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 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 Introduction

1.2 CRANEWAY Team

The following people were involved in the development of CRANEWAY:

Program coordination
Dipl.-Ing. Georg Dlubal
Ing. Marek Posch

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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](image)

- 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.
1 Introduction

CRANEWAY as full or trial 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 trial 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](image)

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.

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.

![Bridge crane graphic]

**Comment**

In this input field, you can write your comments.

![Comment graphic]
2.2 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.
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.

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).
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.

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.

<table>
<thead>
<tr>
<th>Span No</th>
<th>A</th>
<th>B</th>
<th>Number of Internal Panels</th>
<th>Type of Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>Regularly</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>User-defined</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>User-defined</td>
</tr>
<tr>
<td>4</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>Regularly</td>
</tr>
<tr>
<td>5</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>Regularly</td>
</tr>
</tbody>
</table>

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.

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:
2.3 Cross-Section

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

**Girder**

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

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

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].
2 Input Data

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.

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.

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

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.

![Dialog box Info About Cross-Section](image)

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

The buttons below the graphic have the following functions:

<table>
<thead>
<tr>
<th>Button</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displays or hides the stress points</td>
<td></td>
</tr>
<tr>
<td>Displays or hides the c/t-parts</td>
<td></td>
</tr>
<tr>
<td>Displays or hides the numbers of stress points or c/t-parts</td>
<td></td>
</tr>
<tr>
<td>Shows details of the stress points or c/t-parts</td>
<td></td>
</tr>
<tr>
<td>Displays or hides the dimensions of the cross-section</td>
<td></td>
</tr>
<tr>
<td>Displays or hides the principal axes of the cross-section</td>
<td></td>
</tr>
<tr>
<td>Shows entire graphic of the cross-section</td>
<td></td>
</tr>
</tbody>
</table>

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.

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.

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)

Additional Designs
- Perform fatigue design

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

![Edit Detail Categories Dialog Box]

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 $\sigma_z$, 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.
2 Input Data

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](image)

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](image)
2 Input Data

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.

![Additional Designs](image)

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.

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.

![Options](image)

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.

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 $W_{\text{max}}$* option. However, if it is not clear, which loads are governing on which girder, the conservative option *Crane loads at both girders ($W_{\text{max}}$ and $W_{\text{min}}$)* 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.
2 Input Data

Crane Parameters

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

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![Figure 2.35: Section Crane Parameters](image)

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 \( \frac{1}{4} \) 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**.

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![Figure 2.36: Section Crane Parameters](image)

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 \( \frac{1}{4} \) 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.
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 \( \varphi \) of the crane runway beam according to [5].

**Crane Loads**

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

---

Figure 2.37: Dialog box Grouping Wheels

Figure 2.38: Dialog box Dynamic Coefficients

Figure 2.39: Section Crane Loads according to DIN 4132
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 \( H \) and the Skew force \( S \).

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 \( H \) (due to acceleration and braking of the crane bridge), \( H_t \) (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.

### Load Increment

This section controls the increment of the crane load positions.

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.

**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.
2 Input Data

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.

**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.

**CRANEWAY**

**Question**

Should the imperfections be calculated automatically at first and then set as default?

![CRANEWAY Question](image)

Then you can manually define or edit the imperfection parameters.

The *Buckling stress curve* $B_{sc}$ 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).
2 Input Data

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 [▼].

![Figure 2.46: Selection of Eigenmode](image)

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](image)

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

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 $\lambda_i$
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.

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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.
3 Calculation

Localized Plastification

If you select this check box, the equivalent stresses \( \sigma_{eq} \) can be exceeded by 10%. In the stress analysis, the stresses \( \sigma_x \) and \( \sigma_{eq} \) are then compared with the increased limit stresses. The stresses \( \sigma_x \), 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 \( \psi \) 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 Hs and S by 10% and ignore lateral loads Hm*. 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.

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 $M_{ts}$. If the check box is not selected, only the shear stresses due to the shear forces and the first torsional moment $M_{tp}$ 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).
3 Calculation

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

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.

<table>
<thead>
<tr>
<th>Type of Design</th>
<th>Member No.</th>
<th>Location x [m]</th>
<th>Design Criterion</th>
<th>Governing CO</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.4 Stress Analysis</td>
<td>2</td>
<td>3.400</td>
<td>0.885 &lt; 1.000</td>
<td>CO140</td>
</tr>
<tr>
<td>2.5 Deformation - Horizontal</td>
<td>2</td>
<td>3.400</td>
<td>765.182 ≥ 600.000</td>
<td>CO140</td>
</tr>
<tr>
<td>2.6 Fatigue Design</td>
<td>1</td>
<td>1.500</td>
<td>0.853 &lt; 1.000</td>
<td>CO112</td>
</tr>
<tr>
<td>2.7 Flex Building Analysis</td>
<td>1</td>
<td>1.500</td>
<td>0.854 &lt; 1.000</td>
<td></td>
</tr>
<tr>
<td>2.8 Weld - Stress Analysis</td>
<td>1</td>
<td>6.000</td>
<td>0.875 &lt; 1.000</td>
<td>CO62</td>
</tr>
<tr>
<td>2.9 Weld - Fatigue Design</td>
<td>1</td>
<td>5.600</td>
<td>7.596 &gt; 1.000</td>
<td></td>
</tr>
</tbody>
</table>

**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 Results

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.

![Figure 4.3: Window 2.2.1 Internal Forces - Capacity with option All Internal Forces](image)

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.
4 Results

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.

![Figure 4.4: Window 2.2.1 Internal Forces - Capacity with the option Max/min only](image-url)
4.3 Support Forces

This results window offers three sorting options for the display.

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.

![Figure 4.5: Window 2.3 Support Forces with option All support forces](image1)

![Figure 4.6: Window 2.3 Support Forces with option Max/min only](image2)
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.

![Figure 4.7: Window 2.3 Support Forces with option Only max/min advanced](image)

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.

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 $\gamma_F$, combination factor $\psi$, and dynamic coefficient $\phi$ are considered.

Details - Stresses

Below the table, the detailed intermediate results leading to this ratio are shown. They include the normal stresses $\sigma_x$ and $\sigma_z$, shear stress $\tau$, and the equivalent stresses $\sigma_{eqv}$. 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 $\sigma_z$, 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.
4 Results

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

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 $\sigma$, shear stresses $\tau$, and the equivalent stresses $\sigma_{eqv}$ at all cross-section points. At the top edge of the web plate, the normal stresses $\sigma$ 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 $\sigma$, and the shear stresses $\tau$ are calculated from the internal forces which were computed according to the second-order analysis subjected to $\gamma$ 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 $\sigma$. In all, we obtain for the normal stress $\sigma$ 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
- $M_{\omega}$ 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 $M$
- $\omega_M$ 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:

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

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.

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

The descriptions mean:

- $M_{t,s}$ Secondary torsional moment
- $Q_{w}(y_i, z_i)$ 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 $\sigma_z$ are, in contrast to the normal stresses $\sigma_x$ and shear stresses $\tau$, not calculated according to the second-order analysis but according to the following equations:

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

The descriptions mean:

- $W$ Wheel load multiplied by the partial safety factor $\gamma$, and dynamic coefficient $\varphi$
- $c(y_i, z_i)$ 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
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\[ \sigma_{z,i} = \frac{F_{z,Ed}}{l_{eff} \cdot t_w} \]

or for rolled cross-sections

\[ \sigma_{z,i} = \frac{F_{z,Ed}}{(l_{eff} + 2 \cdot r) \cdot t_w} \]

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 \( l_{eff} \)**

<table>
<thead>
<tr>
<th>Case</th>
<th>Description</th>
<th>Effective loaded length ( l_{eff} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Crane rail rigidly fixed to the flange</td>
<td>( l_{eff} = 3.25 \left( I_{eff} \cdot t_w \right)^{1/3} )</td>
</tr>
<tr>
<td>(b)</td>
<td>Crane rail not rigidly fixed to flange</td>
<td>( l_{eff} = 3.25 \left( I_{eff} + l_{c,eff} \right) \cdot t_w^{1/3} )</td>
</tr>
<tr>
<td>(c)</td>
<td>Crane rail mounted on a suitable resilient elastomeric bearing pad at least 6mm thick</td>
<td>( l_{eff} = 4.25 \left( I_{eff} + l_{c,eff} \right) l_{c,eff}^{1/3} )</td>
</tr>
</tbody>
</table>

- \( I_{eff} \): the second moment of area, about its horizontal centroidal axis, of a flange with an effective width of \( b_{eff} \)
- \( I_c \): the second moment of area, about its horizontal centroidal axis, of the rail
- \( l_{c,eff} \): 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 \( b_{eff} \)
- \( t_w \): the web thickness.

\( b_{eff} = b_{fl} + h_t + t_f \) but \( b_{eff} \leq b \)

where:
- \( b \): the overall width of the top flange;
- \( b_{fl} \): the width of the foot of the rail, see figure 5.2;
- \( h_t \): the height of the rail, see figure 5.1;
- \( t_f \): the flange thickness.

Note: Allow for trapezoidal rail, see 5.6.2(2) and 5.6.2(3) in determining \( I_c, l_t \) and \( h_t \).

Figure 4.13: Effective loaded length
4 Results

Designs

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

$$\max \sigma_x \leq f_{y,d}$$
$$\max \sigma_y \leq f_{y,d}$$
$$\max \tau \leq \frac{1}{\sqrt{3}} f_{y,d}$$
$$\max \sigma_{\text{equiv}} \leq f_{y,k} = \frac{f_{y,k}}{\gamma_M}$$

The equivalent stress $\sigma_{\text{equiv}}$ according to VON MISES is determined from the normal and shear stresses as follows:

$$\sigma_{\text{equiv}} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y + 3 \tau^2}$$

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

Since the stress $\sigma_z$ 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.

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

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 $\sigma_x$ have the greatest influence. The greatest normal stress $\sigma_x$ 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 Results

4.5 Deformation Analysis

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

![Image of Deformation Analysis](image)

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 $\phi_x$, $\phi_y$, and $\phi_z$ and the warping $\omega$. All deformation components are relative to the shear center M. The only exception is the displacement $u_x$: 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).
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 \( u_x, u_y, u_z \), the rotations \( \phi_x, \phi_y, \phi_z \), and the warping \( \omega \).

The deformation analysis is performed for the displacements in horizontal direction \( u_x \) 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.

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 4.17: Window 2.6 Fatigue Design Overall

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 $\gamma = 1$. 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 ($\chi = \sigma_{\text{min}}/\sigma_{\text{max}}$) 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.

$$
\sum \left( \frac{\text{max}_{\sigma_i}}{\text{allow}_{\sigma_i}} \right)^k \leq \left( \frac{\text{max}_{\sigma}}{\text{allow}_{\sigma}} \right)^k \leq 1
$$

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

- $\text{max}_{\sigma_i}$: Maximum stress due to single crane i
- $\text{allow}_{\sigma_i}$: Allowable stress for the corresponding stress group
- $\text{max}_{\sigma}$: Maximum stress from several cranes together
- $\text{allow}_{\sigma}$: 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 $\sigma$ or $\tau$ 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 $\sigma_o$ and $\sigma_u$ is difficult. This problem can be solved by using the rainflow method: In this method, the amplitudes and the corresponding top $\sigma_t$ and bottom $\sigma_b$ stresses are determined from the stress diagrams. Furthermore, this method can consider all forms of stress diagrams. The determined stresses $\sigma_t$ and $\sigma_b$ are then used as input parameters for the actual fatigue design.
4 Results

The rainflow method gives the resulting stress couples $\sigma_t$ and $\sigma_b$ 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.

$$\sum s_i \left( \frac{\text{max}_{\sigma_t}}{\text{allow}_{\sigma_t}} \right)^k + \left( \frac{\text{max}_{\sigma_b}}{\text{allow}_{\sigma_b}} \right)^k \leq 1$$

$s_i$ means:
- $s_i = 1.0$ for full period
- $s_i = 0.5$ for half period

For the normal stress $\sigma_z$, in contrast to the stresses $\sigma_x$ and $\tau$, the top stress $\sigma_t$ and the bottom stress $\sigma_b$ 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 $\sigma_t$:

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

where
- $\varphi$ 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 $\pm \frac{1}{4}$ of the rail head width is taken into account. This is done by adding stresses of the according torsional moment $M_{\tau,i}$ 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](image-url)
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

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

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

where

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

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

The descriptions mean:
- $t$ Thickness of the web plate
- $G$ Shear module (steel $G = 8100$ kN/cm²)
- $E$ Modulus of elasticity (steel $G = 21000$ kN/cm²)
- $I_T$ 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 $\sigma_z$ from the wheel load has an influence, according to [2] clause 4.1.2, on the shear stresses at the loaded upper edge of the web plate. The stress $\sigma_z$ from the wheel load induces the shear stress $\tau_{xz}$ 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 $\Delta \sigma$ and $\Delta \tau$ 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 $n = 2 \times 10^6$ 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 $n = 2 \times 10^6$ stress cycles of the detail category. This leads to the following design requirements:

$$\frac{\gamma_{HF} \cdot \Delta \sigma_{E,2}}{\Delta \sigma_C / \gamma_{MF}} \leq 1.0 \quad \text{and} \quad \frac{\gamma_{HF} \cdot \Delta \tau_{E,2}}{\Delta \tau_C / \gamma_{MF}} \leq 1.0$$

where

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

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

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

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

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 $\lambda_i$ for the respective damage classes. The following table is implemented in CRANEWAY.

<table>
<thead>
<tr>
<th>Classes</th>
<th>$S_1$</th>
<th>$S_2$</th>
<th>$S_3$</th>
<th>$S_4$</th>
<th>$S_5$</th>
<th>$S_6$</th>
<th>$S_7$</th>
<th>$S_8$</th>
<th>$S_9$</th>
</tr>
</thead>
<tbody>
<tr>
<td>normal stresses</td>
<td>0.198</td>
<td>0.250</td>
<td>0.315</td>
<td>0.397</td>
<td>0.500</td>
<td>0.630</td>
<td>0.794</td>
<td>1.000</td>
<td>1.260</td>
</tr>
<tr>
<td>shear stresses</td>
<td>0.379</td>
<td>0.436</td>
<td>0.500</td>
<td>0.575</td>
<td>0.660</td>
<td>0.788</td>
<td>0.871</td>
<td>1.000</td>
<td>1.149</td>
</tr>
</tbody>
</table>

NOTE 1: In determining the $\lambda$-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.

![Window 2.7 Plate Buckling Analysis - Overall](image1)

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

![Window 2.7 Plate Buckling Analysis by x-Location](image2)
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.

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 $\sigma$, and shear stresses $\tau$ of the weld seam.
4 Results

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.

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*.

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).

![Critical Load Factors Table](image)

**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](image)

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.

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.
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.

![Printout Report Selection dialog box](image)

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 [Shift].

![Figure 5.5: Context menu in navigator and preview](image)

**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](image)

**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](image)

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.
### Figure 6.3: Result in Excel

<table>
<thead>
<tr>
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<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
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<td>No.</td>
<td>Location</td>
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<td>Coworking</td>
<td>Strain</td>
<td>Stress</td>
</tr>
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<td>2</td>
<td>(m)</td>
<td>(kN/m²)</td>
<td>(kN/m²)</td>
<td>(kN/m²)</td>
<td>(kN/m²)</td>
<td>(kN/m²)</td>
</tr>
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<td>0.00</td>
<td>0.00</td>
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</tr>
</tbody>
</table>
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.

![Dialog box Units and Decimal Places](image)

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.

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](image)

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 $\sigma_x$, $\sigma_y$, $\tau$, and $\sigma_{eqv}$
- Ratio for $\sigma_x$, $\tau$, and $\sigma_{eqv}$
- Deformations
- Internal Forces
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 \( M_\theta \) 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 \( a_w = 5 \text{ mm}, S\ 235 \)
- Self-weight of crane runway girder with rail \( g = 1.35 \text{ kN/m} \)
- 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 \( c = 3.6 \text{ m} \)

Loads

- Vertical wheel loads:
  - \( Q_c = 18.00 \text{ kN} \) due to self-weight
  - \( Q_h = 57.00 \text{ kN} \) due to hoist load
- Horizontal wheel loads:
  - \( H_1 = 20.00 \text{ kN} \)
  - \( H_2(H_1) = -H_2(H_2) = 8.60 \text{ kN} \) Loads from acceleration and braking

![Figure 7.1: Sketch of system](image1)

![Figure 7.2: Cross-section](image2)
7.2 Internal Forces - Capacity

<table>
<thead>
<tr>
<th>Maximum field moment</th>
<th>Acc. to [19]</th>
<th>CRANEWAY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>X-location</td>
<td>X-location</td>
</tr>
<tr>
<td>RC1</td>
<td>147.90 [kNm]</td>
<td>147.20 [kNm]</td>
</tr>
<tr>
<td></td>
<td>2.10 [m]</td>
<td>2.10 [m]</td>
</tr>
<tr>
<td></td>
<td>23.70 [kNm]</td>
<td>23.52 [kNm]</td>
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<tr>
<td></td>
<td>3.36 [m]</td>
<td>2.60 [m]</td>
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<tr>
<td>RC2</td>
<td>132.20 [kNm]</td>
<td>132.00 [kNm]</td>
</tr>
<tr>
<td></td>
<td>2.10 [m]</td>
<td>2.10 [m]</td>
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<tr>
<td></td>
<td>33.60 [kNm]</td>
<td>37.17 [kNm]</td>
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<td>2.58 [m]</td>
<td>2.50 [m]</td>
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<table>
<thead>
<tr>
<th>Maximum supporting moment</th>
<th>Acc. to [19]</th>
<th>CRANEWAY</th>
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<tbody>
<tr>
<td>RC1</td>
<td>-129.87 [kNm]</td>
<td>-129.30 [kNm]</td>
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<tr>
<td></td>
<td>6.00 [m]</td>
<td>6.00 [m]</td>
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<tr>
<td>RC2</td>
<td>-116.37 [kNm]</td>
<td>-116.34 [kNm]</td>
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<td></td>
<td>6.00 [m]</td>
<td>6.00 [m]</td>
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</table>

<table>
<thead>
<tr>
<th>Maximum shear force</th>
<th>Acc. to [19]</th>
<th>CRANEWAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC1</td>
<td>-175.50 [kN]</td>
<td>-172.10 [kN]</td>
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<td></td>
<td>-17.40 [kN]</td>
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</table>

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 eigenvalue 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 \( x = 2.30 \) m (left span)

\[ \sigma_{eqv} = 19.10 \text{ kN/cm}^2 \]

CRANEWAY

\[ \sigma_{eqv} = 19.06 \text{ kN/cm}^2 \]

**Elastic-elastic stress analysis**
The stress analysis is carried out with the partial safety factor \( y_M1 \).

Acc. to [19]

\[ \frac{19.10}{21.36} = 0.894 < 1 \]

LTB design satisfied

CRANEWAY

\[ \frac{19.06}{21.36} = 0.892 < 1 \]

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]  
\[ l_{eff} = 12.8 \text{ cm} \]

**Web compression at transition between fillet radius and web**

Web compression:

\[ \sigma_{oz,Ed} = -5.70 \text{ kN/cm}^2 \]

Corresponding local shear stress:

\[ \tau_{oxz,Ed} = 1.10 \text{ kN/cm}^2 \]

7.5 Plate Buckling Analyses of Web Plate Under Wheel Load

**Length of stiff bearing**

Acc. to [19]  
\[ s_t = 9.0 \text{ cm} \]

**Plate buckling coefficient and critical plate buckling load**

Acc. to [19]  
\[ k_F = 6.00 \]
\[ F_{cr} = 5761 \text{ kN} \]

**Auxiliary values**

Acc. to [19]  
\[ m_1 = 27.3 \]
\[ m_2 = 0.00 \]
\[ l_y = 32.7 \text{ cm} \]
\[ F_y = 845.3 \]
\[ \lambda_{trans} = 0.38 \]
\[ \chi_F = 1.0 \]

**Interaction design**

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

**Web plate buckling**

Acc. to [19]  
\[ \eta = 0.068 < 1.0 \]
7.6 Fatigue Designs

Dynamic coefficients and design locations

Acc. to [19]  
\[ \phi_{fat,1} = 1.05 \]
\[ \phi_{fat,2} = 1.065 \]

Acc. to CRANEWAY  
\[ \phi_{fat,1} = 1.05 \]
\[ \phi_{fat,2} = 1.065 \]

\[ a: \ 112 \ (\sigma_x) \]
\[ 36 \ (\sigma_y) \]

\[ b: \ 80 \ (\sigma_x) \]
\[ c: \ 160 \ (\sigma_x, \sigma_y) \]
\[ 100 \ (\tau_{yz}) \]

\[ d: \ 100 \ (\tau_{xy}) \]

Figure 7.3: Design locations and detail categories

Normal stresses at the top of flange in span

Acc. to [19]  
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/cm\(^2\)  
\( \Delta \sigma_{E,2} = 2.3 \) kN/cm\(^2\)  
\( \eta = 0.24 < 1.0 \)

Acc. to CRANEWAY  
In span at \( x = 2.1 \) m  
max \( M_y = 100.3 \) kNm  
min \( M_y = -20.1 \) kNm  
\( \Delta \sigma_x = 7.33 \) kN/cm\(^2\)  
\( \Delta \sigma_{E,2} = 2.31 \) kN/cm\(^2\)  
\( \eta = 0.237 < 1.0 \)

Normal stresses at web base in span

Acc. to [19]  
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/cm\(^2\)  
\( \Delta \sigma_{E,2} = 1.6 \) kN/cm\(^2\)  
\( \eta = 0.12 < 1.0 \)

Acc. to CRANEWAY  
In span at \( x = 2.1 \) m  
max \( M_y = 100.3 \) kNm  
min \( M_y = -20.1 \) kNm  
\( \Delta \sigma_x = 4.92 \) kN/cm\(^2\)  
\( \Delta \sigma_{E,2} = 1.55 \) kN/cm\(^2\)  
\( \eta = 0.14 < 1.0 \)

Normal stresses at top flange at intermediate column

Acc. to [19]  
max \( M_y = -85.2 \) kNm  
\( \Delta \sigma_x = 4.44 \) kN/cm\(^2\)  
\( \Delta \sigma_{E,2} = 1.4 \) kN/cm\(^2\)  
\( \eta = 0.20 < 1.0 \)

Acc. to CRANEWAY  
max \( M_y = -85.2 \) kNm  
\( \Delta \sigma_x = 4.37 \) kN/cm\(^2\)  
\( \Delta \sigma_{E,2} = 1.38 \) kN/cm\(^2\)  
\( \eta = 0.198 < 1.0 \)
7 Example

7.7 Deflections

Deflections
Acc. to [19] CRANEWAY

Vertical deflection

\[ \delta_v = \gamma \cdot R \cdot l^3/(100 \cdot E_I_b) + \beta \cdot g \cdot l^4/(E_I_b) \]

where \( \beta = 0.0054 \) and \( \gamma = 1.62 \)

\[ \delta_v = 0.50 + 0.02 = 0.52 \text{ cm} \]

\( u_v = 0.52 \text{ cm} \)

Horizontal deflection

\[ \delta_h = \gamma \cdot H_1 \cdot l^4/(100 \cdot E_{I_{Og}}) \]

where \( \gamma = 3.01 \)

\[ \delta_h = 0.72 \text{ cm} \]

\( u_h = 0.72 \text{ cm} \)
A Literature

[16] PETERSEN, Chr.: Stahlbau, Verlag Friedrich Vieweg und Sohn, Braunschweig/Wiesbaden, 3. überarbeitete und erweiterte Auflage, 1993
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