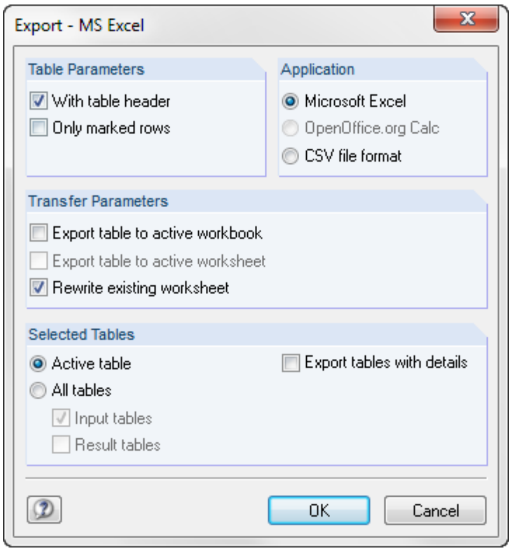
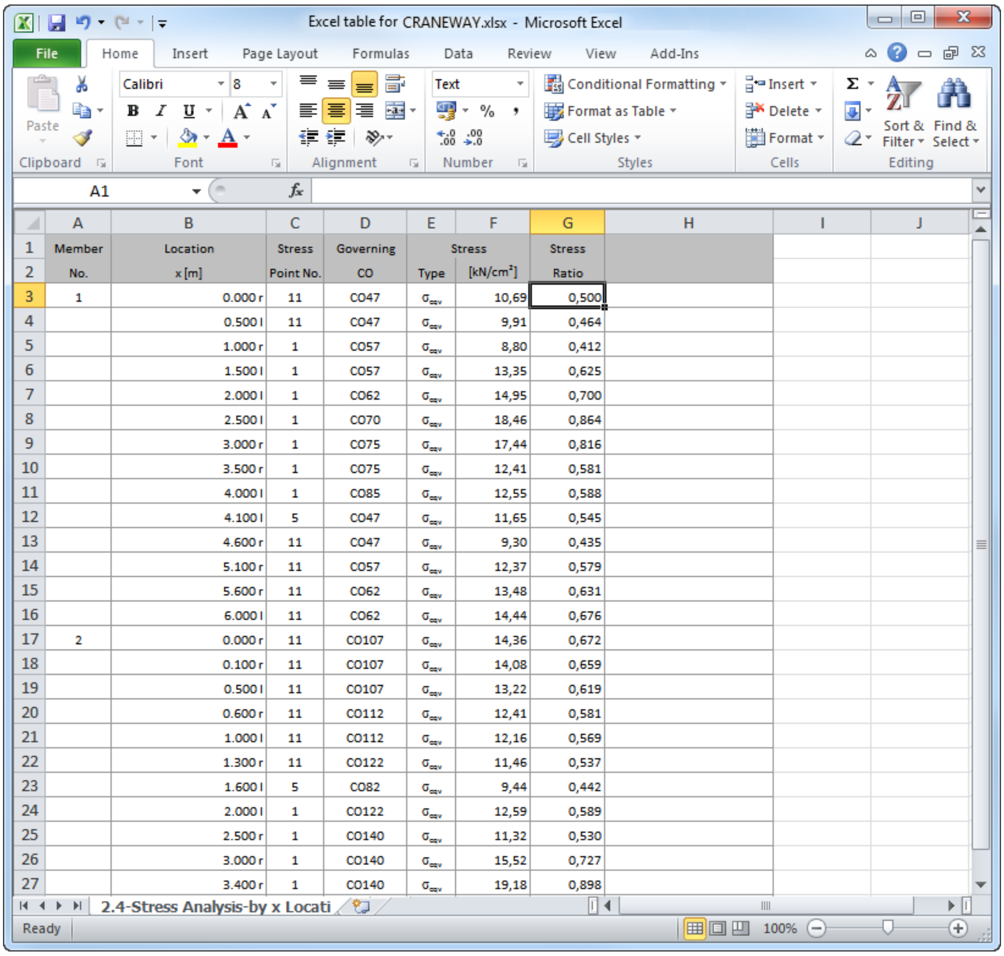


Figure 6.2: Dialog box *Export - MS Excel*

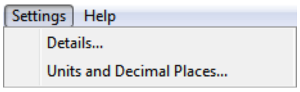
When your selection is complete, you can start the export by clicking [OK]. Excel or OpenOffice will be started automatically, that is, the programs do not have to be opened first.



Member No.	Location x [m]	Stress Point No.	Governing CO	Type	Stress [kN/cm²]	Stress Ratio
1	0.000 r	11	CO47	σ_{eqv}	10,69	0,500
	0.500 l	11	CO47	σ_{eqv}	9,91	0,464
	1.000 r	1	CO57	σ_{eqv}	8,80	0,412
	1.500 l	1	CO57	σ_{eqv}	13,35	0,625
	2.000 l	1	CO62	σ_{eqv}	14,95	0,700
	2.500 l	1	CO70	σ_{eqv}	18,46	0,864
	3.000 r	1	CO75	σ_{eqv}	17,44	0,816
	3.500 r	1	CO75	σ_{eqv}	12,41	0,581
	4.000 l	1	CO85	σ_{eqv}	12,55	0,588
	4.100 l	5	CO47	σ_{eqv}	11,65	0,545
	4.600 r	11	CO47	σ_{eqv}	9,30	0,435
	5.100 r	11	CO57	σ_{eqv}	12,37	0,579
	5.600 r	11	CO62	σ_{eqv}	13,48	0,631
	6.000 l	11	CO62	σ_{eqv}	14,44	0,676
2	0.000 r	11	CO107	σ_{eqv}	14,36	0,672
	0.100 r	11	CO107	σ_{eqv}	14,08	0,659
	0.500 l	11	CO107	σ_{eqv}	13,22	0,619
	0.600 r	11	CO112	σ_{eqv}	12,41	0,581
	1.000 l	11	CO112	σ_{eqv}	12,16	0,569
	1.300 r	11	CO122	σ_{eqv}	11,46	0,537
	1.600 l	5	CO82	σ_{eqv}	9,44	0,442
	2.000 l	1	CO122	σ_{eqv}	12,59	0,589
	2.500 r	1	CO140	σ_{eqv}	11,32	0,530
	3.000 r	1	CO140	σ_{eqv}	15,52	0,727
	3.400 r	1	CO140	σ_{eqv}	19,18	0,898

Figure 6.3: Result in *Excel*

6.2 Menu *Settings*



This menu contains functions for controlling the calculation and units.

Details

This function opens the *Details* dialog box. The tabs of this dialog box are described in chapter 3.1, page 34.

Units and Decimal Places

This function allows you to adjust the units and decimal places of the input and output data. A dialog box appears containing the two tabs *Input Data* and *Results*.

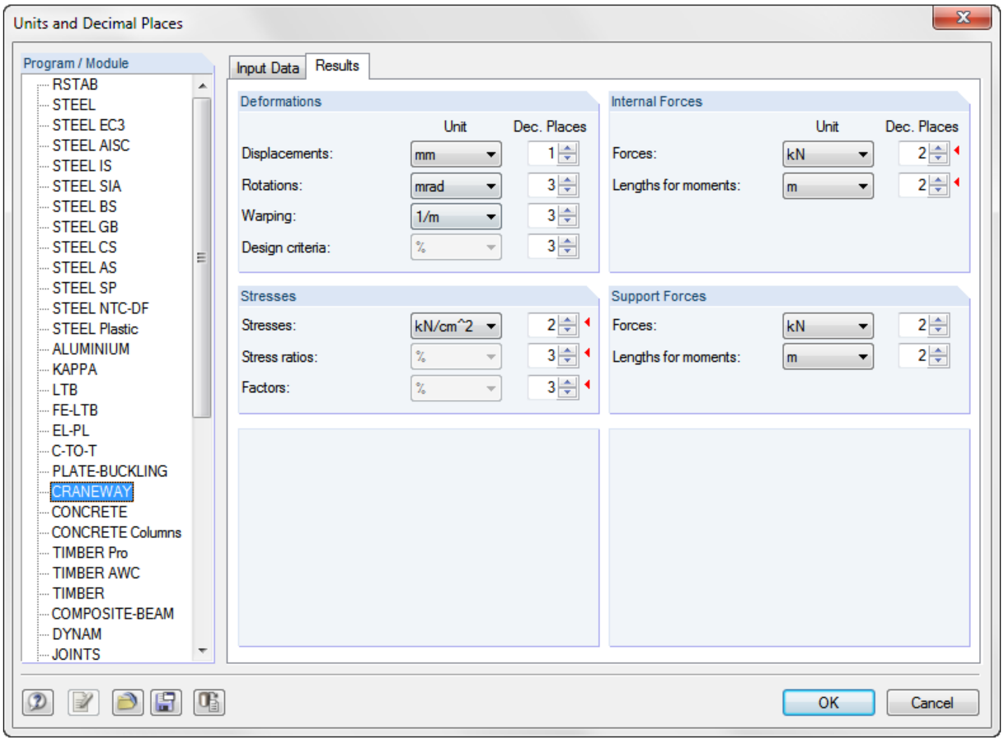


Figure 6.4: Dialog box *Units and Decimal Places*

The settings can be saved as a user profile by clicking [Save as Profile] and reused in other models by clicking [Load Saved Profile]. By clicking [Default], you can restore the default settings.

6.3 Graphic

6.3.1 Input Data

To check the input data graphically, click [3D-Rendering]. A new window appears showing a visualization of the crane runway girder.

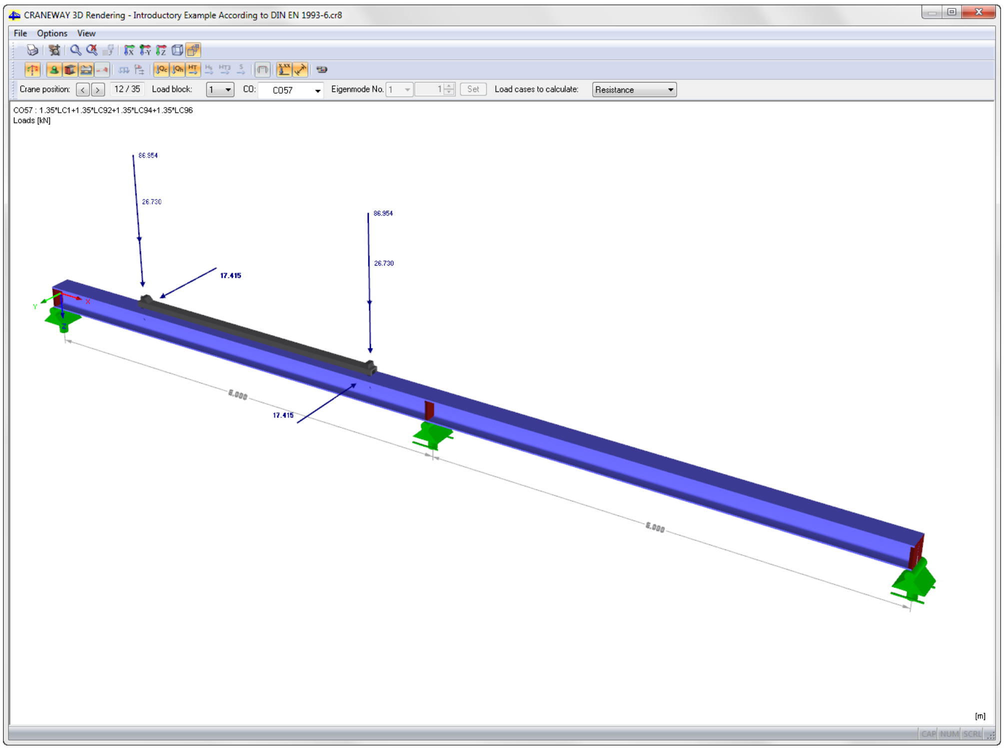


Figure 6.5: Graphic of the crane runway girder

The graphic shows the model of the runway girder and the load positions with the crane position and the acting forces.

The toolbar provides information on the current *Crane Position* and the total number of positions. Here, you can set another crane position. The movement of the crane on the girder can also be visualized by an animation.

Furthermore, you can also display all loads acting in individual crane positions. For all load combinations, you can also display the according imperfections.

In the list *Load cases to calculate*, you can select between the various design situations (resistance, fatigue, deformation, or support forces).

6.3.2 Results

The results can be displayed graphically in the RSTAB or RFEM work window. There, you can use all functions of the *Display* navigator to change the view.

To go to the work window, click [Graphics].

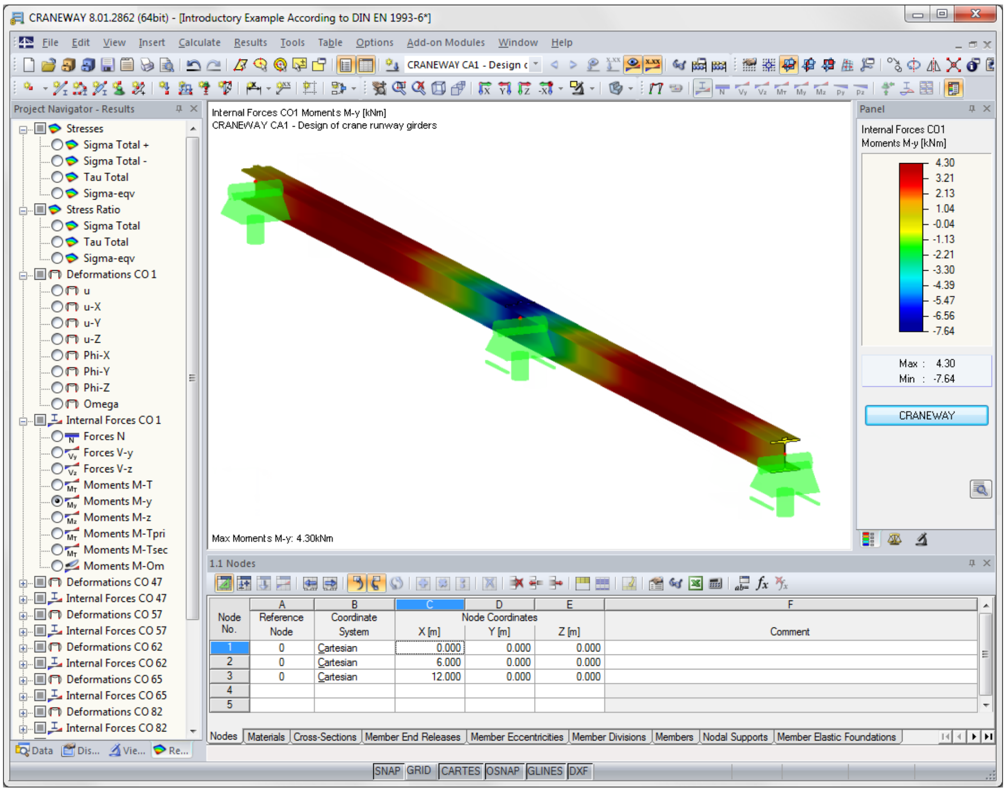


Figure 6.6: Graphic of results

If the results of the CRANEWAY case are not shown, you can display them by clicking the button [Show Results].

Panel

The control panel contains the tabs *Color Spectrum*, *Factors*, and *Filter*. They allow you to check the values by colors and modify the color scales, define the display factors or select the members for the results display.

Navigator

The *Results* navigator controls which result diagrams are to be displayed on the model:

- Stresses σ_{x+}, σ_{x-},τ, and σ_{eqv}
- Ratio for σ_x, τ, and σ_{eqv}
- Deformations
- Internal Forces

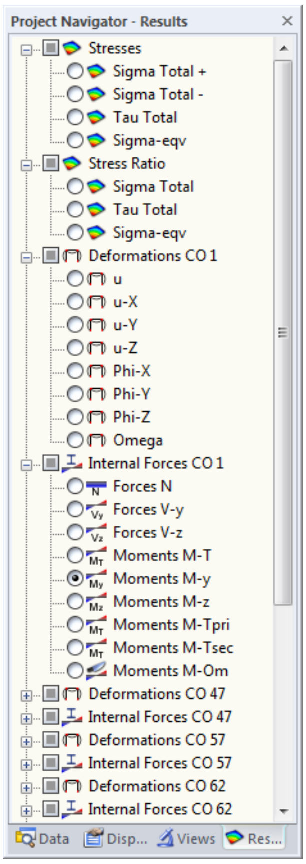


Figure 6.7: *Results* navigator for CRANEWAY

For the display of the *Deformations*, you can visualize the total displacement *u* as well as the displacements and rotations related to the global coordinate axes X,Y, and Z. The displacements in Y-direction always refer to the upper rail edge and also contain components from the rotation of the cross-section.

The *Internal Forces* N, V_y, V_z, M_T, M_y, M_z, M_{Tprim}, M_{Tsek}, and M_ω can be checked graphically.

To return to CRANEWAY, click [CRANEWAY].

7. Example

7.1 Two-Span Crane Runway acc. to DIN EN 1993-6

The following example from literature is calculated with CRANEWAY. In this way, it is possible to understand the calculations and to see the various possibilities of the program in action. The example is from [19].

System

- Two-span crane runway, cross-section HEB 300, flat steel crane rail 5 cm x 3 cm (worn-out), connected with double fillet weld a_w = 5 mm, S 235
- Self-weight of crane runway girder with rail g = 1.35 kN/m
- Transverse stiffeners only at the supports, welded at web and flanges, respectively
- Support on consoles at the hall columns, fork support
- Travel by means of a single crane bridge, crane system IFF
- Hoisting class HC2
- Stress group S_2
- Wheel distance c = 3.6 m

Loads

- Vertical wheel loads:

Q_c=18.00 kN	due to self-weight
Q_h =57.00 kN,	due to hoist load

- Horizontal wheel loads:

H_S =20.00 kN	Guide forces = S-Hs
$H_{T1}(H_1)$ = $-H_{T2}(H_2)$ =8.60 kN	Loads from acceleration and braking

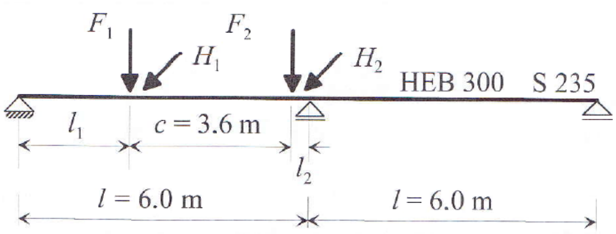


Figure 7.1: Sketch of system

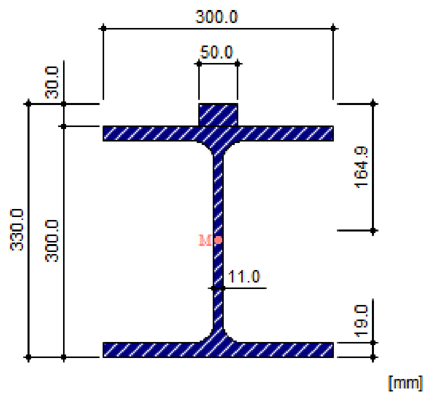


Figure 7.2: Cross-section

7.2 Internal Forces - Capacity

		Acc. to [19]				CRANEWAY			
Maximum field moment				*x-location*				*x-location*	
RC1	$M_{y,d}$	**147.90**	[kNm]	2.10	[m]	**147.20**	[kNm]	2.10	[m]
	$M_{z,d}$	**23.70**	[kNm]	3.36	[m]	**23.52**	[kNm]	2.60	[m]
RC2	$M_{y,d}$	**132.20**	[kNm]	2.10	[m]	**132.00**	[kNm]	2.10	[m]
	$M_{z,d}$	**33.60**	[kNm]	2.58	[m]	**37.17**	[kNm]	2.50	[m]
Maximum supporting moment									
RC1	$M_{y,d}$	**-129.87**	[kNm]	6.00	[m]	**-129.30**	[kNm]	6.00	[m]
RC2	$M_{y,d}$	**-116.37**	[kNm]	6.00	[m]	**-116.34**	[kNm]	6.00	[m]
Maximum shear force									
RC1	$V_{z,d}$	**-175.50**	[kN]	0.00	[m]	**-172.10**	[kN]	0.00	[m]
	$V_{y,d}$	**-17.40**	[kN]	0.00	[m]	**-17.41**	[kN]	0.00	[m]
RC2	$V_{z,d}$	**-157.00**	[kN]	6.00	[m]	**-154.00**	[kN]	6.00	[m]
	$V_{y,d}$	**-27.00**	[kN]	6.00	[m]	**-26.83**	[kN]	6.00	[m]

7.3 LTB Analysis as Stress Analysis

Equivalent imperfections

Acc. to [19]

The camber rise in y-direction is v_y = 1.5 cm.

CRANEWAY

The equivalent imperfections can be determined either automatically according to the eigen-value method or defined manually. For this example, we select the manual definition.

Stress calculation

Acc. to [19]

The maximum equivalent stress according to second-order analysis is obtained for x = 2.28 m (left span) at the upper surface of the top flange

σ_{eqv} = **19.10 kN/cm²**

CRANEWAY

x = 2.30 m (left span)

σ_{eqv} = **19.06 kN/cm²**

Elastic-elastic stress analysis

The stress analysis is carried out with the partial safety factor γ_{M1}.

Acc. to [19]

19.10/21.36 = **0.894** < **1**

LTB design satisfied

CRANEWAY

19.06/21.36 = **0.892** < **1**

Design satisfied

7.4 Load Application Stresses

Loaded length at transition between fillet radius and web

Rail is welded, that is, rigidly fixed to the top flange.

Acc. to [19]	CRANEWAY
l_{eff} = 12.8 cm	l_{eff} = 12.8 cm

Web compression at transition between fillet radius and web

Acc. to [19]	CRANEWAY
Web compression: $\sigma_{oz,Ed}$ = -5.70 kN/cm^2	$\sigma_{oz,Ed}$ = -5.68 kN/cm^2
Corresponding local shear stress: $\tau_{oxz,Ed}$ = 1.10 kN/cm^2	$\tau_{oxz,Ed}$ = 1.14 kN/cm^2

7.5 Plate Buckling Analyses of Web Plate Under Wheel Load

Length of stiff bearing

Acc. to [19]	CRANEWAY
s_s = 9.0 cm	s_s = 9.0 cm

Plate buckling coefficient and critical plate buckling load

Acc. to [19]	CRANEWAY
k_F =6.00	k_F =6.004
F_{cr} = 5761 kN	F_{cr} = 5764.55 kN

Auxiliary values

Acc. to [19]	CRANEWAY
m_1 = 27.3	m_1 = 27.27
m_2 = 0.00	m_2 = 0.00
l_y = 32.7 cm	l_y = 32.6 cm
F_y = 845.3	
$\lambda_{\_trans}$ = 0.38	$\lambda_{\_trans}$ = 0.383
χ_F = 1.0	χ_F = 1.0

Interaction design

Acc. to [19]	CRANEWAY
$\eta_1 = 0.41 < 1.0$	$\eta_1 = 0.409 < 1.0$

Web plate buckling

Acc. to [19]	CRANEWAY
$\eta = 0.068 < 1.0$	$\eta = 0.068 < 1.0$

7.6 Fatigue Designs

Dynamic coefficients and design locations

Acc. to [19]	**CRANEWAY**
$\varphi_{fat,1}$ = 1.05	$\varphi_{fat,1}$ = 1.05
$\varphi_{fat,2}$ = 1.065	$\varphi_{fat,1}$ = 1.065

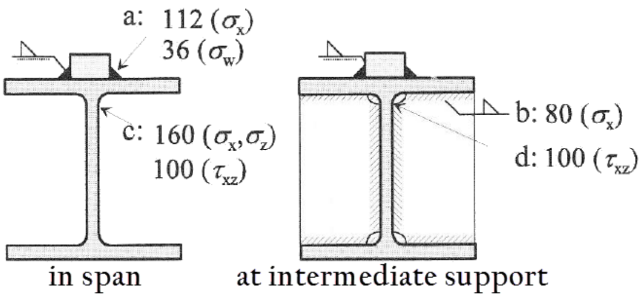


Figure 7.3: Design locations and detail categories

Normal stresses at the top of flange in span

Acc. to [19]	**CRANEWAY**
In span at x = 2.1 m	
max M_y = 100.3 kNm	
min M_y = -20.1 kNm	
$\Delta\sigma_x$ = 7.22 kN/cm²	$\Delta\sigma_x$ = 7.33 kN/cm²
$\Delta\sigma_{E,2}$ =2.3 kN/cm²	$\Delta\sigma_{E,2}$ =2.31 kN/cm²
η = 0.24 < 1.0	η = 0.237 < 1.0

Normal stresses at web base in span

Acc. to [19]	**CRANEWAY**
In span at x = 2.1 m	
max M_y = 100.3 kNm	
min M_y = -20.1 kNm	
$\Delta\sigma_x$ = 5.0 kN/cm²	$\Delta\sigma_x$ = 4.92 kN/cm²
$\Delta\sigma_{E,2}$ =1.6 kN/cm²	$\Delta\sigma_{E,2}$ =1.55 kN/cm²
η = 0.12 < 1.0	η = 0.14 < 1.0

Normal stresses at top flange at intermediate column

Acc. to [19]	**CRANEWAY**
max M_y = -85.2 kNm	
$\Delta\sigma_x$ = 4.44 kN/cm²	$\Delta\sigma_x$ = 4.37 kN/cm²
$\Delta\sigma_{E,2}$ =1.4 kN/cm²	$\Delta\sigma_{E,2}$ =1.38 kN/cm²
η = 0.20 < 1.0	η = 0.198 < 1,0

7.7 Deflections

Deflections

Acc. to [19] **CRANEWAY**

Vertical deflection

$\delta_z = \gamma \cdot R \cdot l^3/(100 \cdot EI_y) + \beta \cdot g \cdot l^4/(EI_y)$

where $\beta = 0.0054$ and $\gamma = 1.62$

$\delta_z = 0.50 + 0.02 = 0.52$ cm $u_z = 0.52$ cm

Horizontal deflection

$\delta_y = \gamma \cdot H_1 \cdot l^3/(100 \cdot EI_{z,Og})$

where $\gamma = 3.01$

$\delta_y = 0.72$ cm$u_y = 0.72$ cm

A Literature

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[4] SIA 161 Stahlbauten, Ausgabe 1990

[5] EN 1991-3: 2006, Eurocode 1: Actions on structures- Part 3: Actions induced by cranes and machinery

[6] EN 1993-6: 2010, Eurocode 3: Design of steel structures - Part 6: Crane supporting structures

[7] EN 1993-1-1: 2005, Eurocode 3: Design of steel structures - Part 1: General rules and rules for buildings

[8] EN 1993-1-9: 2005, Eurocode 3: Design of steel structures - Part 9: Fatigue

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[11] VON BERG, D.: Krane und Kranbahnen. Berechnung, Konstruktion, Ausführung, Stuttgart, Verlag B.G.Teubner, Auflage 1988

[12] Manual FE-LTB (Program for lateral-torsional and torsional-flexural buckling analysis by FEM), DLUBAL Engineering Software, Version July 2013

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