Version
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Add-on Module

RF-FOUNDATION Pro

Design of Single Foundations
acc. to EN 1992-1-1 and EN 1997-1

Program Description

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1. Introduction

1.1 Add-on Module RF-FOUNDATION Pro

Designing single foundations is part of the standard tasks faced by structural engineers in their day-to-day work. The number of designs which must be performed for the ultimate as well as the serviceability limit state requires powerful software in order to design single foundations efficiently.

The add-on module RF-FOUNDATION Pro fulfils these conditions offering its users the possibility to design single foundations economically and to document the results in a verifiable form.

RF-FOUNDATION Pro performs the design for the following foundation types:

- Bucket foundation with smooth or rough bucket sides
- Foundation plate
- Block foundation with smooth or rough bucket sides

The offered foundation types cover a multitude of foundation layouts used in the construction practice.

The reinforced concrete design of the foundations is performed according to the standard

EN 1992-1-1:2004 + AC:2010 [1]

The geotechnical designs are performed according to the following standard:

EN 1997-1 [2]

If desired, it is possible to deactivate the individual types of design specifically.

The load cases and combinations used for the design with RF-FOUNDATION Pro must be created in the main program RFEM. After the calculation, the support reactions of the load cases and combinations are available in the add-on module. Furthermore, it is possible to deactivate individual support reactions for the design of the foundation.

The results of the foundation design can be documented in the printout report of RFEM. Moreover, RF-FOUNDATION Pro provides reinforcement drawings which can also be exported to a DXF document.

We hope you will enjoy working with RF-FOUNDATION Pro.

Your DLUBAL Team

1.2 RF-FOUNDATION Pro Team

The following people were involved in the development of RF-FOUNDATION Pro:

Program coordination

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1.3 Using the Manual

Topics like installation, graphical user interface, results evaluation, and printout are described in the manual of the main program RFEM. The present manual focuses on typical features of the add-on module RF-FOUNDATION Pro.

The description of the program follows the sequence and structure of the module's input and results windows. The text of the manual shows the described **buttons** in square brackets, for example [Edit]. The buttons are also shown in the left margin. The **expressions** that appear in dialog boxes, windows, and menus are set in *italics* to clarify the explanations.

At the end of the manual, you find the 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 by using various filter criteria.

We have also written some blog reports and posts in social media about how to work with RF-FOUNDATION Pro. There, you can find useful information for the program handling. To open the Dlubal blog, go to https://www.dlubal.de/blog/en. Use the 'Search' function on the top right to find specific articles about RF-FOUNDATION Pro.

1.4 Open the Add-on Module RF-FOUNDATION Pro

RFEM provides the following options to start the add-on module RF-FOUNDATION Pro.

Menu

To open the add-on module, select

Add-on Modules → **Foundations** → **RF-FOUNDATION Pro**.

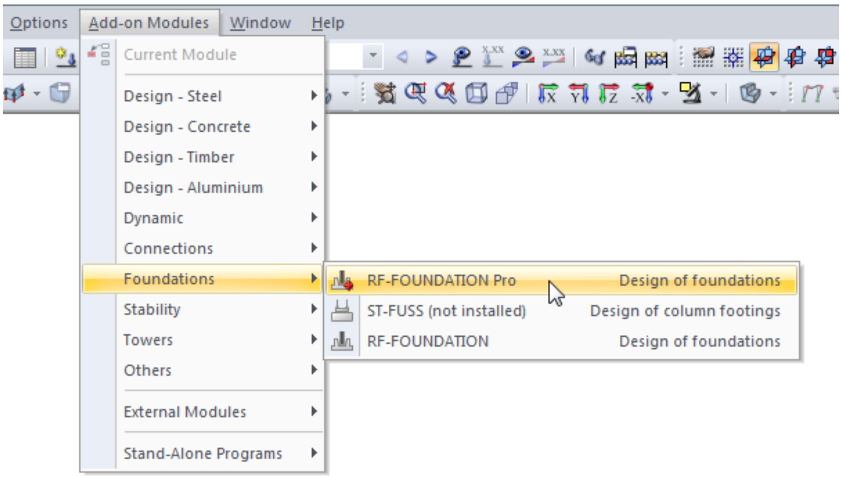


Figure 1.1: Menu *Add-on Modules* → *Foundations* → *RF-FOUNDATION Pro*

Navigator

Alternatively, you can start the add-on module in the *Data* navigator by clicking

Add-on Modules → RF-FOUNDATION Pro.

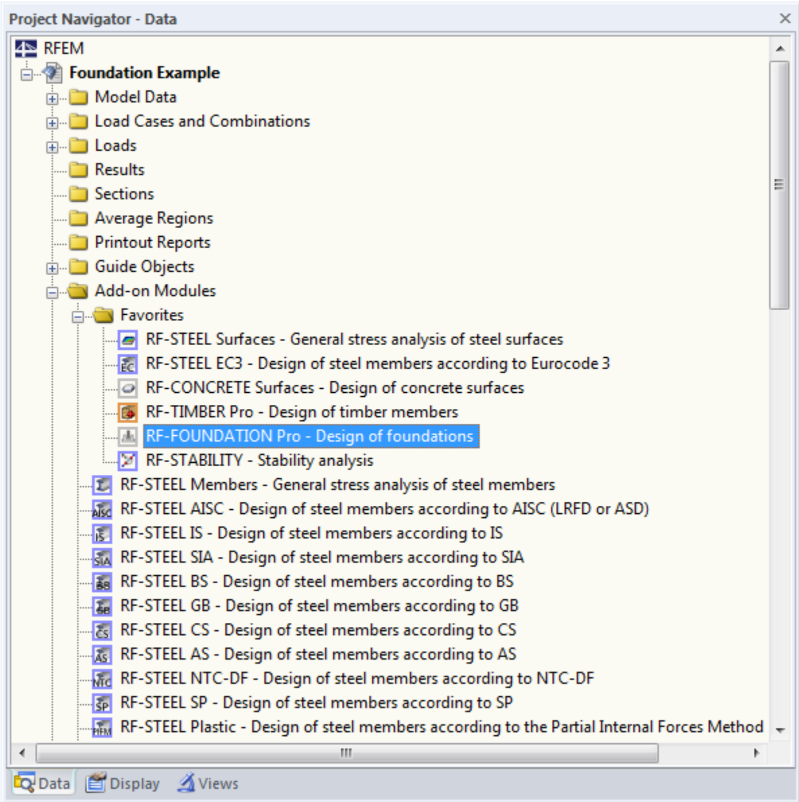


Figure 1.2: Data navigator: *Add-on Modules → RF-FOUNDATION Pro*

You have the possibility to store add-on modules as *Favorites* in the *Data* navigator: Right-click the relevant module entry to open its shortcut menu. Then, select the option ***Favorite***.

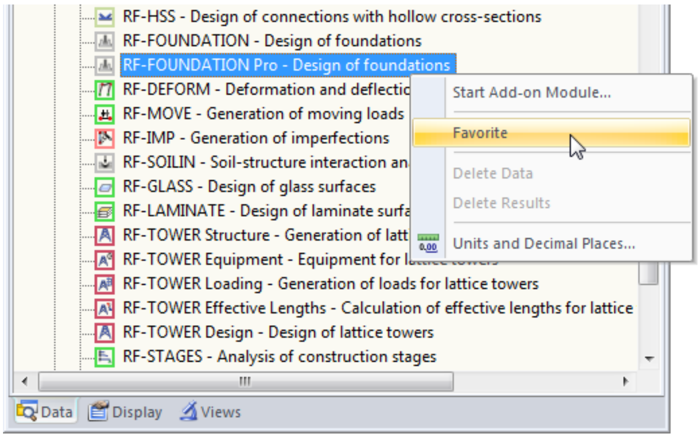


Figure 1.3: Defining RF-FOUNDATION Pro as favorite add-on module

RF-FOUNDATION Pro cannot be started directly as a stand-alone program. The add-on module is integrated in the main program RFEM, which means that the model with the corresponding foundation must be opened in RFEM before you start RF-FOUNDATION Pro.

2. Input Data

2.1 General Data

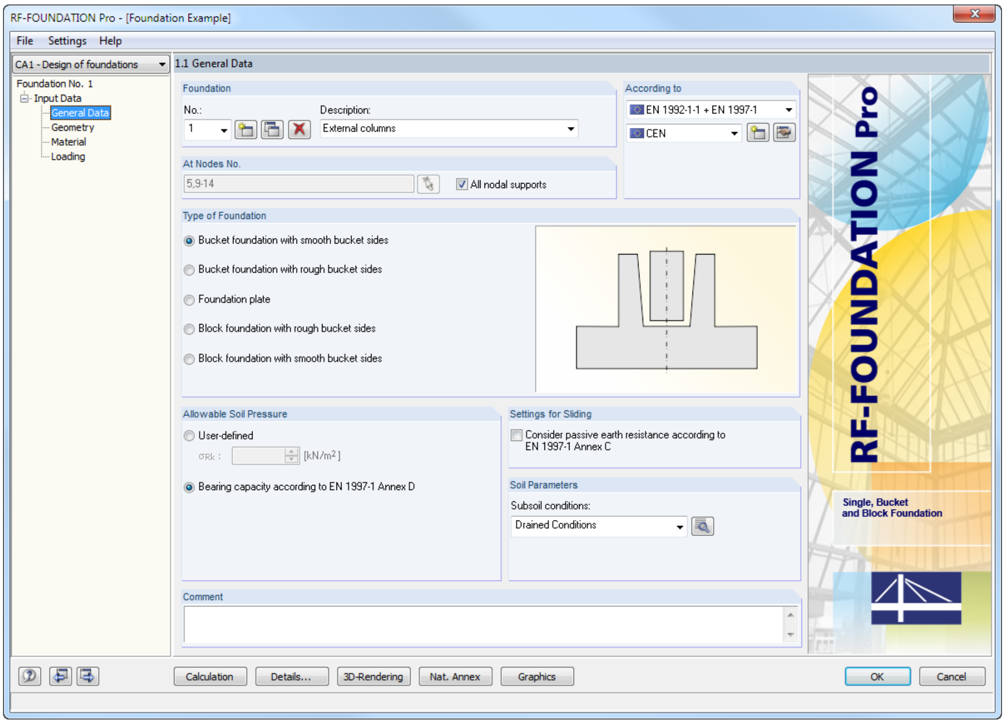
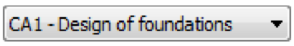
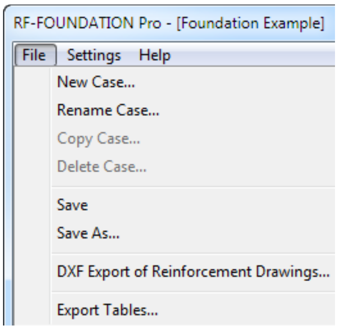


Figure 2.1: Window 1.1 *General Data*



After starting RF-FOUNDATION Pro, a new window opens. On the left, you can see the navigator displaying all module windows that can be selected.

Above, you find a list with already available design cases. To open the list, click the arrow button [▼]. Then, you can select a design case by clicking the corresponding entry.



Below the title bar, you find the menus *File*, *Settings*, and *Help*.

In the *File* menu, you find the commands to create a new design case or to delete, rename or copy an existing case (see Chapter 7.1, page 62). Moreover, you have the possibility to save the file and to export the geometry of the foundation as well as the reinforcement drawings.

For more information about exporting results, see Chapter 7.4 *Export of Results*.

The [Details] button is available in each input window of RF-FOUNDATION Pro. Clicking the button enables access to the *Details* dialog box where different settings can be defined for the calculation.

The *Details* dialog box is described in Chapter 3.1 on page 28.

Design case / Foundation No.

In RF-FOUNDATION Pro, you have to distinguish between the design case (RF-FOUNDATION Pro case) and the foundation.

A **design case** is the case to which you can assign as many foundations as you want. When you start a new design case, a **foundation** is created by default (*Foundation No. 1*). All nodal supports of the model are allocated to this foundation.

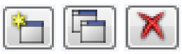
As shown in Figure 2.1, a foundation with the foundation number *1* was created for case *CA1*. The checkbox for *All nodal supports* in the window section below is selected. A bucket foundation with smooth bucket sides will be created for nodes number 5 and 9-14.

In case of large models with different foundation shapes and column dimensions, it can be necessary to analyze several foundations in one case. In the current design case, you can define a new foundation where it is possible to change the foundation type or select an eccentric column arrangement.

Foundation

The number of the current foundation is displayed in the list.

Figure 2.2: Window section *Foundation*



You can use the three buttons to the right to create a [New] foundation, to [Copy] or [Delete] a foundation.

Furthermore, it is possible to assign a *Description*.

At Nodes No.

This window section manages the numbers of the nodes for which the current foundation parameters are applied.

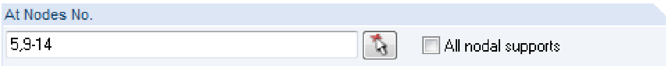


Figure 2.3: Window section *At Nodes No.*

With the [Select] button [↖] you can select the relevant nodes also in the RFEM graphic. The dialog box *Multiple Selection* opens. Already selected support nodes can be deleted by clicking the [Clear] button.

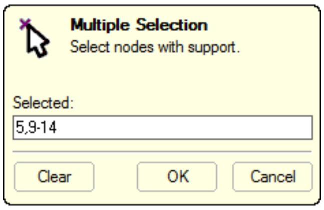


Figure 2.4: Selecting the nodes in RFEM

Alternatively, it is possible to select the checkbox *All nodal supports*. Then, RF-FOUNDATION Pro will assign to the foundation all nodes on which a nodal support is available.

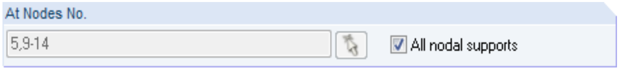


Figure 2.5: Selection of all nodes having support properties

A node can be selected only <u>once</u> in a RF-FOUNDATION Pro case. To design another foundation with the same node number, you have to create a new design case.

When copying a foundation (e.g. foundation No. 1), all support nodes which have not been selected for the first foundation will be assigned automatically to the new foundation and set for the design.

According to

The following standards are available for the design in RF-FOUNDATION Pro:

- Reinforced concrete design according to **EN 1992-1-1:2004/AC:2010**
- Geotechnical analyses according to **EN 1997-1**

The governing National Annex can be selected in a list.

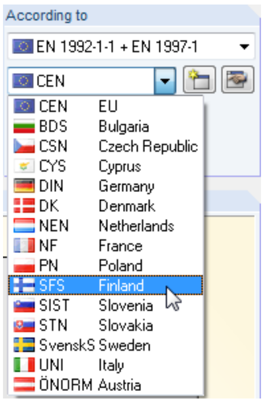


Figure 2.6: Window section *According to*

Nat. Annex

Use the [Edit] button to open a dialog box where you can check the parameters of the currently selected annex. The [Nat. Annex] button at the bottom of the module window has the same function.

With the [New] button you can create a user-defined National Annex.

Find more information about the available standards and annexes in Chapter 7.3 on page 65.

Type of Foundation

Here, you specify the layout of the foundation. You can see it dynamically displayed in the graphic to the right.

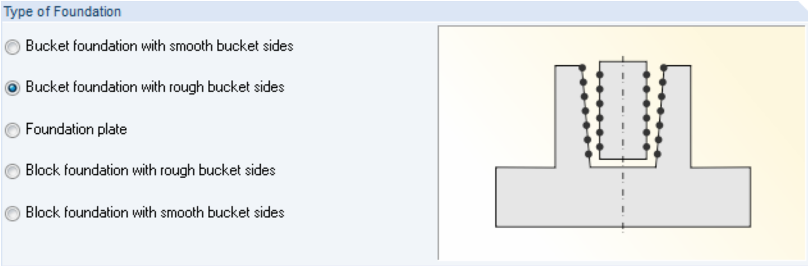


Figure 2.7: Window section *Type of Foundation*

The following foundation types can be selected:

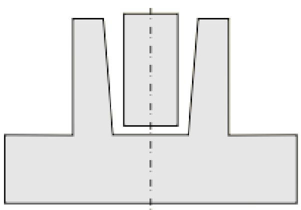
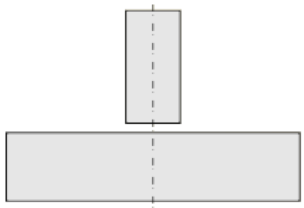
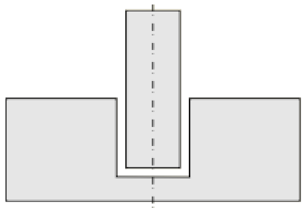
Bucket foundation	Foundation plate	Block foundation
		

Table 2.1: Foundation types

The bucket and block foundations are further differentiated with regard to the surface texture of the inner bucket sides which can be smooth or rough.

Allowable Soil Pressure

In this window section, you can choose between two or three (DIN setting) input options.

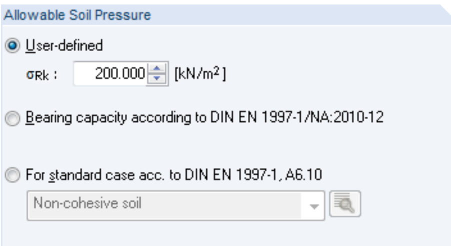
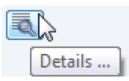


Figure 2.8: Window section *Allowable Soil Pressure*

The characteristic soil pressure can be *User-defined*. It is used for the contact stress analysis $\sigma_{Ed} \leq \sigma_{Rd} = \sigma_{Rk} / \gamma_{R,v}$ according to EN 1997-1.

Another possibility is to perform the design of the allowable soil pressure by the *Bearing capacity* according to EN 1997-1 annex D.



If the National Annex for Germany is set, you can also determine the allowable soil pressures by means of the tables *For standard case* according to DIN EN 1997-1, A6.10. First, you have to specify if the soil is cohesive or non-cohesive. Then, you can use the [Details] button to open a dialog box where the soil group is determined (see picture below).

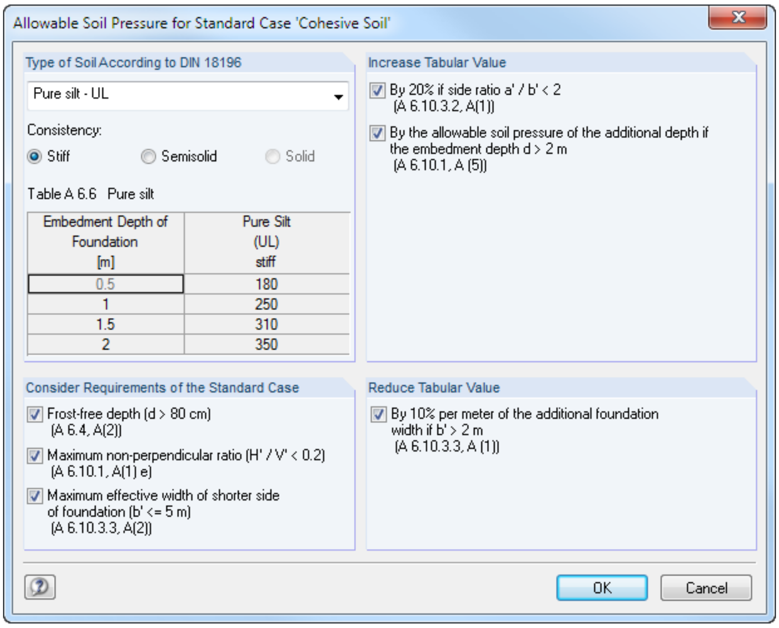


Figure 2.9: Dialog box *Allowable Soil Pressure for Standard Case 'Cohesive Soil'*

The dialog box facilitates the determination of the allowable soil pressure. The relevant soil pressure is determined depending on the foundation embedment depth from the table.

Here, RF-FOUNDATION Pro interpolates the value of the allowable soil pressure ($\sigma_{R,d}$) for the foundation's effective embedment depth *d* on the basis of the intermediate values of the standard case table.

In module window 2.2 *Governing Design Criteria*, the table value of the allowable soil pressure applied to the ground failure analysis according to Table A 6.6 (al σ_{Tab}) is shown.

Settings for Sliding

In this window section, you can decide if you want to consider the passive earth resistance according to EN 1997-1 annex C for the design of the foundation.

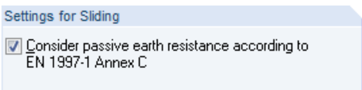


Figure 2.10: Window section *Settings for Sliding*

When the check box is selected, further settings for the sliding resistance design are enabled in the dialog box *Design Parameters for Foundation Plate* which is available in module window 1.2 (see Figure 2.18, page 17).

Soil Parameters

This window section offers settings for the soil conditions. In the list, you can choose drained or undrained conditions of the soil.

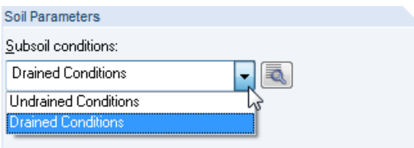


Figure 2.11: Window section *Soil Parameters*

Click the [Details] button next to the selection box to open a dialog box used for defining the soil parameters. The appearance of the dialog box depends on the selected subsoil conditions (see following figures).

Drained conditions

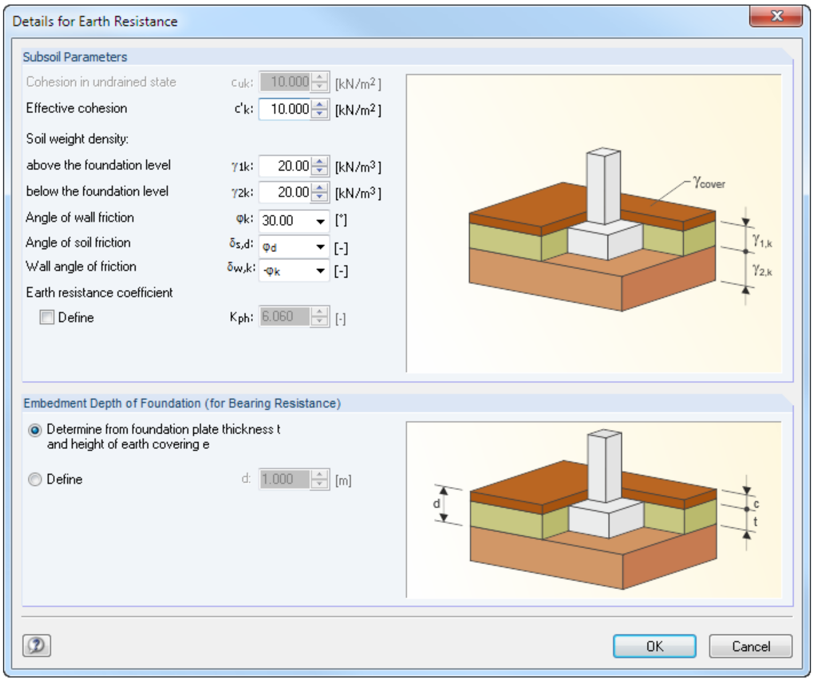


Figure 2.12: Dialog box *Details for Earth Resistance* for drained subsoil conditions

In the *Details for Earth Resistance* dialog box, you can define the *Angle of wall friction* φ_k as well as the *Angle of soil friction* $\delta_{s,d}$.

With the options available in the *Embedment Depth of Foundation* section, you decide whether the depth is determined from the plate thickness *t* and the earth covering *e* based on the design of the foundation in the ultimate limit state or whether the user-defined value *d* is to be applied.

Undrained conditions

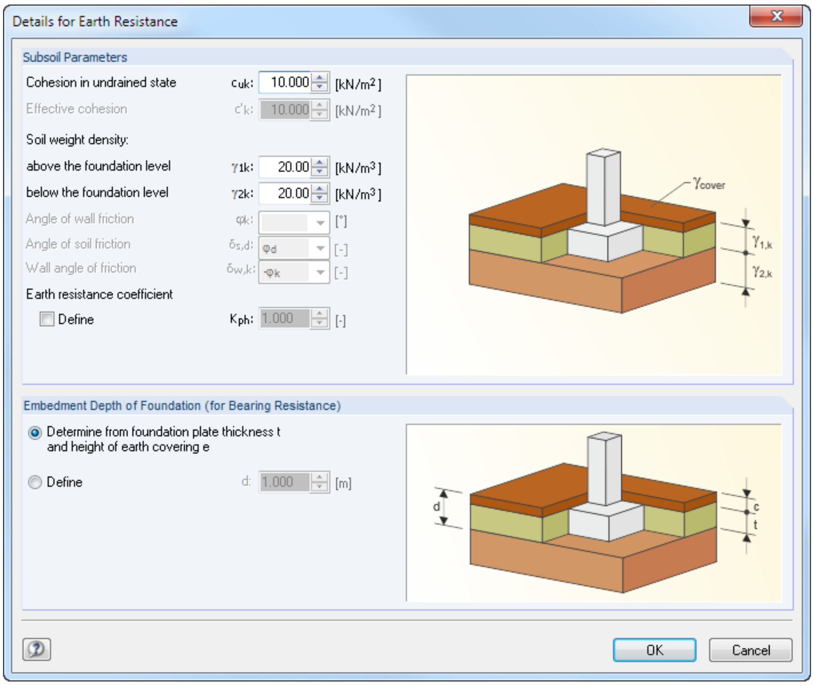


Figure 2.13: Dialog box *Details for Earth Resistance* for undrained subsoil conditions

In this dialog box, you have to enter the value of the *Cohesion in undrained state* c_{uk}.

2.2 Geometry

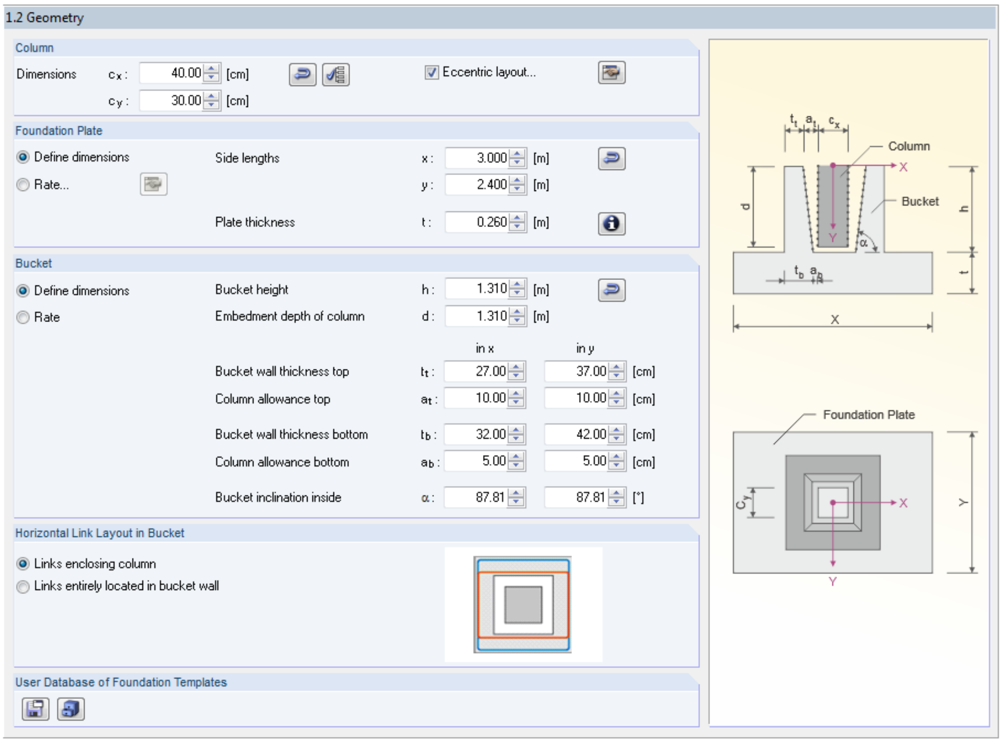


Figure 2.14: Window 1.2 *Geometry*

2.2.1 Column

This window section manages the parameters of the column.

Figure 2.15: Window section *Column* - definition of column dimensions and layout

Standard column dimensions are set by default in both text boxes c_x and c_y. They can be adjusted to the actual conditions. Use the button [Import Column Dimensions from RFEM] to import the dimensions of the column cross-section from the RFEM model.

With the button [Import Column Dimensions from Selected Cross-Section] you can also select another cross-section created in RFEM.

When the check box for *Eccentric layout* is selected, you can offset the center point of the column relative to the center point of the plate. The eccentricity must be defined in a separate dialog box (see following figure) that you can access by clicking the [Edit] button to the right.

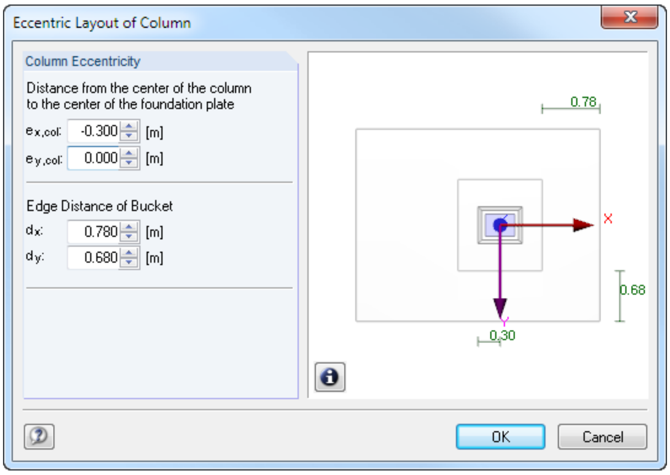
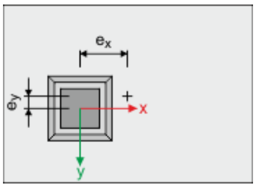


Figure 2.16: Dialog box *Eccentric Layout of Column*



The *Column Eccentricity* can be defined with four text boxes. The first two boxes describe the distance of the column center from the centroid of the foundation plate.

Please pay attention to the sign: For example, if you want to arrange the column with an offset to the left, the distance e_x must be entered positively because the centroid of the foundation plate lies in the positive x-direction seen from the center of the column (coordinate system of support).

In the two boxes below, you enter the distances of the bucket opening from the edges of the foundation plate. These values always have positive signs.

The interactive dialog graphic shows the top view of the foundation including the coordinate system of support. The graphic is useful for defining the column eccentricity. Use the [Info] button to switch between the interactive graphical representation and the sketch of the system.

2.2.2 Foundation Plate

Figure 2.17: Defining or rating the foundation plate dimensions

In this window section, you decide if you want to specify the dimensions of the foundation plate manually or if you want the program to rate them.

Define dimensions

When the manual definition is selected, the three text boxes to the right are enabled. You can enter the side lengths and the thickness of the foundation plate.

The minimum dimensions specified in Chapter 3.2 must be observed!

If the foundation plate has been dimensioned iteratively by the program (see below), it is possible to import the determined dimensions with the [Import] button. Then, you can adjust the values, for example in order to use rounded dimensions.

Rate

RF-FOUNDATION Pro determines the dimensions of the foundation plate according to the requirements resulting from the soil-mechanical analyses.

Click the [Edit] button to access the parameters needed for dimensioning the foundation plate. The dialog box *Design Parameters for Foundation Plate* (see the following page) opens.

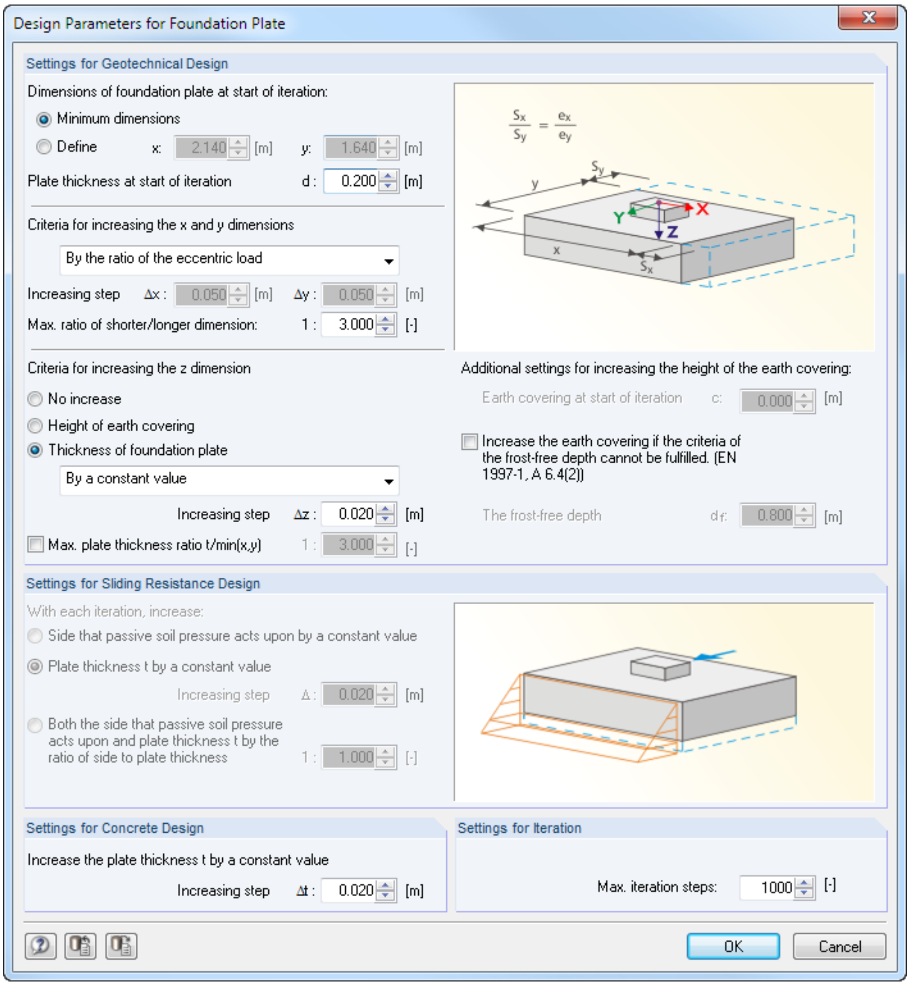
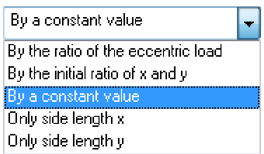


Figure 2.18: Dialog box *Design Parameters for Foundation Plate*

Settings for Geotechnical Design

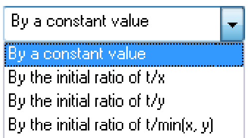
You have to decide which *Dimensions of foundation plate at start of iteration* you want to use (minimum dimensions or user-defined initial values).



The *Criteria for increasing the x and y dimensions* control the way how the parameters are changed during the dimensioning in the iteration steps. Several options are available for selection in the list (see figure shown on the left). Furthermore, the dimensioning takes account of a user-defined limit ratio between both side lengths.

The following *Criteria for increasing the z dimension* can be selected for the determination of the plate thickness.

- No increase
- Height of earth covering
- Thickness of foundation plate



The option *Thickness of foundation plate* offers a list with different possibilities for the dimensioning. In this case, a user-defined limit ratio between the plate thickness and the minimum side length is also taken into account.

The dimensioning to be carried out by the program can also *Increase the earth covering* if the criterion for the frost-free embedment is not fulfilled. Here, you have to specify the earth covering *c* at the beginning of the iteration and the embedment depth d_f.

Settings for Sliding Resistance Design

To access this dialog section, the check box *Consider passive earth resistance according to EN 1997-1 Annex C* must be selected (see Figure 2.10, page 13).

With the first two dimensioning options you increase the *Side* of the foundation or the *Plate thickness* iteratively until the design of the sliding resistance is fulfilled. When the third option is activated, it is possible to specify a user-defined ratio for increasing the foundation side in relation to the foundation thickness. If the length of the foundation side is increased within an iteration step, for example by one centimeter, the plate thickness will be increased as well by one centimeter when a ratio of 1:1 is set.

Settings for Concrete Design

Here, you enter the *Increasing step* Δt to increase the plate thickness so that the reinforced concrete designs will be fulfilled.

Settings for Iteration

The number of *iteration steps* is used to set an upper limit for possible calculation runs.

2.2.3 Bucket

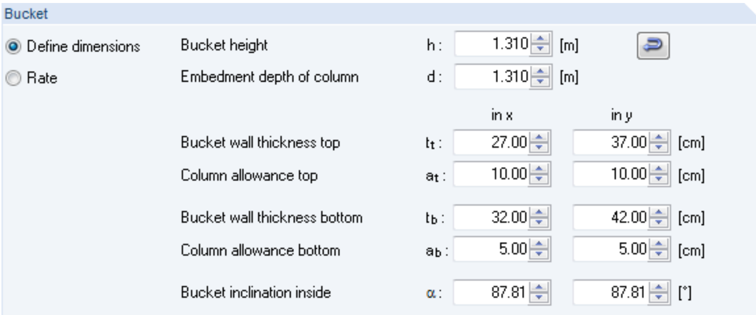
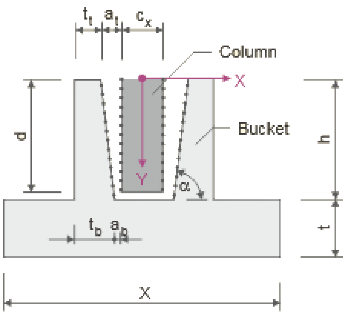


Figure 2.19: Window section *Bucket*



You can decide if you want to specify the dimensions of the bucket manually, or if the program rates them.

Define dimensions

When the manual definition is selected, you can access the text boxes to the right. Use them to describe the bucket geometry.

If you have selected the *Block foundation* type in module window 1.1, the boxes for the bucket wall thicknesses at the top and bottom are locked. If the *Foundation plate* has been set, all boxes are deactivated.

If the bucket has been rated iteratively by the program (see below), you can import the determined dimensions with the [Import] button. Then, you can adjust the values, for example in order to use rounded dimensions.

Rate

RF-FOUNDATION Pro determines the dimensions of the bucket according to the requirements resulting from the column and plate geometry (see Figure 2.18).

2.2.4 Horizontal Link Layout in Bucket

Figure 2.20: Window section *Horizontal Link Layout in Bucket*

In this window section, you decide if the links in the bucket walls enclose the column or are *entirely located in the bucket wall*.

The options are locked for the foundation types *Block foundation* and *Foundation plate*.

2.2.5 User Database of Foundation Templates

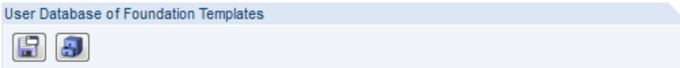


Figure 2.21: Window section *User Database of Foundation Templates*

You can store the current foundation geometry in a library by using the [Save] button. A dialog box opens where you enter a name for the new template.

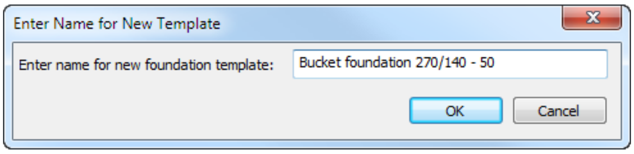


Figure 2.22: Dialog box *Enter Name for New Template*

Click [OK] to import the foundation to the *Database of Foundation Templates*.

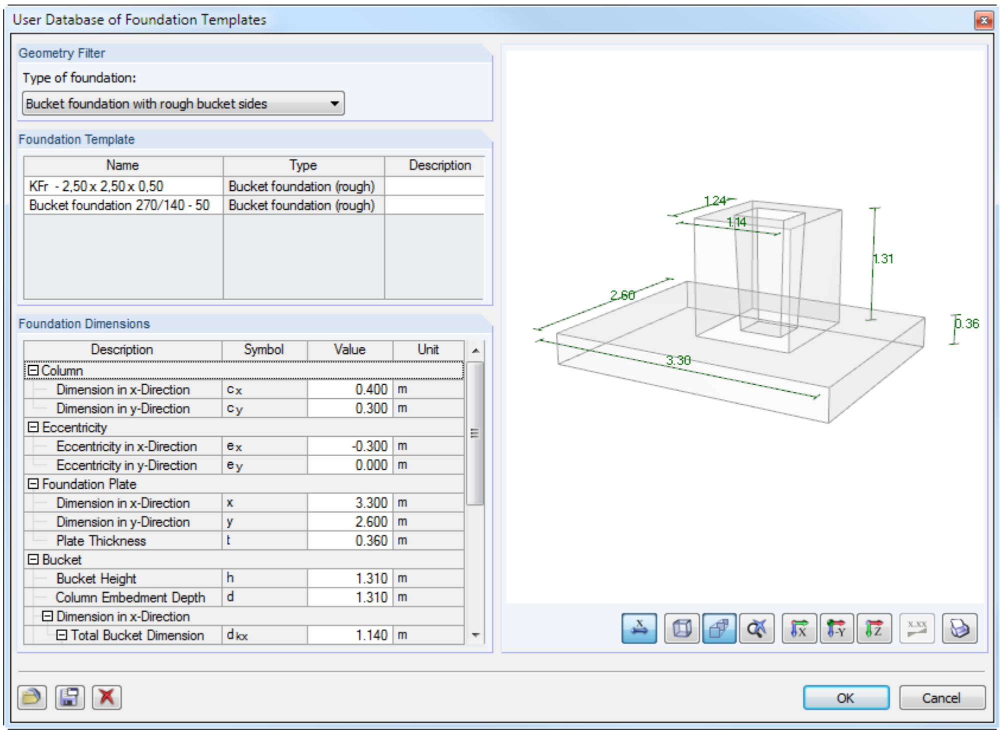


Figure 2.23: Dialog box *User Database of Foundation Templates*

2.3 Materials

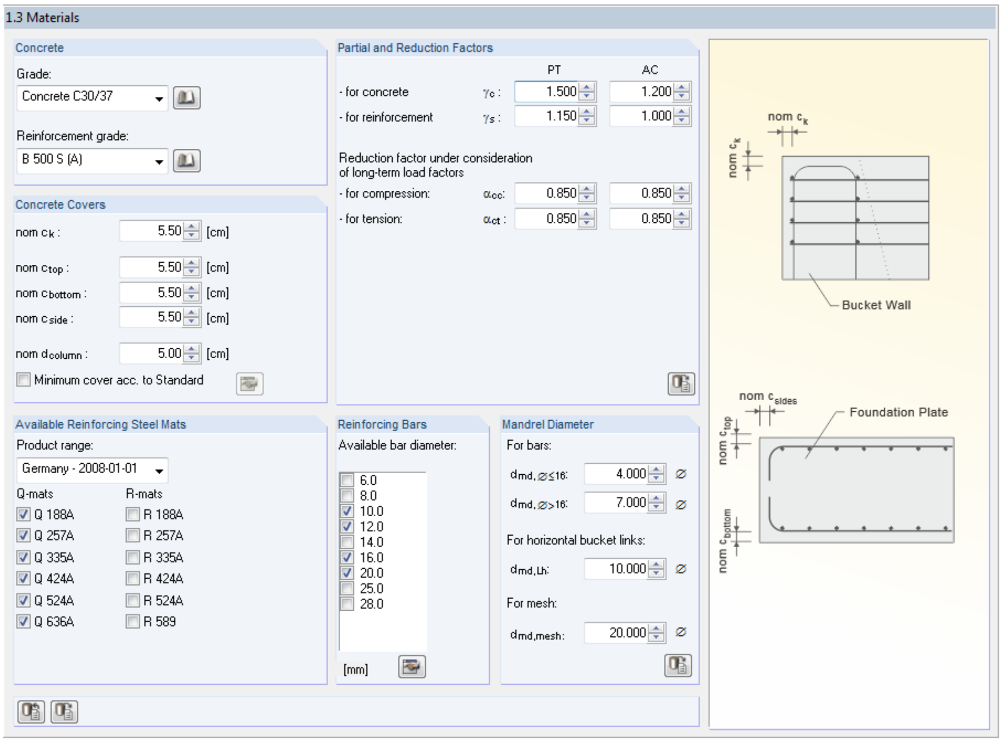
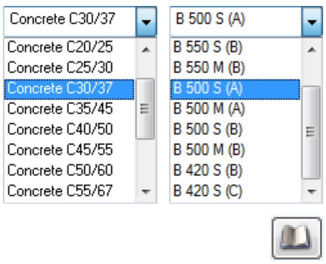


Figure 2.24: Window 1.3 *Materials*

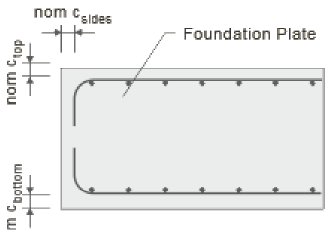
In this module window, you define the materials with the partial safety factors as well as the settings for the reinforcement.

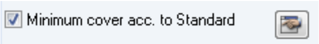


Concrete

The window section offers two lists where you can select the concrete *Grade* and the *Reinforcement grade*. The standardization of the material is based on the National Annex that has been set in module window 1.1 *General Data*.

It is also possible to define the concrete and reinforcing steel grades with the [Library] buttons. The dialog box *Material Library* additionally displays the properties of the materials. Again, it is the National Annex that sets the materials available for selection.





Concrete Covers

Here, you define the concrete cover for the different sides of the foundation. The meaning of the symbols is made clear by the sketches in the graphic on the right in the module window.

It is also possible to determine the concrete cover by the specifications in the standard. Then, the check box for *Minimum cover acc. to Standard* must be selected. Click the [Edit] button to access a dialog box where the concrete covers c_{bottom}, c_{top}, c_{side}/c_{bucket} can be determined from parameters (see following figure).

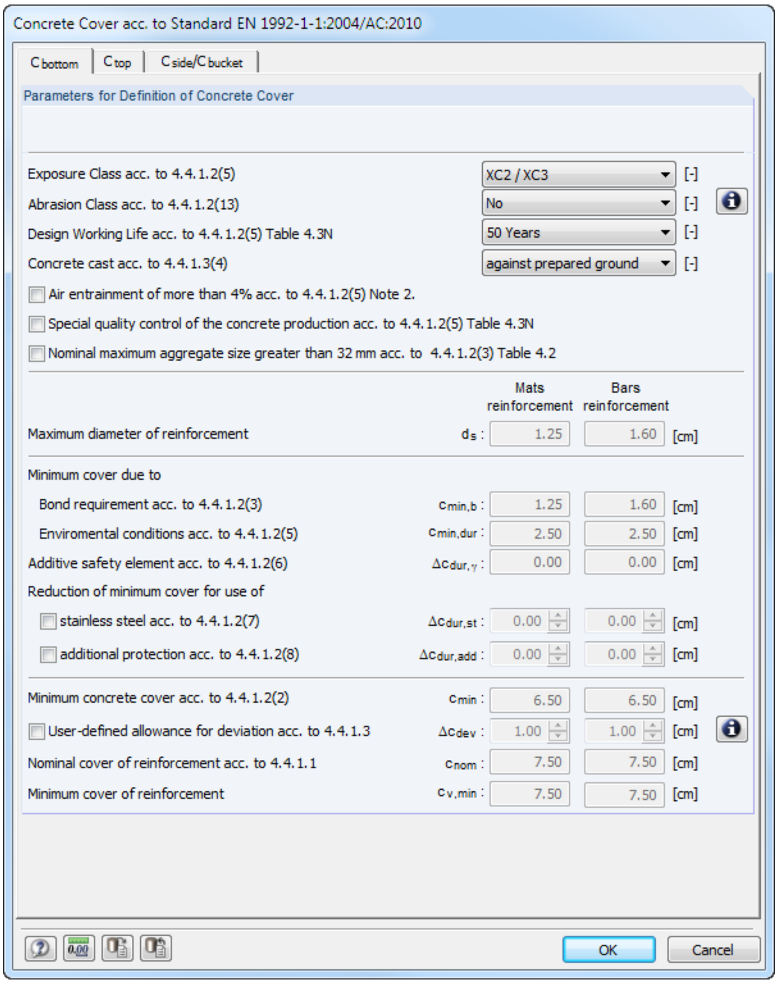
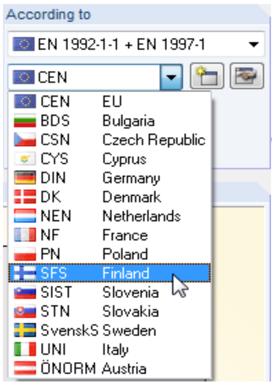


Figure 2.25: Dialog box *Concrete Cover acc. to Standard*



Partial and Reduction Factors

This window section allows for adjusting both the partial safety factors for concrete and reinforcing steel and the reduction factors needed to consider long-term effects. The values are preset according to the selected standard. There are minor differences in the descriptions of the design situations displayed in the column headings.

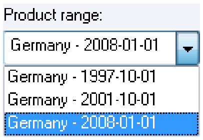
If the standard EN 1992-1-1 + EN 1997-1 has been selected without any country-specific National Annex, the basic design situation is described by *PT* (persistent and transient) and the accidental design situation by *AC*. This applies also to some national annexes.

When the German National Annex has been set, the description for the permanent design situation is *BS-P/BS-T*. For the accidental design situation it is *BS-A*.

The *long-term load factors* α_{cc} and α_{ct} for compression and tension are preset with 0.85, the factor α_{ct} for bond is preset with 1.00.

Any changes made can be reset by clicking the [Reset to Default Values for Eurocode] button.

Reinforcing Steel Mats / Reinforcing Bars / Mandrel Diameter



In the window section *Available Reinforcing Steel Mats*, you can set a product range in the list. The current range *Germany - 2008-01-01* is set as default.

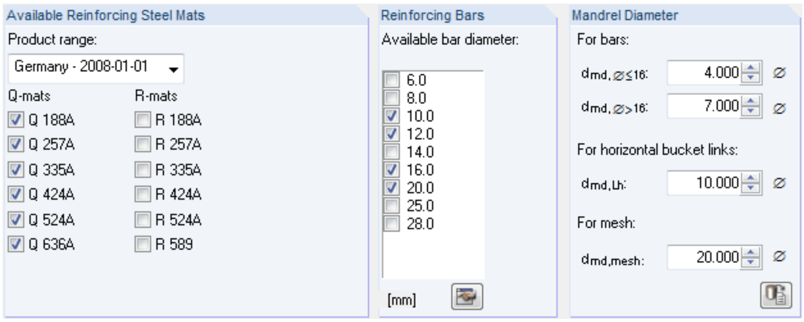


Figure 2.26: Selection of standard reinforcing steel mats and reinforcing bars

For the design of the foundation it is possible to select particular meshes from the product range.

In case the selected mats area is not sufficient for the design of the foundation plate, supplementary reinforcement in the form of rebars must be inserted. The possible bar diameters can be specified in the window section *Reinforcing Bars*.

Use the [Edit] button to reduce or extend the list of available rebar diameters.

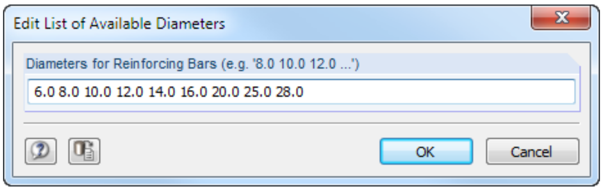


Figure 2.27: Dialog box *Edit List of Available Diameters*

Irrespective of the foundation type defined in module window 1.1, you have to specify at least one rebar section for the design of the foundation.

If the required cross-sectional area of the reinforcement is larger than it is possible to reach by using the selected diameters, the program shows the following error message:

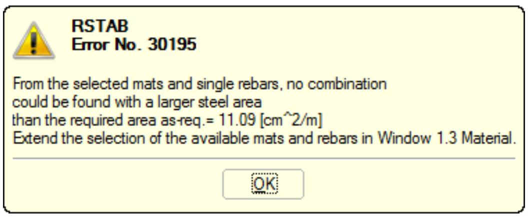
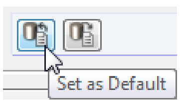


Figure 2.28: Error message for insufficient steel cross-sectional area



The current mesh and rebar configuration can be saved as default setting used for other design cases by clicking the [Set as Default] button below the window sections. With the [Default] button to the right you can preset the mats and bars in this module window.

2.4 Loading

Module window 1.4 *Loading* consists of several tabs.

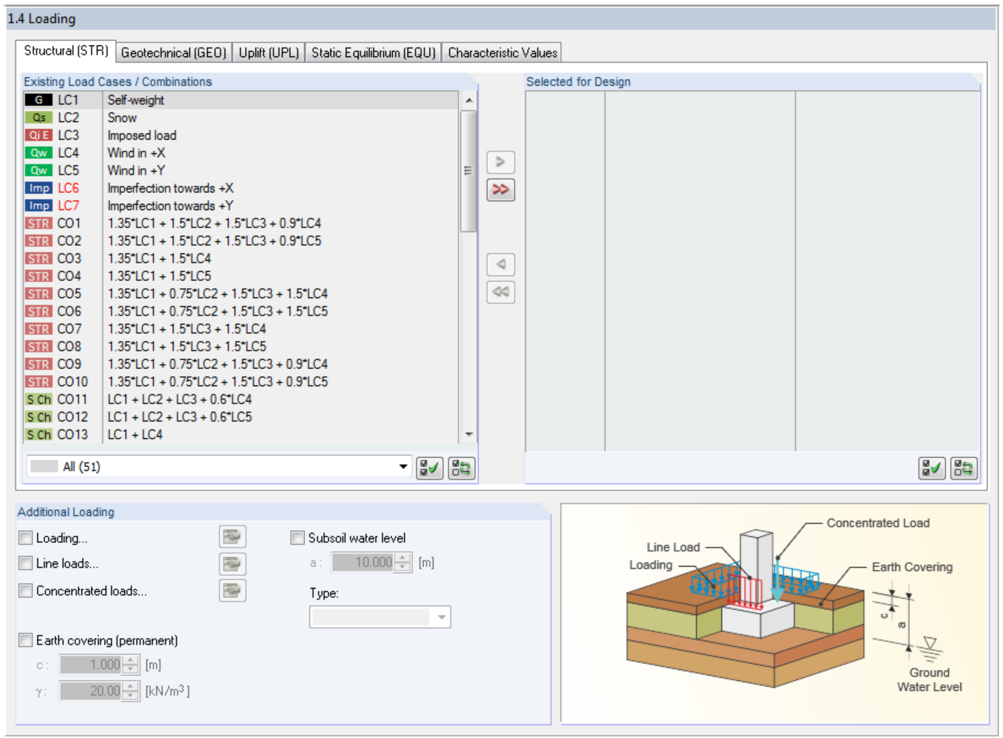


Figure 2.29: Window 1.4 *Loading*, tab *Structural (STR) and Geotechnical (GEO)*

Existing Load Cases / Combinations

This window section contains all load cases, load combinations, and result combinations that have been created in RFEM.

To transfer selected entries to the window section *Selected for Design*, click [▶]. Alternatively, you can double-click the entries. The button [▶▶] transfers the complete list to the right.

Multiple selection of load cases is possible with the common Windows function where you hold down the [Ctrl] key. In this way, you can transfer several load cases at once.

Load cases without load data as well as imperfection load cases are marked red. They cannot be designed. When you transfer such a load case, a corresponding warning appears.

Depending on the settings in the *Details* dialog box (see Figure 3.1, page 28), the tabs are shown or hidden. For example, the tab *Uplift (UPL)* is omitted if the design according to EN 1997-1, 2.4.7.4 is not activated.

The load cases must be selected separately for each design situation.

This means that in each of the activated tabs for

- ***Structural (STR) and Geotechnical (GEO)***
- ***Uplift (UPL)***
- ***Static Equilibrium (EQU)***
- ***Characteristic Values***

at least one load case or combination must be selected for the design.

Below the load case list, you find different filter options which make the selection of the design-relevant load cases and combinations easier. For example, you can use the filter to display only the result combinations. The value in brackets indicates how many entries are available for the respective filter setting.

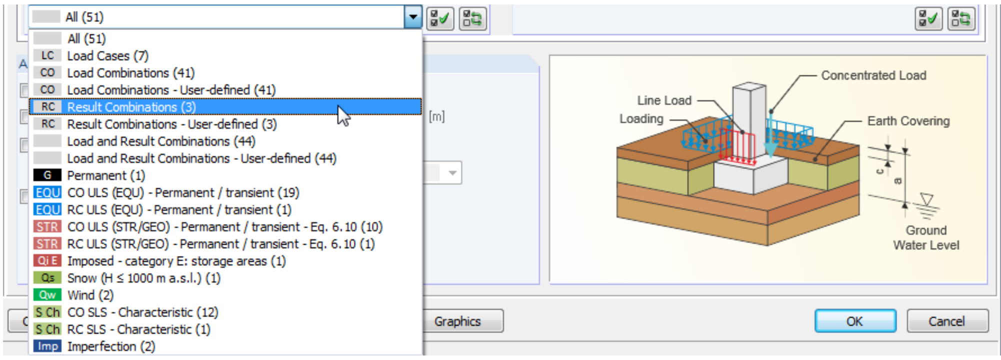


Figure 2.30: Filter for selection of load cases and combinations

The buttons have the following functions:

	Selects all cases in the list
	Inverts selection of load cases

Table 2.2: Buttons in window section *Existing Load Cases / Combinations*

Selected for Design

The window section to the right lists the load cases, load combinations, and result combinations that are selected for the design. To remove selected entries from the list, click [◀], or double-click the entries. To transfer the entire list to the left, click [◀◀].

In addition, you have to specify the design situation that is applied to the load cases and combinations to be designed. Click in the text box to enable the assignment.

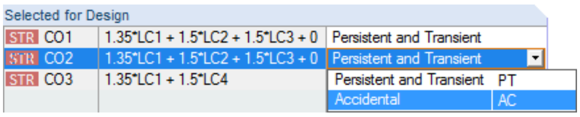
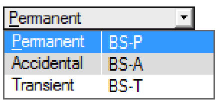


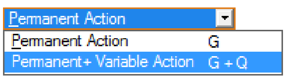
Figure 2.31: Assigning the design situation

For the analyses of the structural system (STR) and the soil (GEO), the uplift (UPL), and the equilibrium limit state (EQU) you can choose between the basic combination *Persistent and Transient PT* and *Accidental AC*. Both options are provided in the list for most national annexes.



For the National Annex of Germany, however, the list shows the following entries:

- Permanent BS-P
- Accidental BS-A
- Transient BS-T



In the window tab *Characteristic Values*, you can assign a design situation also for the German National Annex: The load constellation selected for the design of a 'twisted foundation' can contain only permanent loads or support forces from permanent and variable loads. Of course, in this case the design of the *Highly eccentric loading in the core* according to EN 1997-1, A 6.6.5 must be activated in the *Details* dialog box.

According to EN 1997-1 A 6.6.5, the verification of the first core range considers actions from permanent loads. For the verification of the second core range, actions from permanent and variable loads are used.

Additional Loading

In the lower part of the module window, you can activate more loads for the design. The symbolic graphic to the right shows how the additional loads act on the foundation.

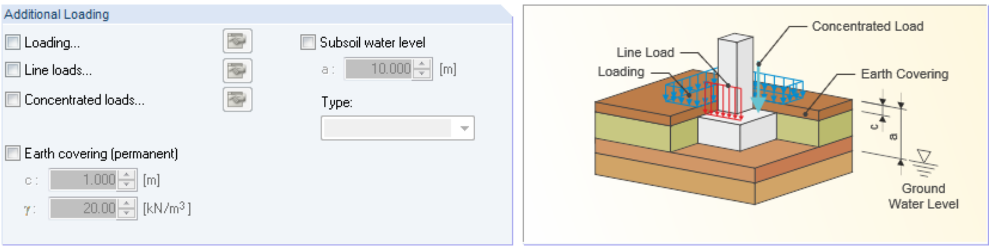


Figure 2.32: Window section *Additional Loading*

Loading

Selecting the check box opens the *Loading* dialog box for entering parameters.

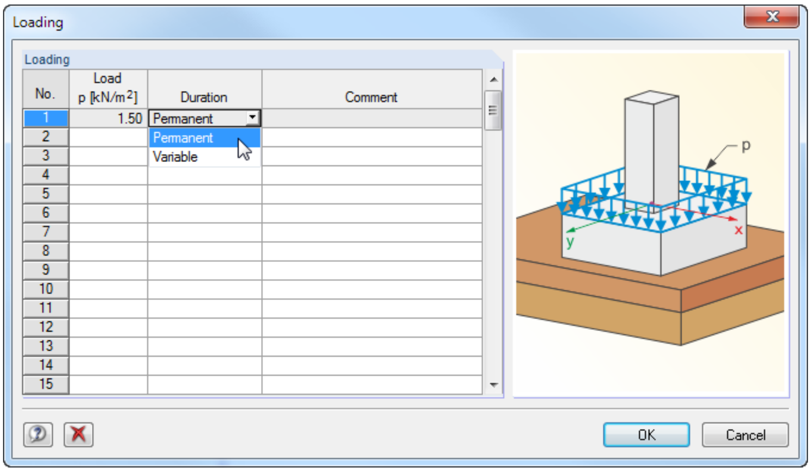


Figure 2.33: Dialog box *Loading*

The loading is uniformly applied as a surface load to the entire foundation area from which the cross-sectional area of the column is subtracted. In the *Duration* column, you decide if this additional surface load acts *Permanent* or *Variable*.

A *Comment* describing the additional load appears also in the printout report.

Line loads

Selecting the check box opens the *Line Loads* dialog box for entering parameters.

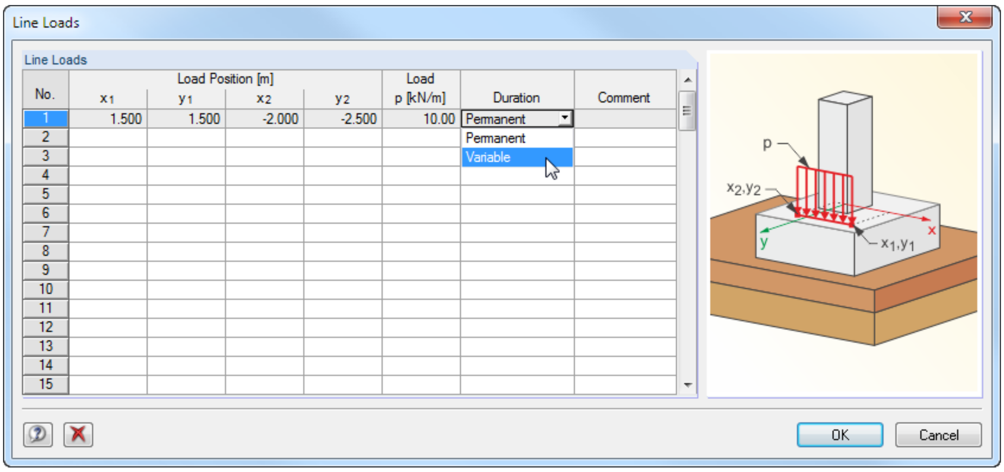


Figure 2.34: Dialog box *Line Loads*

The *Load Position* of the line load can be described by the coordinates of its start and end points. The entered values refer to the coordinate system of the support.

The line load can be defined only as a constant load. In the *Duration* column, you decide if the load acts *Permanent* or *Variable*.

Concentrated loads

Selecting the check box opens the dialog box *Concentrated Loads* for entering parameters.

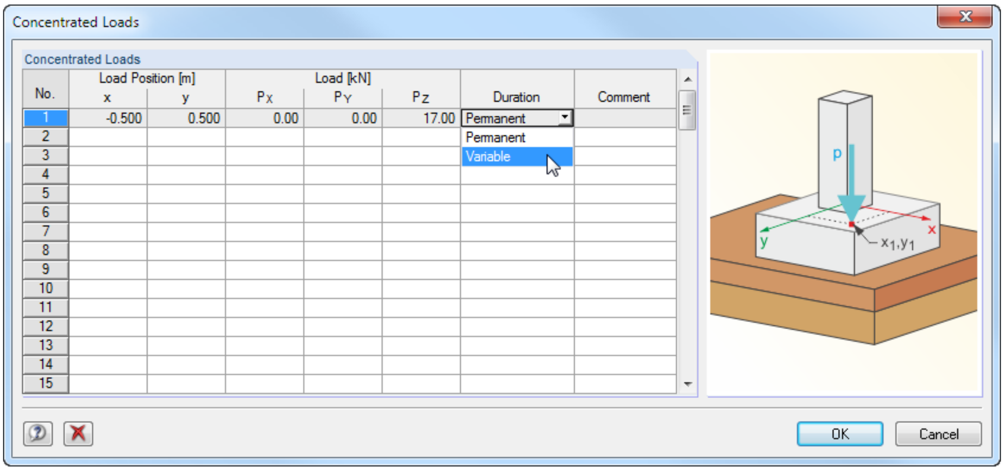
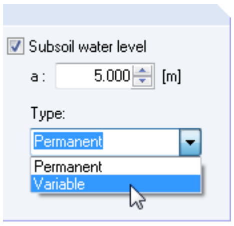


Figure 2.35: Dialog box *Concentrated Loads*

The *Load Position* is relative to the coordinate system of the support. In the table columns P_X, P_Y and P_Z, you can enter the loading components available in the X-, Y- and Z-direction.

In the *Duration* column, you decide if the load acts as *Permanent* or *Variable*.

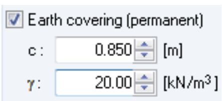
Subsoil water level



You can also take into account the impact of the groundwater. The value *a* describes the depth of the water table measured from the top edge of the earth covering to the water level.

In the *Type* list, you decide if the groundwater acts *Permanent* or *Variable*.

Earth covering



The loading due to the earth covering is generally applied as a permanent load.

If the check box is selected, you can specify the height *c* of the earth covering as well as the specific weight *γ* of the soil. The dimension measured from the top edge of the foundation plate applies to the value *c*. The specific weight is preset with 20 kN/m³.

If you have defined that the height of the earth covering will be increased in order to fulfill the geotechnical designs in the dialog box *Design Parameters for Foundation Plate* (see Figure 2.18), the earth covering cannot be deactivated in Window 1.4.

If the layout of the foundation plate dimensions leads to the result that the entered earth covering is not sufficient for a frost-free embedment depth, the height of the earth covering will be automatically increased according to the settings in the *Design Parameters* dialog box (see Figure 2.18).

The automatically increased value of the earth covering is not visible in module window 1.4. Instead, the actual applied covering height *c* is displayed in the results window 2.1 *Geometry*.

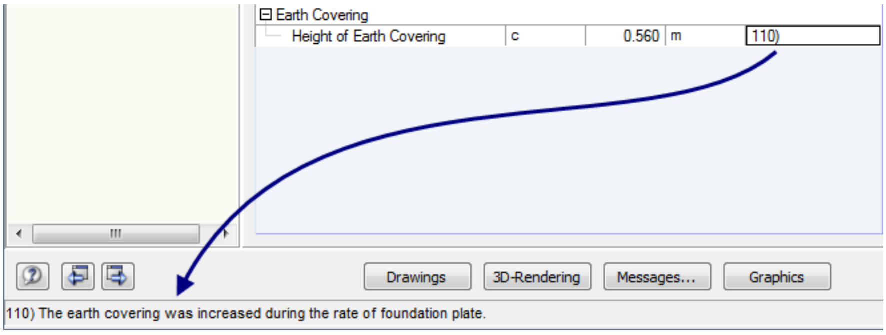


Figure 2.36: Note about automatically increased earth covering after calculation

3. Calculation

3.1 Detail Settings

Before you start the calculation, it is recommended to check the design details. To open the corresponding dialog box, use the [Details] button available in every window of the add-on module.

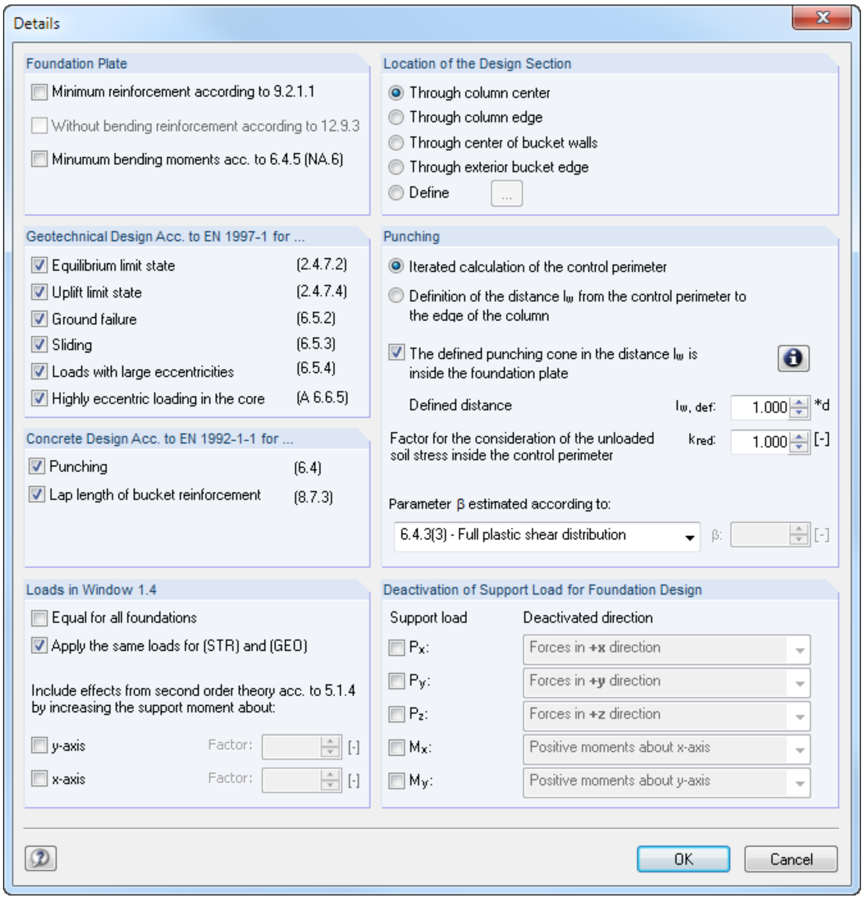


Figure 3.1: Dialog box *Details*

3.1.1 Foundation Plate

You can set a *Minimum reinforcement according to 9.2.1.1* for the foundation plate. In this case, the required minimum area of the longitudinal tension reinforcement is taken into account according to [1] 9.2.1.1 for the design.

The option *Without bending reinforcement according to 12.9.3* is currently in preparation. This setting will allow you to design the foundation according to [1] 12.9.3 as a single foundation without reinforcement.

3.1.2 Location of the Design Section

In this window section, you define the location of the section for which the bending design of the foundation plate is performed. This specification applies to the top and the bottom reinforcement layer of the foundation plate.

The position of the design section for the reinforcement's bottom and top layer can also be *Define*d individually: Selecting the option opens a dialog box where the position of the design section can be described by the distances *Delta-x* and *Delta-y* (see following figure).

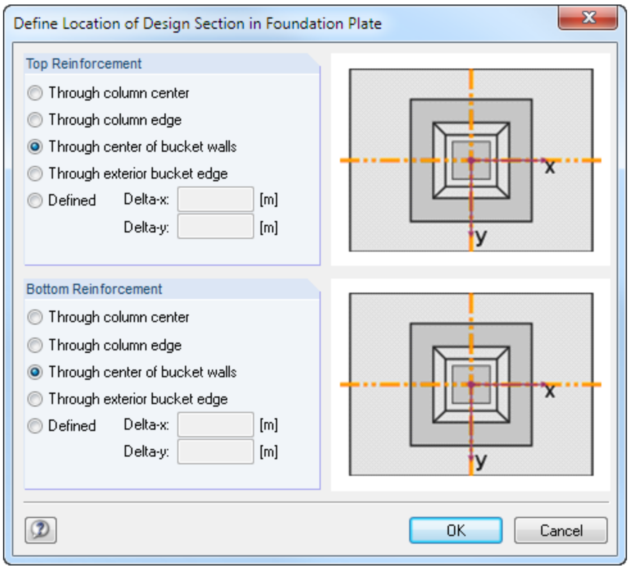


Figure 3.2: Dialog box *Define Location of Design Section in Foundation Plate*

3.1.3 Geotechnical Design Acc. to EN 1997-1

The check boxes in this dialog section determine the geotechnical designs included in the verification.

At least one geotechnical design must be selected for the verification!

The settings also affect the load cases that must be selected for the design in module window 1.4. For example, the window tab *Uplift (UPL)* is omitted in Window 1.4 if the uplift limit state design according to [2] 2.4.7.4 is deactivated.

Equilibrium limit state (EQU)

In accordance with [2] 2.4.7.2, the design for the limit state of the static equilibrium or the overall displacement of the structural system or the ground is the following:

$$E_{dst,d} \leq E_{stb,d} + T_d$$

Formula 3.1

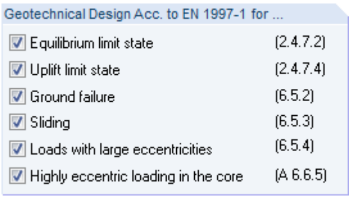
RF-FOUNDATION Pro performs this design as follows:

$$M_{dst,i} \leq M_{stb,i}$$

Formula 3.2

The moment *M* represents the destabilizing or stabilizing moment resulting on an edge *i*.

The actions created by the moments must be reduced (stabilizing) or increased (destabilizing) with the corresponding partial safety factor γ_F from [2] A.2.



Uplift limit state (UPL)

According to [2] clause 2.4.7.4, the verification for the uplift must be performed in such a way that the design value of the combination of destabilizing permanent and variable vertical actions $V_{dst,d}$ is less than or equal to the sum of the design value of the stabilizing permanent vertical actions $G_{stb,d}$ and of the design value of any additional resistance R_d to uplift.

$$V_{dst,d} \leq G_{stb,d} + R_d$$

where $$V_{dst,d} = \left| G_{dst,k} \cdot \gamma_{G,dst} + Q_{dst,k} \cdot \gamma_{Q,dst} \right|$$

$$G_{stb,d} = G_{stb,k} \cdot \gamma_{G,stb}$$

Formula 3.3

The additional resistance R_d as a result of any acting stabilizing shear force can but does not need to be considered for this design. This resistance is not taken into account in RF-FOUNDATION Pro.

The partial safety factors γ must be taken from [2] A.4.

Ground failure

The design for the ground failure belongs to the limit state STR/GEO-2 according to [2]. The actions acting perpendicular to the foundation's base level are compared with the design values of the resistances.

$$V'_d \leq R_d$$

Formula 3.4

An analytical method according to [2] 6.5.2(2) is applied. In [2] annex D, you find an informative example for determining the ground failure resistance analytically.

The actions and resistances must be reduced with the partial safety factors γ according to [2] A.3.

Effective area in case of off-center loading

The ground failure analysis considers only a part of the actually existing base area, which is the part where the resulting axial force acts on the center.

The effective area *A'* is calculated at the beginning of the verification.

$$A' = B' \cdot L'$$

where $B' \leq L'$

$B' = B - 2e_b$ e_b is the effective load eccentricity that belongs to side B

$L' = L - 2e_l$ e_l is the effective load eccentricity that belongs to side L

Sliding

According to [2] clause 6.5.3, a failure due to sliding in the base area must be analyzed if the load vector is not normal to this area.

A risk for sliding exists if the design value of the force H_d resulting parallel to this area in the direction of the displacement is larger than the sum of the design values of the resistance against sliding $R_{s,d}$ and the earth resistance $R_{p,d}$.

Therefore, it must be verified that the following condition is met:

$$H_d \leq R_{s,d} + R_{p,d}$$

Formula 3.5

The resistances must be reduced with the partial safety factors γ according to [2] A3.3.1.

Resistance against sliding for drained conditions

$$R_{s,d} = \frac{R_{s,k}}{\gamma_{R,h}}$$

$$R_{s,k} = V'_d \cdot \tan(\delta_{s,d})$$

For the design value of the angle of soil friction according to [2] 6.5.3 (10) the standard allows for cast-in-situ concrete foundations to apply the design value of the critical angle of shearing resistance φ_d. This angle must be reduced with the partial safety factor γ according to [2] A.3.2.

$$\delta_{s,d} = \varphi_d = \frac{\varphi'_k}{\gamma_{\varphi'}}$$

According to [2] /NA:2010-12, the following must be fulfilled: $\delta_{s,k} \leq 35°$.

Resistance against sliding for undrained conditions

$$R_{s,d} = \frac{R_{s,k}}{\gamma_{R,h}}$$

$$R_{s,k} = A' \cdot \frac{c_{uk}}{\gamma_{cu}}$$

Earth resistance

$$R_{p,d} = \frac{R_{p,k}}{\gamma_{R,v}}$$

$$R_{p,x,k} = 0.5(\sigma_{p,t} + \sigma_{p,b}) \cdot d \cdot x$$

$$R_{p,y,k} = 0.5(\sigma_{p,t} + \sigma_{p,b}) \cdot d \cdot y$$

$$\sigma_{p,o} = c'_d \cdot K_{pch} + K_{agh} \cdot (p_{d,perm} + p_{d,var} + \gamma_{c,d} \cdot c)$$

$$\sigma_{p,u} = c'_d \cdot K_{pch} + K_{pgh} \cdot (\gamma_{1,d} \cdot d + p_{d,perm} + p_{d,var} + \gamma_{c,d} \cdot c)$$

$$p_{d,perm} = p_{k,perm} \cdot \gamma_Q$$

$$p_{d,var} = p_{k,var} \cdot \gamma_G$$

If $\alpha = \beta = \delta = 0$, the passive earth pressure due to cohesion can be assumed as follows:

$$K_{pch} = 2 \cdot \sqrt{K_{pgh}}$$

For [2] /NA:2010-12, δ should be zero according to 6.5.3 (16). Therefore, the formula above is always used for the design according to the German National Annex.

Loads with large eccentricities

In accordance with [2] 6.5.4, no special arrangements must be taken if the following applies in general to a rectangular base area:

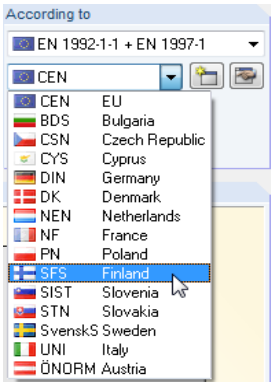
$$e_x \le e_{all} = \frac{1}{3} \cdot b_x$$

Formula 3.6

$$e_y \le e_{all} = \frac{1}{3} \cdot b_y$$

Formula 3.7

Highly eccentric loading in the core (only for DIN EN 1997-1)



When the German National Annex has been set, the description for the permanent design situation is *BS-P/BS-T*. For the accidental design situation it is *BS-A*.

The verification according to [2] A 6.6.5 checks if a gaping of joints due to permanent actions and unfavorable load combinations occurs beyond the centroid of the base area.

Permanent actions

The resultant from all characteristic loading V_k acting on the foundation base should be within the first core area. Only actions but no resistances are considered.

Unfavorable combination from permanent and variable actions

The resultant from all characteristic loading V_k should not be outside the second core area. Again, only actions are considered.

Verification showing that V_k is inside the first core area:

$$\frac{e_x}{b_x} + \frac{e_y}{b_y} \le \frac{1}{6}$$

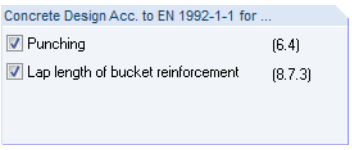
Formula 3.8

Verification showing that V_k is not outside the second core area:

$$\left(\frac{e_x}{b_x}\right)^2 + \left(\frac{e_y}{b_y}\right)^2 \le \frac{1}{9}$$

Formula 3.9

3.1.4 Concrete Design Acc. to EN 1992-1-1



This dialog section allows you to deactivate *Punching* for the steel design. Then, the options in the *Punching* dialog section to the right are disabled.

Checking the *Lap length of bucket reinforcement* according to [1] 8.7.3 is only available for bucket and block foundations with rough bucket or wall sides.

3.1.5 Punching

This dialog section manages the parameters that are relevant for the punching shear designs.

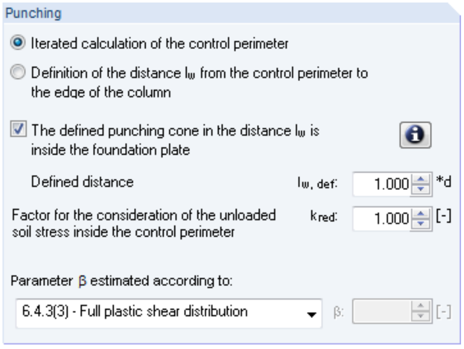


Figure 3.3: Dialog section *Punching*

The control perimeter can be determined by an *Iterated calculation* or specified by a manual *Definition of the distance l_w*.

The check box for *The defined punching cone in the distance l_w* and the $l_{w,def}$ text box are accessible even if the punching has been deactivated in the *Concrete Design* dialog section. The check mark controls the position of the punching cone relative to the foundation plate. If the cone does not lie within the plate, the plate's minimum dimensions will be adjusted with the punching cone during the layout process.

Click the [Info] button to open a graphic showing the foundation parameters.

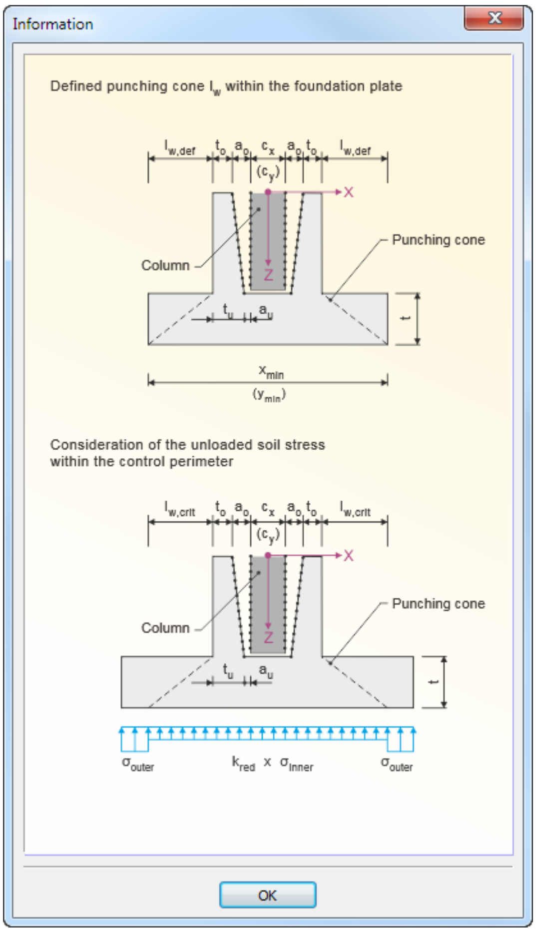


Figure 3.4: Dialog box *Information* for rough bucket foundation

Furthermore, the *Punching* dialog section offers the possibility to adjust the component of the favorably acting soil stresses for the punching shear design by means of the *Factor for the consideration of the unloaded soil stress inside the control perimeter*.

According to [1] 6.4.4, it is allowed to apply the sum of ground pressures within the punching cone as a relief of up to 100 % if the control perimeter for the punching shear design of the foundation plate was determined iteratively. If the constant perimeter is assumed in a distance of 1.0 d in order to simplify the calculation, it is allowed to assume only 50 % of the sum of soil pressures within the constant perimeter as a relief.

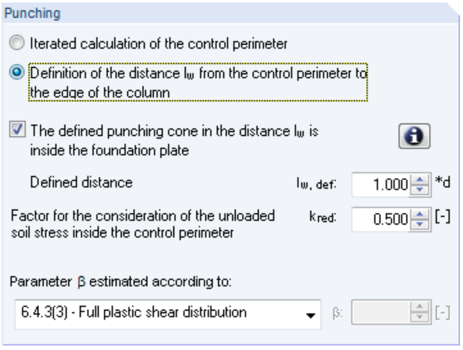
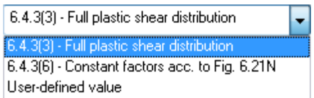
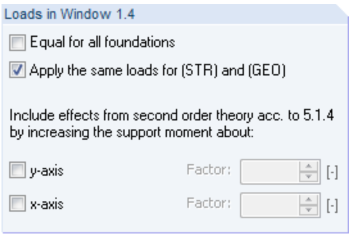


Figure 3.5: Factor k_{red} depending on defined distance



With the list at the end of the dialog section you can find out the *Parameter β* by using different possibilities. The load increment factor can be determined under the assumption of a fully plastic shear stress distribution according to [1] 6.4.3 (3) or on the basis of constant factors according to [1] 6.4.3 (6). In addition, it is possible to enter a user-defined value into the *β* box.

3.1.6 Loads in Window 1.4



Use the check box *Equal for all foundations* to define that the loading of the first foundation is applied also to all further, newly added foundations. This option is not active by default so that each foundation is designed with its own loads.

If you deactivate the default option *Apply the same loads for (STR) and (GEO)*, you can enter the load cases separately for the reinforced concrete design and the geotechnical designs in module window 1.4 *Loading*.

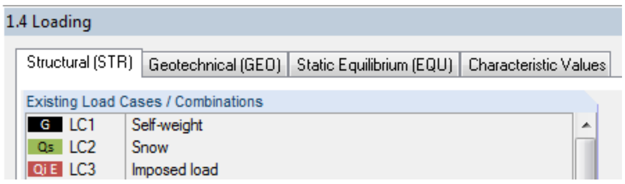


Figure 3.6: Window 1.4 *Loading* with separate input for *Structural (STR)* and *Geotechnical (GEO)*

Moreover, this dialog section allows you to *Include effects from second order theory acc. to 5.1.4 by increasing the support moment*. This may apply for example to the foundation of a reinforced concrete bracket that was designed by using the model column method according to linear static analysis.

If the check boxes are selected, you can specify factors for the y- and x-axis to increase the fixing moment. In this way, it is possible to consider the influence from second-order analysis.

3.1.7 Deactivation of Support Loads for Foundation Design

With the check boxes in this dialog section you can prevent particular support reactions for the design. Separate settings are possible for the support loads **Px**, **Py** and **Pz** and the support moments **Mx** and **My**. The specifications apply to the current design case only.

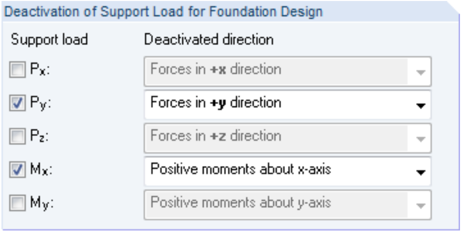
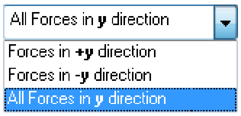


Figure 3.7: Dialog section *Deactivation of Support Load for Foundation Design*

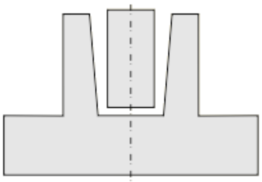


When a *Support load* type is selected, you can open the corresponding list and select the forces or moments that you want to ignore (in positive or negative direction, or all).

If components of support reactions are suppressed for the design, it is documented in the results windows available after the calculation.

3.2 Minimum Dimensions

Bucket foundation with smooth bucket sides



Minimum dimensions

Minimum side lengths from column dimensions:

$$x = c_x + 2 \cdot (t_{tx} + a_{tx}) + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot (t_{ty} + a_{ty}) + 2 \cdot |e_y|$$

Minimum side lengths for control perimeter within foundation plate:

$$x = \max \begin{Bmatrix} c_x + 2 \cdot (l_{sw}) + 2 \cdot |e_x| \\ c_x + 2 \cdot (t_{tx} + a_{tx}) + 2 \cdot |e_x| \end{Bmatrix}$$

$$y = \max \begin{Bmatrix} c_y + 2 \cdot (l_{sw}) + 2 \cdot |e_y| \\ c_y + 2 \cdot (t_{ty} + a_{ty}) + 2 \cdot |e_y| \end{Bmatrix}$$

where l_{sw} Distance between punching cone and column edge

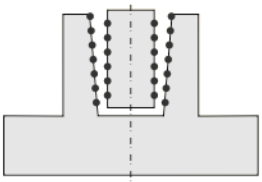
Minimum embedment depth of column

Minimum embedment depth *min t* according to [1] 10.9.6.3:

$$\min\ t = 1.2 \cdot c$$

Minimum embedment depth recommended according to [1] /NA:2011-01:

$$\min\ t_1 = 1.5 \cdot c$$



Bucket foundation with rough bucket sides

Minimum dimensions

Minimum side lengths from column dimensions:

$$x = c_x + 2 \cdot (t_{tx} + a_{tx}) + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot (t_{ty} + a_{ty}) + 2 \cdot |e_y|$$

Minimum side lengths for control perimeter within foundation plate:

$$x = c_x + 2 \cdot (t_{tx} + a_{tx}) + 2 \cdot (l_{sw}) + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot (t_{ty} + a_{ty}) + 2 \cdot (l_{sw}) + 2 \cdot |e_y|$$

where l_{sw} Distance between punching cone and column edge

Minimum embedment depth of column

The minimum embedment depth is calculated according to [6] Chapter 16.3.3.1.

$$e = \left| \frac{M}{P_z \cdot c} \right|$$

Variable	Description
e	Related load eccentricity
M	Fixing moment of column on top side of bucket
P_z	Axial force of column
c	Column dimension

Table 3.1: Variables for calculation of minimum embedment depth

$e \leq 0.15$:

$$\min\ t_1 = 1.2 \cdot c$$

$0.15 < e < 2.00$:

$$\min\ t_1 = \left(1.2 + \frac{2.0 - 1.2}{2.0 - 0.15} \cdot (e - 0.15) \right) \cdot c$$

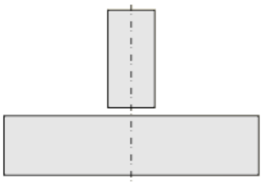
$e \geq 2.00$:

$$\min\ t_1 = 2.0 \cdot c$$

If a value entered in module window 1.2 *Geometry* falls below the minimum value (see Figure 2.19, page 18), the program replaces the value automatically by the minimum value. When the foundation plate thickness is increased, the minimum side lengths will be recalculated automatically.

Foundation plate

The following conditions apply to the minimum dimensions, depending on the selected plate thickness *t* and the specified position of the control perimeter (see *Details* dialog box):



$$t_{min} = 20\ \text{cm}$$

Minimum side lengths from column dimensions:

$$x = c_x + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot |e_y|$$

Minimum side lengths for control perimeter within foundation plate:

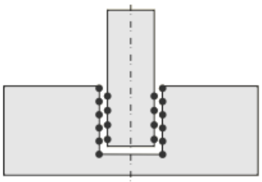
$$x = c_x + 2 \cdot l_{sw} + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot l_{sw} + 2 \cdot |e_y|$$

Variable	Description
c_x	Column dimension in the x-direction
c_y	Column dimension in the y-direction
x	Foundation plate dimension in the x-direction
y	Foundation plate dimension in the y-direction
t	Thickness of foundation plate
e	Eccentricity of column
l_{sw}	Distance between punching cone and column edge

Table 3.2: Variables of foundation geometry

Block foundation with rough bucket sides



Minimum dimensions

The same minimum thicknesses t_{min} and minimum side lengths, which are valid for the foundation plate (see above), apply to the block foundation.

$$t_{min} = 20\ \text{cm}$$

Minimum side lengths from column dimensions:

$$x = c_x + 2 \cdot a_{tx} + 2 \cdot |e_x| + 20\ \text{cm}$$

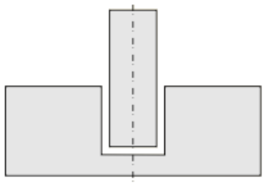
$$y = c_y + 2 \cdot a_{ty} + 2 \cdot |e_y| + 20\ \text{cm}$$

Minimum embedment depth of column

Minimum embedment depth according to [4] 2.6.4:

$$t = 1.5 \cdot c$$

Block foundation with smooth bucket sides



Minimum dimensions

Minimum plate thickness:

$$t_{min} = h + max(15\ cm; 10\ cm + c_{nom,top} + c_{nom,bottom})$$

Minimum side lengths from column dimensions:

$$x = c_x + 2 \cdot a_{tx} + 2 \cdot |e_x| + 50\ cm$$

$$y = c_y + 2 \cdot a_{ty} + 2 \cdot |e_y| + 50\ cm$$

The foundation plate is increased about 50 cm (25 cm on each side of the column) in order to provide enough space for the vertical links Lvx and Lvy.

Minimum side lengths for control perimeter within the foundation plate:

$$x = c_x + 2 \cdot l_{sw} + 2 \cdot |e_x|$$

$$y = c_y + 2 \cdot l_{sw} + 2 \cdot |e_y|$$

Variable	Description
h	Thickness of foundation plate
c_{nom}	Concrete cover
c_x / c_y	Column dimension in the x- and y-direction
a_t / a_b	Column allowance top and bottom
e_x / e_y	Eccentricity in the x- and y-direction
l_{sw}	Distance between punching cone and column edge

Table 3.3: Variables for determination of minimum dimensions

Minimum embedment depth of column

Like the bucket foundation with smooth bucket sides (see above), the minimum embedment depth *min t* is the following according to [1] 10.9.6.3:

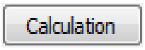
$$min\ t = 1{,}2 \cdot max(c_x; c_y)$$

Minimum embedment depth recommended according to [1] /NA:2011-01:

$$min\ t_1 = 1{,}5 \cdot max(c_x; c_y)$$

The minimum value is taken into account accordingly for the design performed with the National Annex of Germany.

3.3 Start Calculation



To start the calculation, click the [Calculation] button that is available in all input windows of the add-on module.

RF-FOUNDATION Pro searches for the results of the load cases, load and result combinations to be designed. If they cannot be found, the RFEM calculation starts to determine the design-relevant internal forces.

You can start the calculation also in the RFEM user interface: Use the dialog box *To Calculate* (menu **Calculate** → **To Calculate**) where the design cases of the add-on modules as well as the load cases or load combinations are listed.

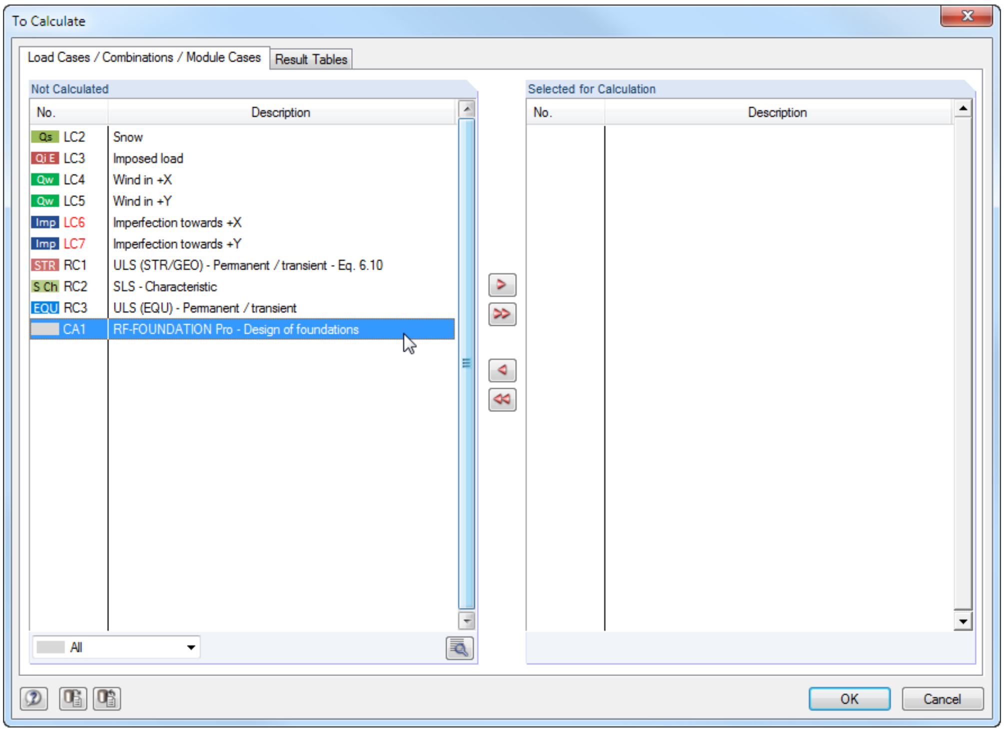
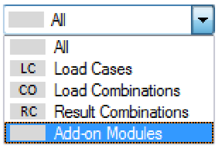


Figure 3.8: Dialog box *To Calculate* in RFEM



If the design cases from RF-FOUNDATION Pro are missing in the *Not Calculated* list, select *All* or *Add-on Modules* in the drop-down list below.

To transfer the selected RF-FOUNDATION Pro cases to the list on the right, use the button [▶]. Then, click [OK] to start the calculation.

Alternatively, you can start the calculation of a design case by using the drop-down list in the toolbar: Select the RF-FOUNDATION Pro case, and then click [Show Results].

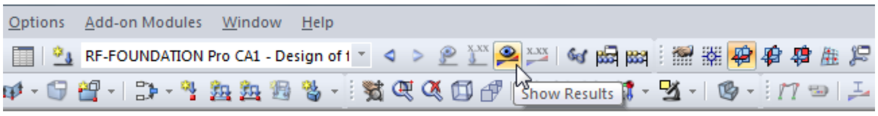


Figure 3.9: Direct calculation of a RF-FOUNDATION Pro design case in RFEM

Subsequently, you can observe the calculation process in a separate dialog box.

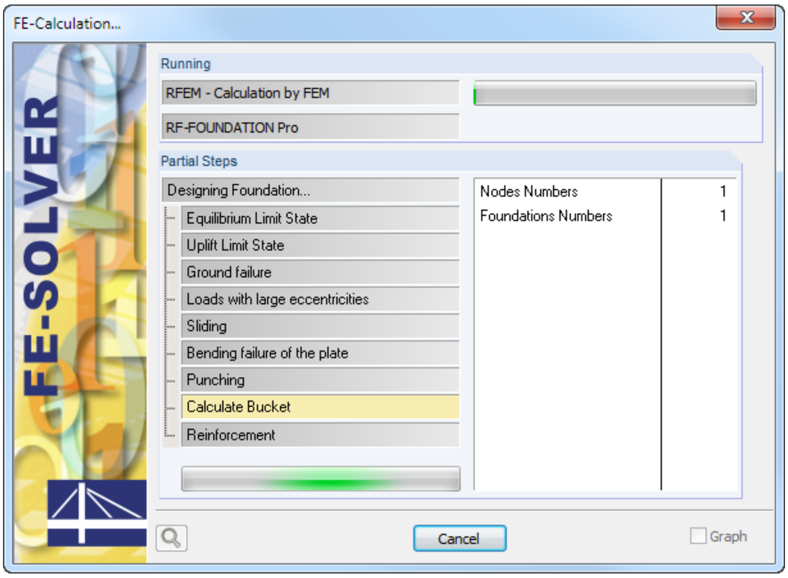
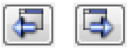


Figure 3.10: RF-FOUNDATION Pro calculation

4. Results

Module window 2.1 *Geometry* is displayed immediately after the calculation.



The navigator on the left shows the other results windows where the governing designs as well as the reinforcements are indicated. To select a window, click the corresponding navigator entry. To go to the previous or subsequent window, use the buttons shown on the left. Alternatively, you can use the function keys to go the next [F2] or previous [F3] window.

Click [OK] to save the results. You exit RF-FOUNDATION Pro and return to the main program.

Chapter 4 *Results* describes the different results windows one by one. Evaluating and checking the results is described in Chapter 5 *Results Evaluation* on page 53.

4.1 Geometry

Module window 2.1 shows all dimensions resulting from the design process for the foundation plate and, if applicable, the bucket.

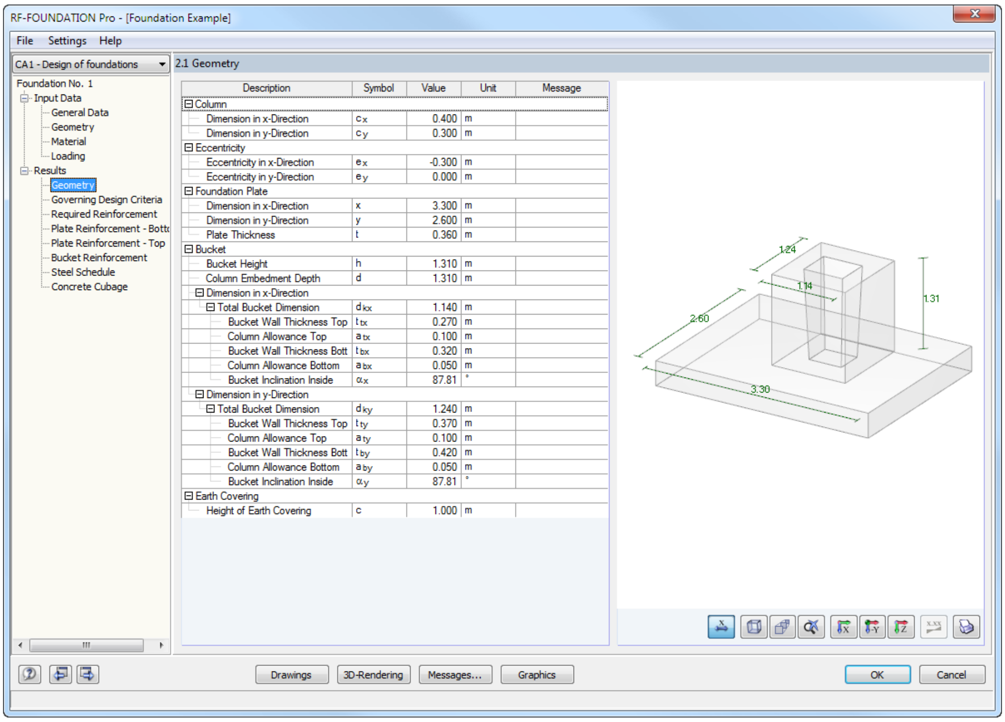


Figure 4.1: Window 2.1 *Geometry*

As common in Windows applications, the list entries can be expanded with [+] and collapsed with [-]. The amount of output data depends on the foundation type: For example, there are no bucket dimensions for a designed foundation plate.

The foundation is graphically represented on the right in the module window. In this graphical window, you can use the mouse functions that you already know from RFEM: It is possible to zoom, shift or rotate the view. The corresponding buttons are described in Chapter 5.1 on page 53.

4.2 Governing Design Criteria

The upper part of the window offers a summary of the governing designs sorted by design criteria.

The lower part contains detailed data for the design that is selected in the upper part.

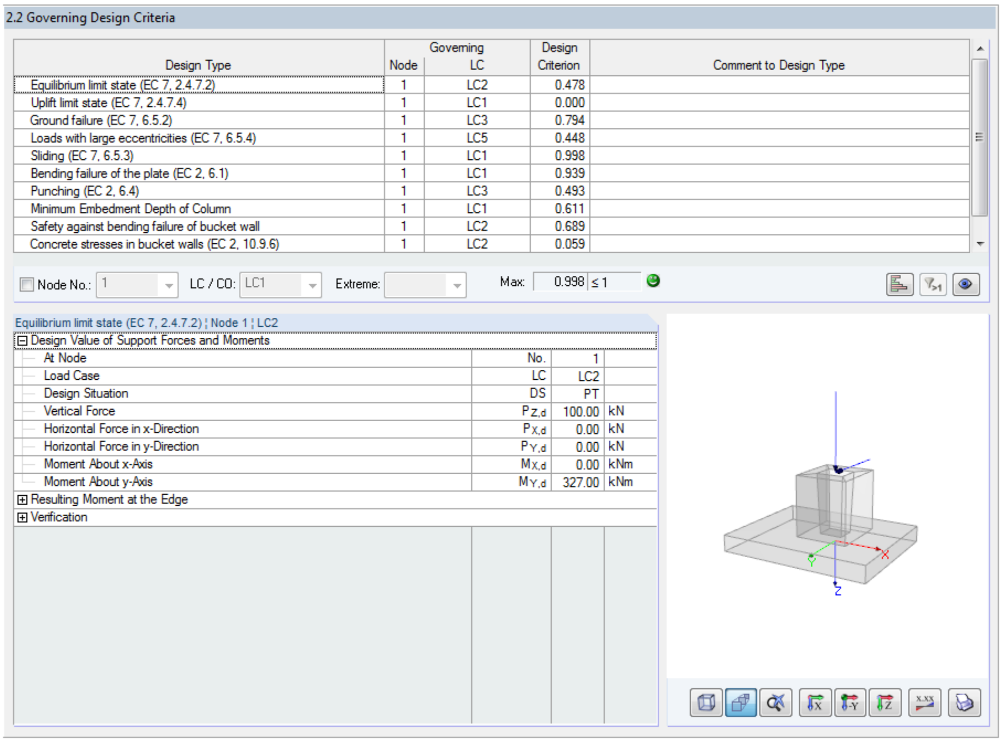


Figure 4.2: Window 2.2 *Governing Design Criteria*

Design Type

This table column shows the description of the performed design.

Governing Node / LC

The two columns show information about the support node on which the governing support force is available and the load case, load combination or result combination where the force occurs.

Design Criterion

When the *Rate* option has been set, the dimensions are always chosen in a way that the design criterion is ≤ 1.00, and thus the respective design is fulfilled. When the option *Define dimensions* has been set, the designs that are not fulfilled with the entered dimensions are described with values that are > 1.00.

In case a design is not required, it is indicated by *0.000*.

Comment to Design Type

The final table column can contain important notes describing the design. These notes are summarized in a dialog box that you can access by clicking the [Messages] button.

Result filter

Below the table, you see a row with a check box and several lists.

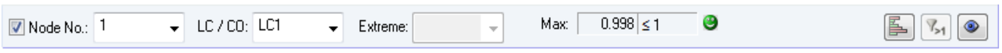
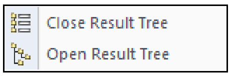


Figure 4.3: Result filter for table

If the check box *Node No.* is selected, you can use the list and select a node whose results you want to be displayed in the table. The *LC / CO* list can additionally be used to filter the results by load cases. This function has also been described in the DLUBAL blog: www.dlubal.com/blog/12558

Details

As an example for the structure of a details table, find a presentation of the designs for the concrete stresses in the bucket walls below.



The shortcut menu of the details table can be used to open or close the entire results tree: Right-click anywhere in the details table to access the options shown on the left.

⊟ Bucket Wall in x-Direction	Criterion	0.059	
⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC2	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	100.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	0.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	0.00	kN
Moment About x-Axis	$M_{X,d}$	0.00	kNm
Moment About y-Axis	$M_{Y,d}$	327.00	kNm
⊟ Top Concrete Stress	$\sigma_{c,t,x}$	1371.95	kN/m²
Top Horizontal Force in x-Direction	$H_{t,x}$	299.54	kN
Provided Embedment Depth	prov d	1.310	m
Total Bucket Dimensions	$d_{k,Y}$	1.240	m
Top Bucket Wall Thickness	$t_{t,Y}$	0.370	m
⊟ Verification			
Provided Concrete Stress	σ_{cx}	1371.95	kN/m²
Concrete Design Value	f_{cd}	23333.3	kN/m²
Design Criterion	Criterion	0.059	
⊟ Bucket Wall in y-Direction	Criterion	0.022	
⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC3	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	500.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	0.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	0.00	kN
Moment About x-Axis	$M_{X,d}$	150.00	kNm
Moment About y-Axis	$M_{Y,d}$	-150.00	kNm
⊟ Top Concrete Stress	$\sigma_{c,t,y}$	524.445	kN/m²
Top Horizontal Force in y-Direction	$H_{t,y}$	137.40	kN
Provided Embedment Depth	prov d	1.310	m
Total Bucket Dimensions	$d_{k,X}$	1.140	m
Top Bucket Wall Thickness	$t_{t,X}$	0.270	m
⊟ Verification			
Provided Concrete Stress	σ_{cy}	524.445	kN/m²
Concrete Design Value	f_{cd}	23333.3	kN/m²
Design Criterion	Criterion	0.022	

Figure 4.4: Details for concrete stress design in bucket walls

The output is subdivided into two sections for the x- and y-directions. First, the governing internal forces are listed, the required intermediate results follow. At the end, you see the design criterion that is displayed for each direction.

Graphic

The graphical window in this module window shows an interactive graphic of the foundation. The picture is aligned with the table row selected in the details table to the left.

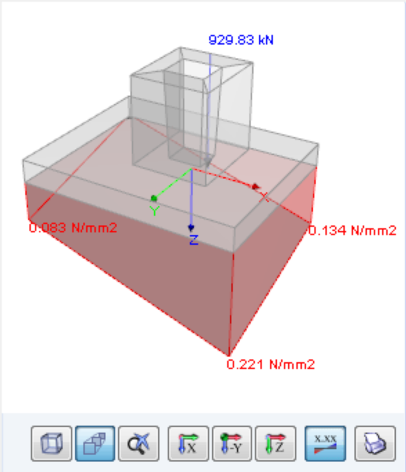


Figure 4.5: Graphic of compression stresses

For example, the figure above demonstrates how the compression stresses are distributed under the foundation plate. These stresses are contained in the details of the punching shear design.

The view functions and buttons are described in Chapter 5.1 on page 53.

4.3 Required Reinforcement

Also this module window consists of two tables and a graphical window.

2.3 Required Reinforcement

Type of Reinforcement	Pos.	Reinforcement Description	Reinforcement Area	Reinforcement Unit	Comment
Foundation Plate, Bottom, in x, Area I	2	$a_{x,I}$	10.26	cm²/m	
Foundation Plate, Bottom, in y, Area I	3	$a_{y,I}$	6.57	cm²/m	
Foundation Plate, Top, in x	4	a_x	1.69	cm²/m	
Foundation Plate, Top, in y	4	a_y	0.00	cm²/m	
Horizontal Bucket Links (outside all sides)	5,8	Lh	4.046	cm²	
Horizontal Bucket Links LhX (outside, in x-direction)	7,10	LhX	0.842	cm²	
Horizontal Bucket Links LhY (outside, in y-direction)	6,9	LhY	2.601	cm²	
Vertical Bucket Links LvX (Bucket Wall in x-Direction	14	Lv_X	4.509	cm²	
Vertical Bucket Links LvY (Bucket Wall in y-Direction	11	Lv_Y	1.985	cm²	
Reinforcement in Bucket Wall in x-Direction	12	$Lv_{x,wall}$	0.000	cm²	

Foundation Plate, Bottom, in x, Area I ¦ Pos: 2 ¦ Name: ax,I

⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC1	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	300.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	-50.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	20.00	kN
Moment About x-Axis	$M_{X,d}$	100.00	kNm
Moment About y-Axis	$M_{Y,d}$	250.00	kNm
⊟ Design Strip			
⊞ Design Value of Acting Bending Moment	$M_{Ed,x,4}$	37.70	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,x,4}$	37.76	kNm
⊞ Verification			
⊟ Details on the Selected Reinforcement			
Required Reinforcement per Meter	req $a_{x,I}$ (per r	10.26	cm²/m
Provided Reinforcement per Meter	prov $a_{x,I}$ (per	10.27	cm²/m
Defined Width of Reinforcement Area I	y_I (defined)	2.600	m
Designed Width of Reinforcement Area I	y_I (designed)	2.200	m
Selected Basic Mat	Description	Q 524A	
Provided Mat Reinforcement	prov $a_{x,Mat}$	5.24	cm²/m
Selected Reinforcement Bar	d_s	8.0	mm
Rebar Spacing	s	10.0	cm

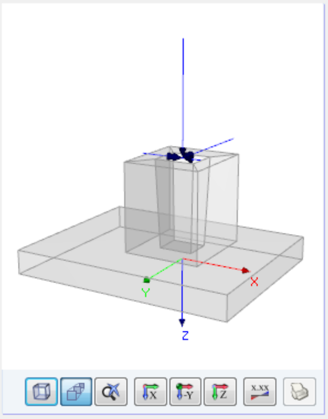


Figure 4.6: Window 2.3 *Required Reinforcement*

Type of Reinforcement

This table column lists the parts of the foundation for which the reinforcement is provided (foundation plate, horizontal and vertical bucket links, reinforcement in bucket wall). In addition, it is indicated in which direction and position the reinforcement must be arranged.

Pos

Each reinforcement receives a position name under which it can be found later in the reinforcement drawing (see Chapter 5.3, page 57).

Reinforcement Description

Here, the reinforcement's short descriptions are indicated as symbols.

Reinforcement Area

This column shows the required areas of reinforcement steel.

Unit

If necessary, the units of the reinforcement areas can be adjusted as described on page 64.

Details

The lower part of the module window lists the design details of the reinforcement type that is selected in the table above.

Foundation Plate, Bottom, in x, Area I ¦ Pos: 2 ¦ Name: ax,l

⊞ Design Value of Support Forces and Moments			
⊟ Design Strip			
⊞ Design Value of Acting Bending Moment	$M_{Ed,x,4}$	37.70	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,x,4}$	37.76	kNm
⊟ Verification			
⊟ Required Reinforcement	req $A_{x,4}$	3.34	cm^2
Width of Foundation Plate Strip	y_{strip}	0.325	m
Required x Reinforcement per Meter	req a_x (per m	10.26	cm^2/m
⊟ Provided Reinforcement	prov $A_{x,4}$	3.34	cm^2
Width of Foundation Plate Strip	y_{strip}	0.325	m
Provided x Reinforcement per Meter	prov a_x	10.27	cm^2/m
Design Criterion	Criterion	1.000	
⊟ Details on the Selected Reinforcement			
Required Reinforcement per Meter	req $a_{x,I}$ (per r	10.26	cm^2/m
Provided Reinforcement per Meter	prov $a_{x,I}$ (per	10.27	cm^2/m
Defined Width of Reinforcement Area I	y_I (defined)	2.600	m
Designed Width of Reinforcement Area I	y_I (designed)	2.200	m
Selected Basic Mat	Description	Q 524A	
Provided Mat Reinforcement	prov $a_{x,Mat}$	5.24	cm^2/m
Selected Reinforcement Bar	d_s	8.0	mm
Rebar Spacing	s	10.0	cm
Reinforcement Area of Rebars	prov a (Bar)	5.03	cm^2/m

Figure 4.7: Details table for reinforcement of foundation plate, bottom, in x, area I

Graphic

The graphical window in this module window shows an interactive graphic of the foundation. The picture is aligned with the table row selected in the details table to the left.

3D-Rendering

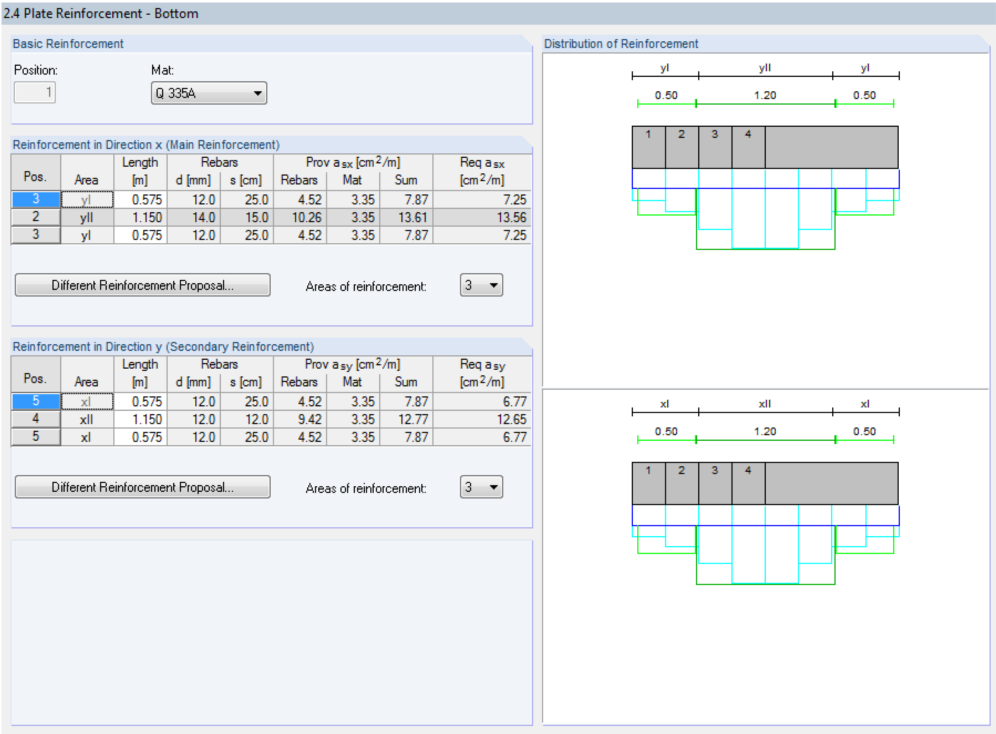
Click the [3D-Rendering] button to visualize the reinforcement in a separate graphical window. This function is described in Chapter 5.2 on page 54.

Drawings

Use the [Drawings] button to look at the reinforcement drawings of the foundation (see Chapter 5.3, page 57).

4.4 Plate Reinforcement - Bottom

In this module window, the reinforcement for the bottom side of the foundation plate is shown. The plate reinforcement is suggested by the program but can be changed here.

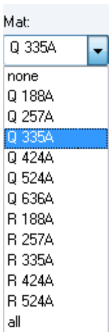


Pos.	Area	Length [m]	Rebars d [mm]	Rebars s [cm]	Prov a_{sx} [cm²/m] Rebars	Mat	Sum	Req a_{sx} [cm²/m]
3	yI	0.575	12.0	25.0	4.52	3.35	7.87	7.25
2	yII	1.150	14.0	15.0	10.26	3.35	13.61	13.56
3	yI	0.575	12.0	25.0	4.52	3.35	7.87	7.25

Pos.	Area	Length [m]	Rebars d [mm]	Rebars s [cm]	Prov a_{sy} [cm²/m] Rebars	Mat	Sum	Req a_{sy} [cm²/m]
5	xI	0.575	12.0	25.0	4.52	3.35	7.87	6.77
4	xII	1.150	12.0	12.0	9.42	3.35	12.77	12.65
5	xI	0.575	12.0	25.0	4.52	3.35	7.87	6.77

Figure 4.8: Window 2.4 *Plate Reinforcement - Bottom*

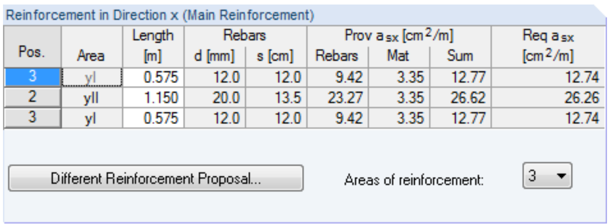
Basic Reinforcement



In the upper part of the module window, the suggested basic reinforcement is indicated with a position number. The *Mat* can be changed by using the list. The list contains all mat types activated for the design in module window 1.3 (see Figure 2.26, page 22).

Reinforcement in Direction x / Reinforcement in Direction y

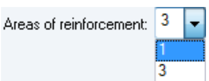
In both window sections, it is possible to adjust the bar reinforcement suggested by RF-FOUNDATION Pro.



Pos.	Area	Length [m]	Rebars d [mm]	Rebars s [cm]	Prov a_{sx} [cm²/m] Rebars	Mat	Sum	Req a_{sx} [cm²/m]
3	yI	0.575	12.0	12.0	9.42	3.35	12.77	12.74
2	yII	1.150	20.0	13.5	23.27	3.35	26.62	26.26
3	yI	0.575	12.0	12.0	9.42	3.35	12.77	12.74

Figure 4.9: Adjusting the reinforcement (here: main reinforcement in direction x)

Areas of reinforcement



With the list you can define if the bar reinforcement is divided in one or three *Areas of reinforcement*.

If one reinforcement area is set, the bending reinforcement required from the design is applied to the entire plate width. If three reinforcement areas are possible, the plate width is subdivided into three areas. Then, the required reinforcement is inserted by curtailment, which proves to be more efficient in most cases.

In the first table column, the *Pos.* position name of the reinforcement is displayed.

The *Area* column describes the area of the plate reinforcement. In case you have set three areas of reinforcement, you get two external reinforcement areas (indicated by *yI* in Figure 4.9) and one reinforcement area in the plate center (indicated by *yII* in Figure 4.9).

The *Length* column shows the dimensions of the individual areas of reinforcement that are available in the x- or y-direction. These lengths are also displayed in the graphical reinforcement layout for the main and secondary reinforcement direction (see Figure 4.10).

In the table columns *Rebars*, *Prov* a_{sx} and *Req* a_{sx}, the selected reinforcement is shown. In addition to the rebar diameters and spacing, you see the reinforcement area of the provided and the required reinforcement.

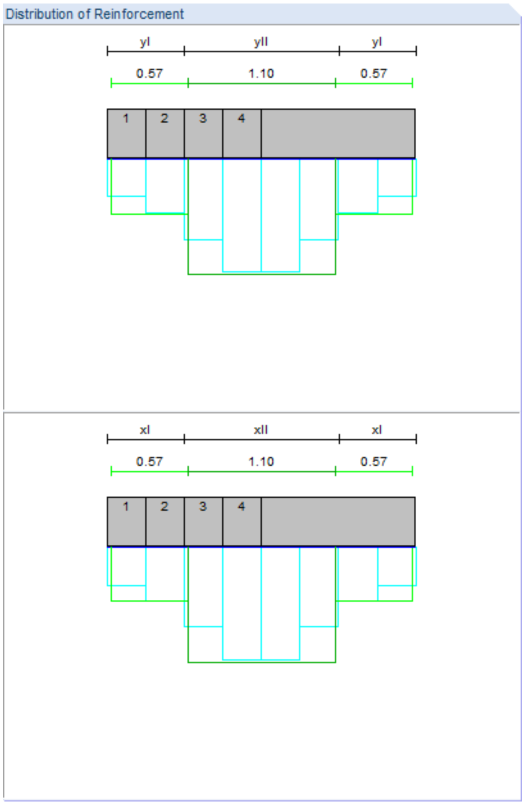


Figure 4.10: Graphic of reinforcement layout

RF-FOUNDATION Pro determines the main and secondary reinforcement direction according to the actions applied to the foundation. If the main reinforcement is oriented in the x-direction, the reinforcement in the x-direction lies in the lowest layer.

Different Reinforcement Proposal

Different Reinforcement Proposal...

Use the button [Different Reinforcement Proposal] to select an alternative reinforcement for the plate. The dialog box *Select Different Reinforcement Proposal* opens (see following figure).

In this dialog box, you can define another mat as the basic reinforcement (any mat set according to module window 1.2 *Material* is possible). Furthermore, please note that the mat for the basic reinforcement can only be specified for the main reinforcement direction. The other dialog box used to change the secondary reinforcement direction presets the mat of the main reinforcement direction. There, the mat list is not accessible, as shown in Figure 4.11.

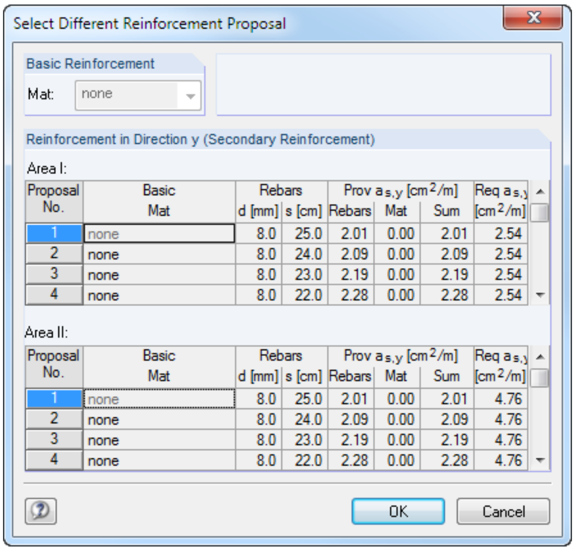
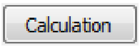


Figure 4.11: Dialog box *Select Different Reinforcement Proposal* (here: secondary reinforcement)

In the tables, you can choose an alternative reinforcement for each *Area*. The combinations of basic mats and rebars are predefined. Rebar diameters or spacing cannot be changed here.

The combinations of the reinforcements are sorted in ascending order by the available areas of reinforcement *Prov* a_s. You can select the relevant proposal by clicking in the list of all possible reinforcement combinations. Then, click [OK] to transfer the new reinforcement to module window 2.4.



If the reinforcement for the main or secondary direction has been changed, the results must be recalculated. Use the [Calculation] button which is enabled after any modification of the reinforcement.

4.5 Plate Reinforcement - Top

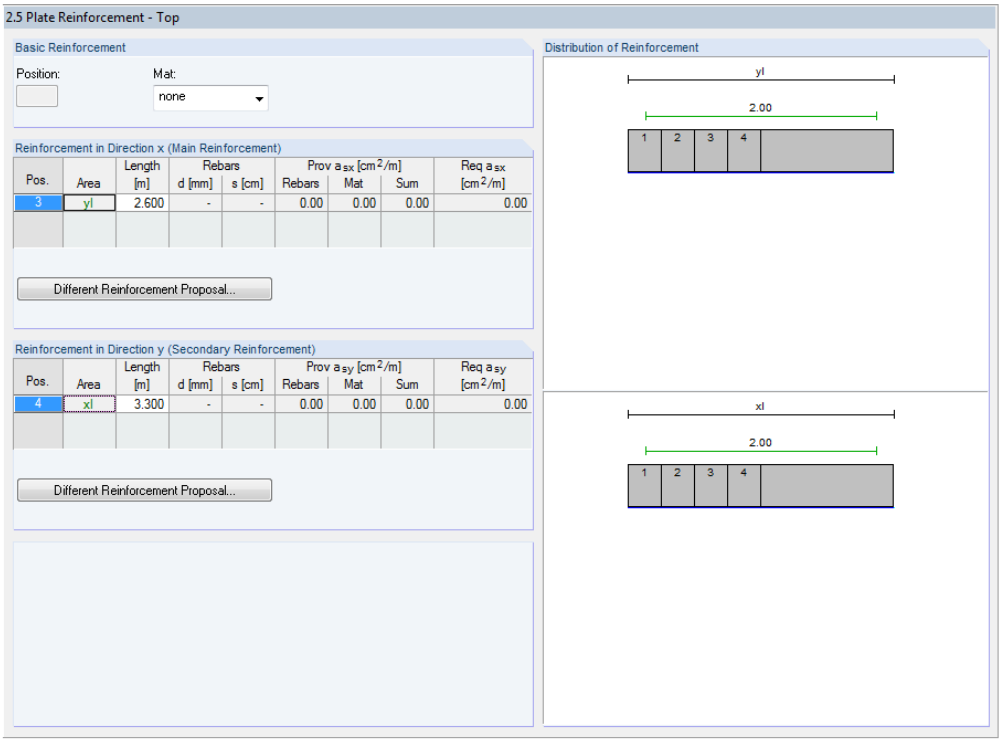


Figure 4.12: Window 2.5 *Plate Reinforcement - Top*

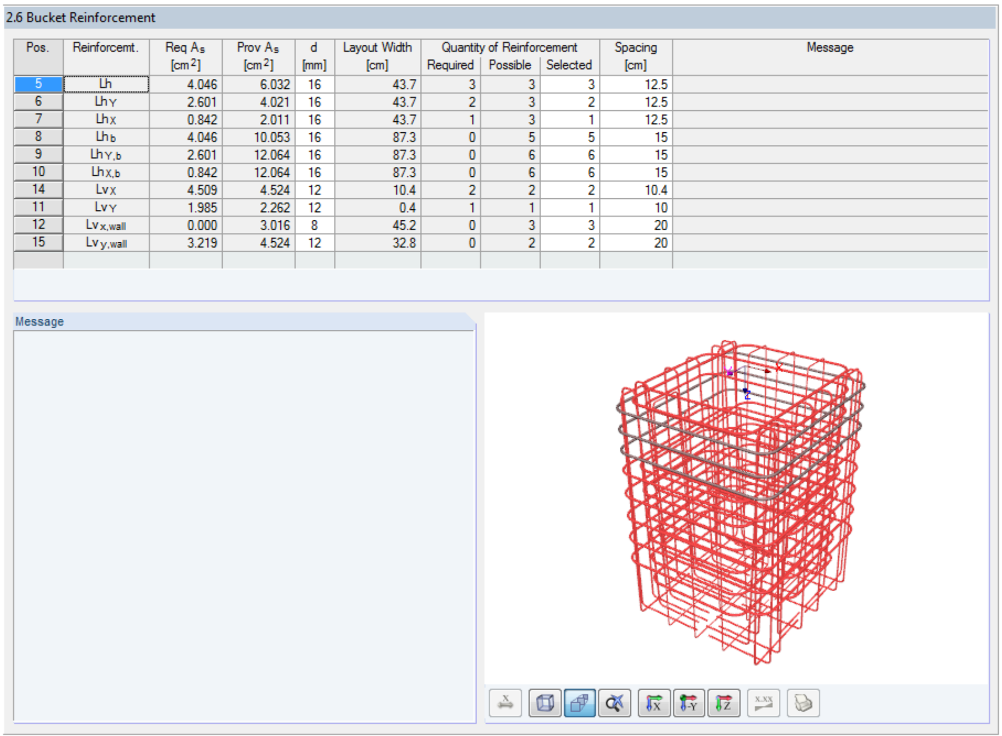
The structure of Window 2.5 with its input options is the same like in Window 2.4 *Plate Reinforcement - Bottom* (see Chapter 4.4). Again, it is possible to select a reinforcement combination from a list as an alternative to the designed reinforcement.

The only difference to Window 2.4 is that the curtailment of reinforcements is not possible: The same design moment is applied to all eight design areas.

4.6 Bucket Reinforcement

This module window shows the reinforcement of the bucket. It is possible to change the bucket reinforcement suggested by the program.

The window is not available when the foundation type *Foundation plate* has been set.


2.6 Bucket Reinforcement

Pos.	Reinforcemt.	Req A_s [cm²]	Prov A_s [cm²]	d [mm]	Layout Width [cm]	Quantity of Reinforcement Required	Possible	Selected	Spacing [cm]	Message
5	L_h	4.046	6.032	16	43.7	3	3	3	12.5	
6	L_{hY}	2.601	4.021	16	43.7	2	3	2	12.5	
7	L_{hX}	0.842	2.011	16	43.7	1	3	1	12.5	
8	L_{hb}	4.046	10.053	16	87.3	0	5	5	15	
9	$L_{hY,b}$	2.601	12.064	16	87.3	0	6	6	15	
10	$L_{hX,b}$	0.842	12.064	16	87.3	0	6	6	15	
14	L_{vX}	4.509	4.524	12	10.4	2	2	2	10.4	
11	L_{vY}	1.985	2.262	12	0.4	1	1	1	10	
12	$L_{vx,wall}$	0.000	3.016	8	45.2	0	3	3	20	
15	$L_{vy,wall}$	3.219	4.524	12	32.8	0	2	2	20	

Figure 4.13: Window 2.6 *Bucket Reinforcement*

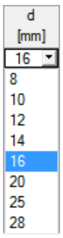
The upper table displays the individual positions of the bucket reinforcement including reinforcement areas as well as diameter, number and spacing of rebars.

The graphic shows a rendered representation of the bucket reinforcement. When you click on a position listed in the table, you can see that it is marked in gray in the graphic. Again, you can use the mouse functions that you already know from RFEM in order to zoom, shift or rotate the view. The corresponding buttons are described in Chapter 5.1 on page 53.

The determined bucket reinforcement can be modified in the table columns that have a white background. The values in the gray columns are set by the program and cannot be changed.

The following changes can be carried out for the reinforcement:

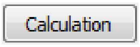
- Diameter of reinforcement
- Selected quantity of reinforcement
- Spacing of reinforcement



The bar diameter *d* can be changed by using the list. For the selection it is important to bear in mind that the reinforcement with its bar and mandrel diameters must still fit in the bucket walls.

The table columns *Selected Quantity of Reinforcement* and *Spacing* are interdependent. Use those columns to adjust the number of rebars or the bar spacing (considering the possible layout width). If the spacing is changed, the number of possible rebars is adjusted automatically. For example, if the spacing is reduced, the number of bars that can be placed in the given *Layout Width* is displayed in the table column *Possible*. Then, using this target specification, the desired number of rebars can be entered.

If it is the opposite case where the number of selected reinforcing bars is changed, the program adjusts the spacing between the rebars automatically.



In case of modifications, it is necessary to recalculate the bucket reinforcement. Use the [Calculation] button for the recalculation.

If the changed entry results in errors during the layout of the reinforcement, the problem causing position is highlighted with red in the table. A note appears in the window section *Message*, which is useful for a new adjustment of the reinforcement.

4.7 Steel Schedule

2.7 Steel Schedule

General	
Foundation No.: 1 At nodes: 1 Number of foundations: 1 Description:	Reinforcement steel: B 500 S (A)

Reinforcing Steel Mats Bottom and Top

Position No.	Main Reinforcemt. Direction	Type of Mat	Weight [kg/m²]	Area Without Lap [m²]	Weight per Foundation [kg]	Total Weight [kg]
4	x-Direction	Q 188A	3.01	9.57	28.8	28.8

Additional Rebar and Bucket Reinforcement

Position No.	Number per Foundation	Total Number	⌀ [mm]	Section Length [cm]	Total Length [m] ⌀8	⌀10	⌀12	⌀16
2	22	22	8	341.0	75.02			
3	12	12	8	269.6	32.36			
5	3	3	16	479.3				14.38
6	2	2	16	391.9				7.84
7	1	1	16	442.2				4.42
8	5	5	16	479.3				23.96
9	6	6	16	373.3				22.4
10	6	6	16	423.0				25.38
11	4	4	12	374.0			14.96	
12	6	6	8	379.2	22.75			
14	8	8	12	366.8			29.35	
15	4	4	12	366.8			14.67	
Date:				running m	130.14		58.98	98.38
				kg/run. m	0.39	0.62	0.89	1.58
To plan No.:				kg	51.35		52.37	155.28
				Total Weight:	**258.99+28.8 (Standard Mats) = 287.79 kg**			

Figure 4.14: Window 2.7 *Steel Schedule*

No changes are possible in this results window.

The steel schedule offers information about the mats (mesh reinforcement). Moreover, detailed data is displayed for additional rebars and the bucket reinforcement of each position:

- Number of rebars per foundation
- Total rebar number of all foundations
- Section length of a link
- Total length of all links

In addition, the *Total Length* of all reinforcing bars that have the same diameter as well as the *Total Weight* of the bars and mats are shown.

4.8 Concrete Cubage

2.8 Concrete Cubage

Foundation No.: 1 At nodes: 1 Number of foundations: 1 Description:		Concrete grade: Concrete C35/45
	Volume per Foundation [m³]	Volume of all Foundations [m³]
Foundation Plate	3.09	3.09
Bucket	1.53	1.53
Backfill Concrete	0.17	0.17

Figure 4.15: Window 2.8 *Concrete Cubage*

The results window provides information on how many cubic meters of concrete are needed for the *Foundation Plate*, the *Bucket* and the *Backfill Concrete* between the bucket and the column of one or all foundations.

5. Results Evaluation

After the design, you have several possibilities to evaluate the results and to prepare them for the documentation.

5.1 Graphic of Foundation in Results Window

In most results windows, dynamic graphics are displayed showing the foundation or reinforcement. They illustrate the parameters and help you to keep a clear overview.

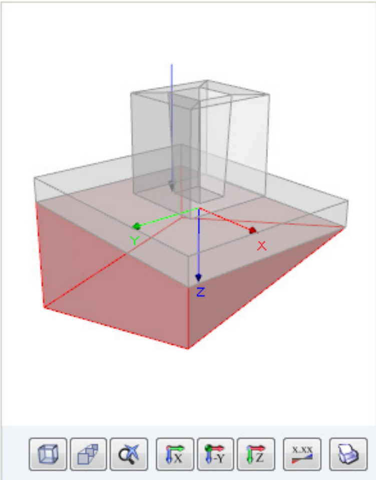


Figure 5.1: Interactive graphic in module window 2.2 for safety against bending failure

The buttons below the graphic have the following functions:

Button	Description	Function
	Dimensions	Turns on/off dimension lines
	Isometric view	Shows object in isometric view
	Perspective view	Turns on/off perspective view
	Show all graphic	Resets full view of foundation
	View in X	Shows view in direction of X-axis
	View in -Y	Shows view in opposite direction of Y-axis
	View in Z	Shows view in direction of Z-axis
	Values	Shows and hides load and result values
	Print	Allows for printing current foundation graphic

Table 5.1: Graphic buttons in results windows

Use the mouse to zoom, shift or rotate the view. The functions are described in Chapter 3.4.9 of the RFEM manual (see also the following chapter 5.2).

5.2 3D-Rendering

The [3D-Rendering] button is available in all results windows, offering the possibility to access a photo-realistic representation of the foundation.

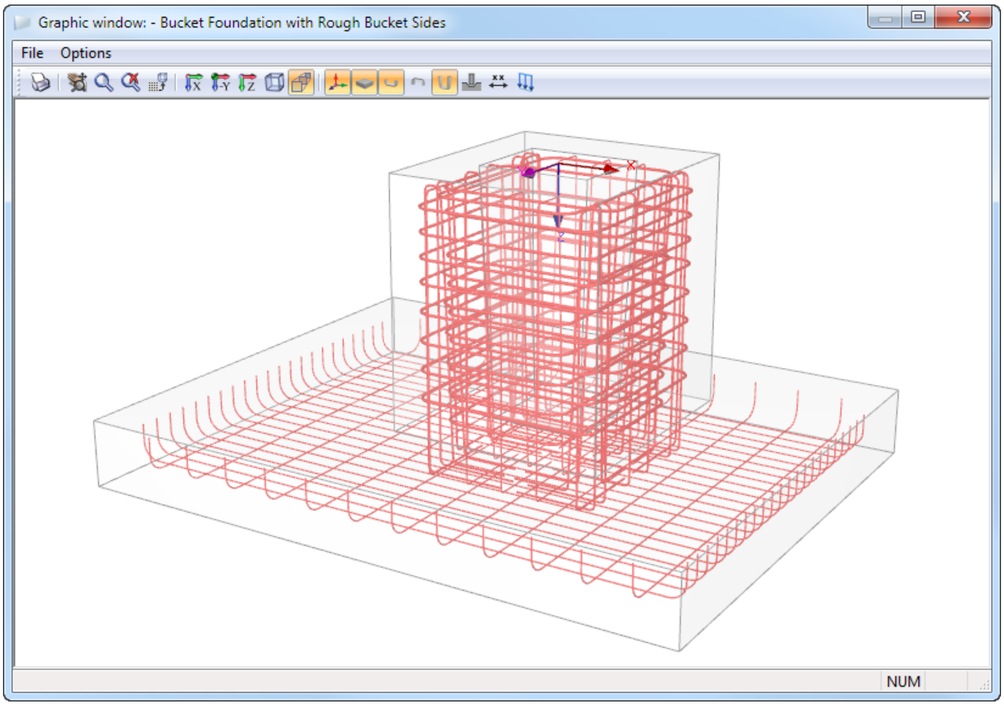


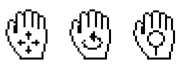
Figure 5.2: *Graphical window* with 3D rendering of a bucket foundation reinforcement

Menu bar

The ***File*** menu provides functions for printing the graphic (see Chapter 6.2).

With the functions of the ***Options*** menu, you can adjust the graphical representation:

Grab (Move, Rotate, Zoom)



The symbol of the mouse pointer turns into a hand. Thus, it is possible to shift, rotate or zoom the graphic display of the foundation.

To shift the foundation, click with the hand symbol in the graphical window, keep the mouse button pressed and move the pointer in the corresponding direction.

To rotate the foundation, click in the graphical window while keeping the [Ctrl] key pressed and move the pointer in the corresponding rotational direction.

To zoom the foundation, move the mouse up or down while keeping the [Shift] key pressed.

It is also possible to adjust the view directly with the mouse (see Chapter 3.4.9 of the RFEM manual).

Zoom

The symbol of the mouse pointer turns into a magnifying glass. Now, if you draw a window across a particular zone of the graphic, it is enlarged in a partial view.

Reinforcement to Display

Clicking this menu item opens the dialog box *Reinforcement to Display*.

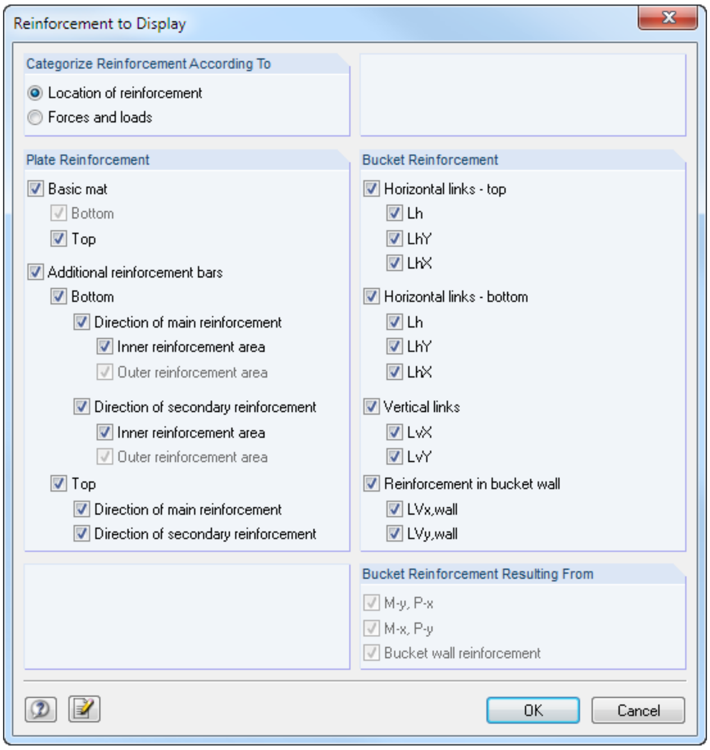


Figure 5.3: Dialog box *Reinforcement to Display*

By selecting the check boxes you can decide which of the reinforcement types are displayed in the foundation's 3D rendering mode. Depending on the foundation type, some entries are not selectable.

If you switch from the option *Location of reinforcement* to the option *Forces and loads* in the dialog section *Categorize Reinforcement According To*, the dialog section in the bottom right becomes accessible. There, it is possible to select the reinforcement resulting from particular loads.

White Background

Select this menu item to change the black graphical background, which is default, to a white one. The setting remains active for the current design case.

The white background can be permanently set by using the Configuration Manager of RFEM (see Chapter 3.4.10 of RFEM manual).

Toolbar

The toolbar offers different possibilities for printing and adjusting the graphical representation.

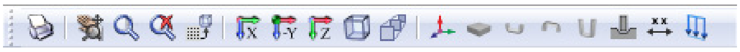


Figure 5.4: Toolbar buttons

In addition to the buttons described in Table 5.1, the following functions are available:

Button	Description	Function
	Previous view	Shows the last selected view
	Axes	Shows and hides the axis symbols
	Member	Shows and hides the connected member
	Dimensions	Turns on/off the dimension lines
	Loads	Shows and hides the loads

Table 5.2: Buttons in *Graphical window*

With these functions, it is not only possible to check the reinforcement but also the applied loading.

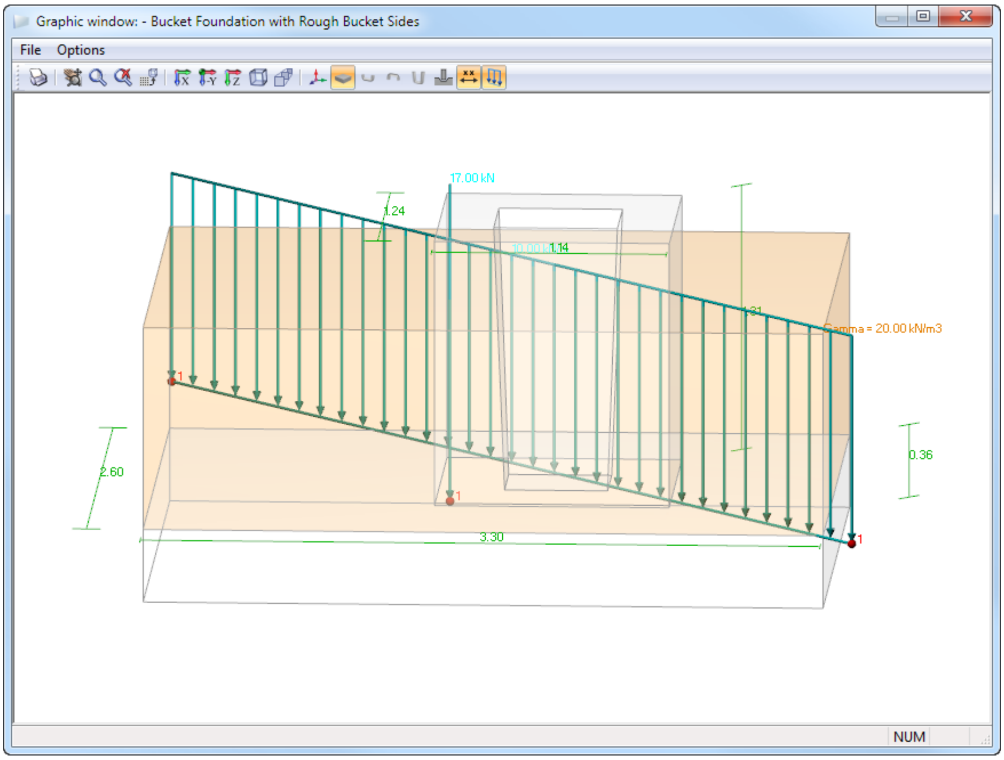


Figure 5.5: Foundation graphic with loads and dimensions

5.3 Reinforcement Drawings

The [Drawings] button is available in all results windows, offering the possibility to access a reinforcement drawing for the foundation.

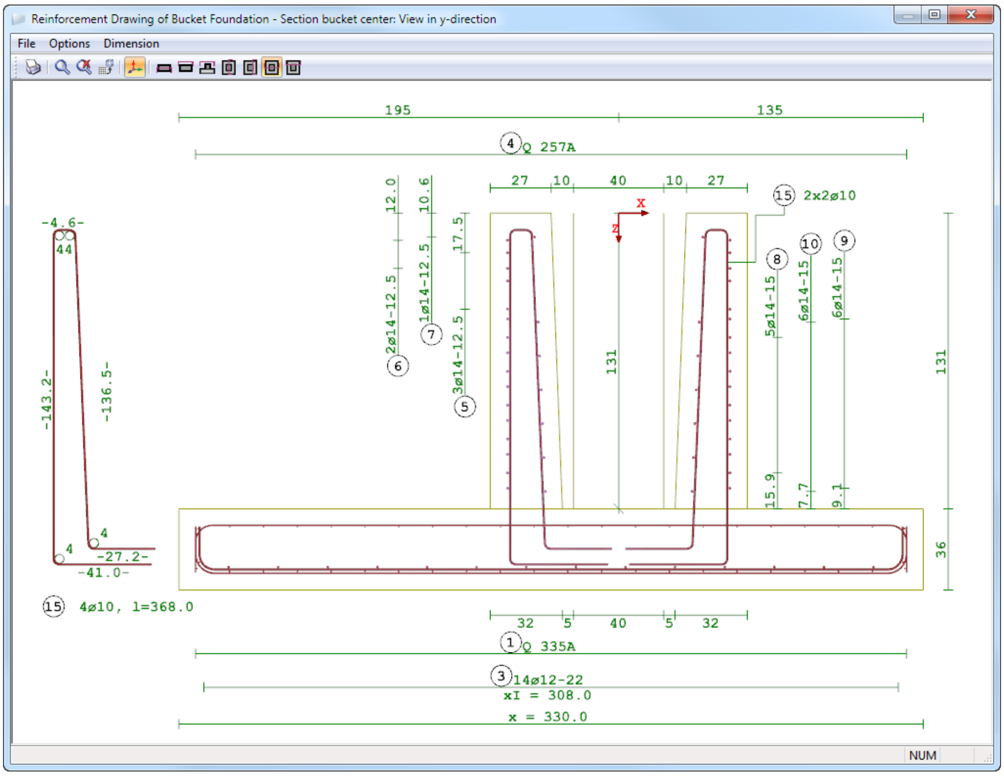


Figure 5.6: Reinforcement drawing of a bucket foundation

Menu bar

The ***File*** menu provides functions for printing the graphic (see Chapter 6.2).

You can enlarge the graphical representation with the zoom function in the ***Options*** menu (see description in the previous chapter 5.2).

The functions in the ***Dimension*** menu help you control the dimensioning of the bars in the excerpt on the left (position *15* in the previous figure) for the rebar fabrication:

- *Tangential*: Lengths relative to outside edges of reinforcement
- *Axial*: Lengths relative to centroid of reinforcement (center lines)
- *Center of mandrel*: Lengths relative to center point of mandrel

Toolbar

The toolbar offers different possibilities for printing and modifying the section that runs through the foundation.

Figure 5.7: Toolbar buttons

Depending on the foundation type, up to seven different sections are available for selection:

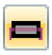
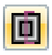
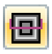
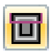
Button	Description	Function
	Section A-A	Top view of bottom plate reinforcement
	Section B-B	Top view of top plate reinforcement
	Section C-C	Top view of bucket
	Section D-D	Section through bucket center, viewing direction in X
	Section E-E	Section through bucket wall, viewing direction in X
	Section F-F	Section through bucket center, viewing direction in Y
	Section G-G	Section through bucket wall, viewing direction in Y

Table 5.3: Buttons in *Reinforcement Drawing*

If the structure does not require any reinforcement for the top layer, for example in case of a plate foundation, the button for the section B-B is deactivated.

5.4 Results on RFEM Model

The graphic of the foundation can also be displayed on the RFEM model: Click the [OK] button to exit the add-on module RF-FOUNDATION Pro. Then, go to the RFEM menu bar, and select the RF-FOUNDATION Pro design case in the load case list.

Now, the foundation is visualized in a 3D rendering in the work window of RFEM. If you cannot see it, you must turn on the results by using the [Show Results] button.

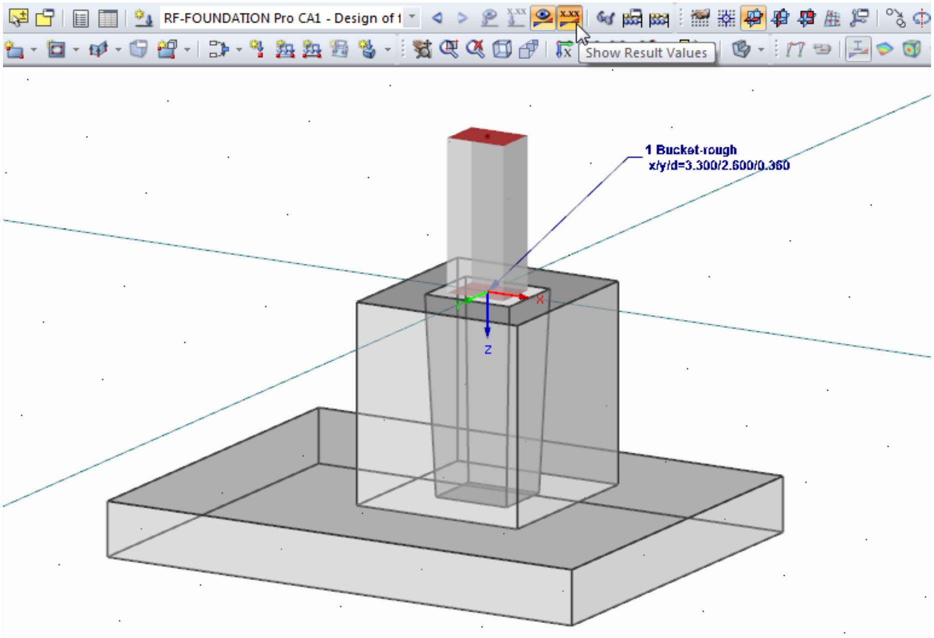
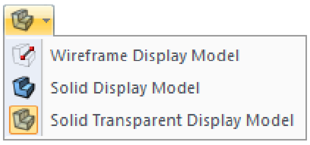


Figure 5.8: Graphical representation of a bucket foundation in RFEM work window (display option: solid transparent)



If the *Solid Transparent Display Model* is set, the foundation is presented as shown in Figure 5.8. Hidden edges and surfaces are visible.

The *Solid Display Model* shows the foundation – as the entire model – with filled surfaces. With the *Wireframe Display Model*, RFEM displays symbolically only the number of the foundation, the foundation type and the dimensions of the foundation plate.

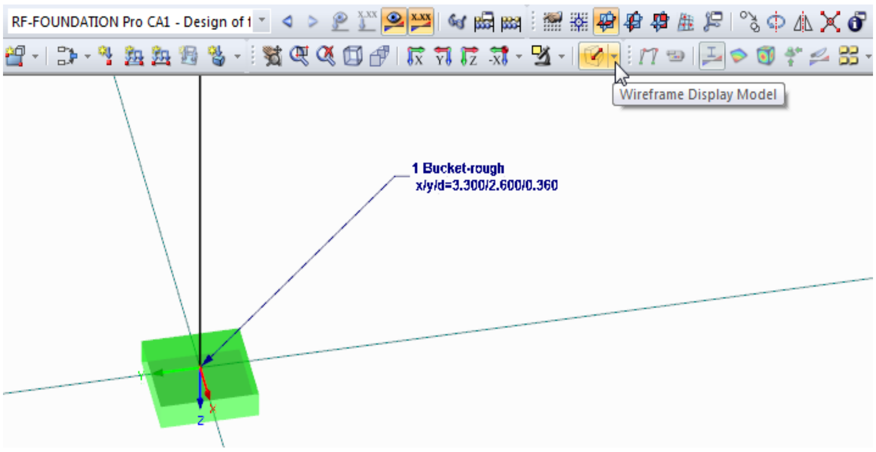


Figure 5.9: Bucket foundation represented with wireframe model

6. Printout

6.1 Printout Report

Like in RFEM, the program generates a printout report for the RF-FOUNDATION Pro results, to which you can add graphics and descriptions. The selection in the printout report determines which data of the design module will be included in the final printout.

Large and complex structural systems can be clearly documented if the data is split into several printout reports. In this way, it is possible to print for example the output of the add-on module RF-FOUNDATION Pro in a separate printout report.

The printout report is described in the RFEM manual. In particular, Chapter 10.1.3.4 *Selecting Data of Add-on Modules* describes how to prepare input and output data from add-on modules for the printout. Various selection options are available for RF-FOUNDATION Pro. You can define, for example, how the designs are documented (*Short form*, *Long form*) and which reinforcement drawings are included in the report.

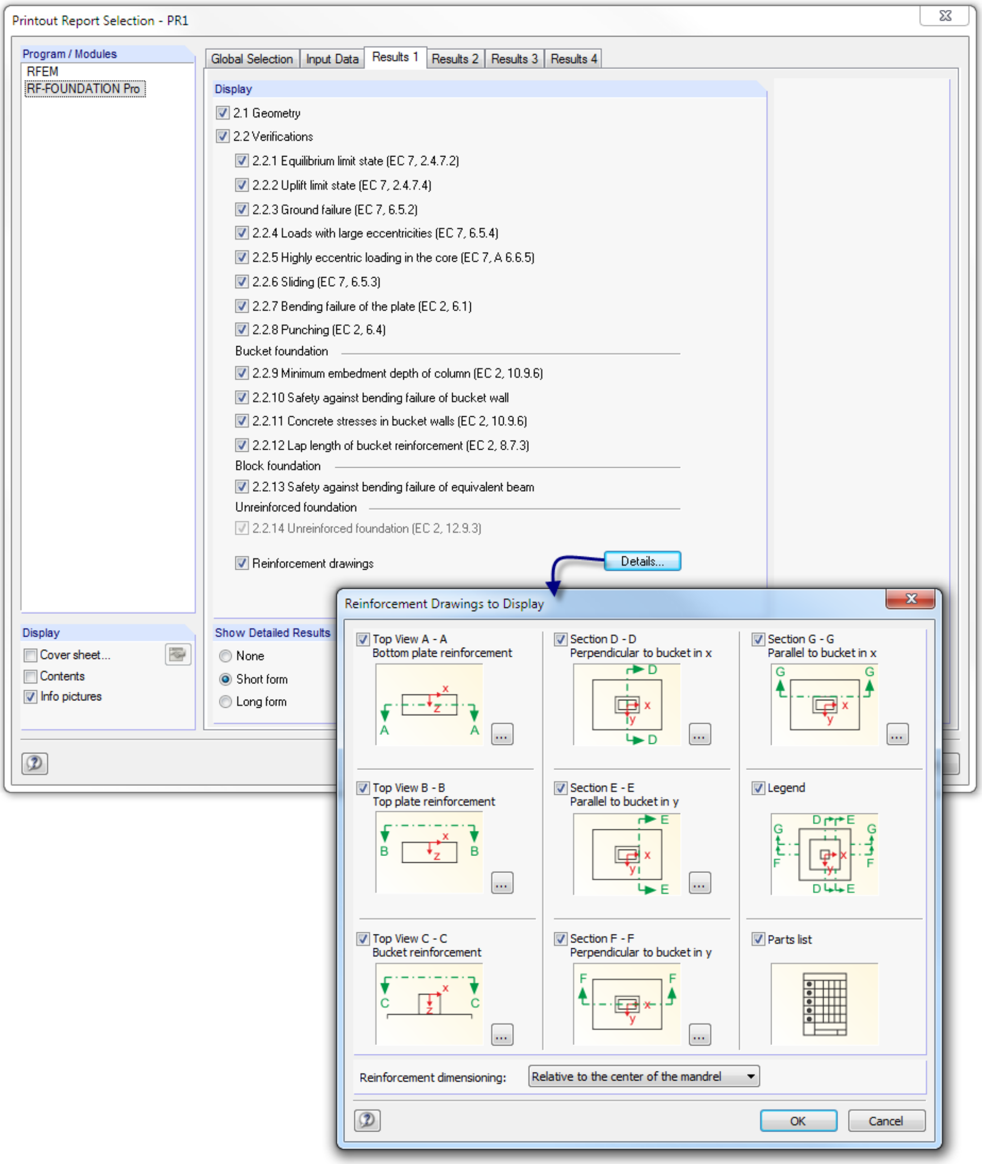


Figure 6.1: Selection of RF-FOUNDATION Pro data in printout report

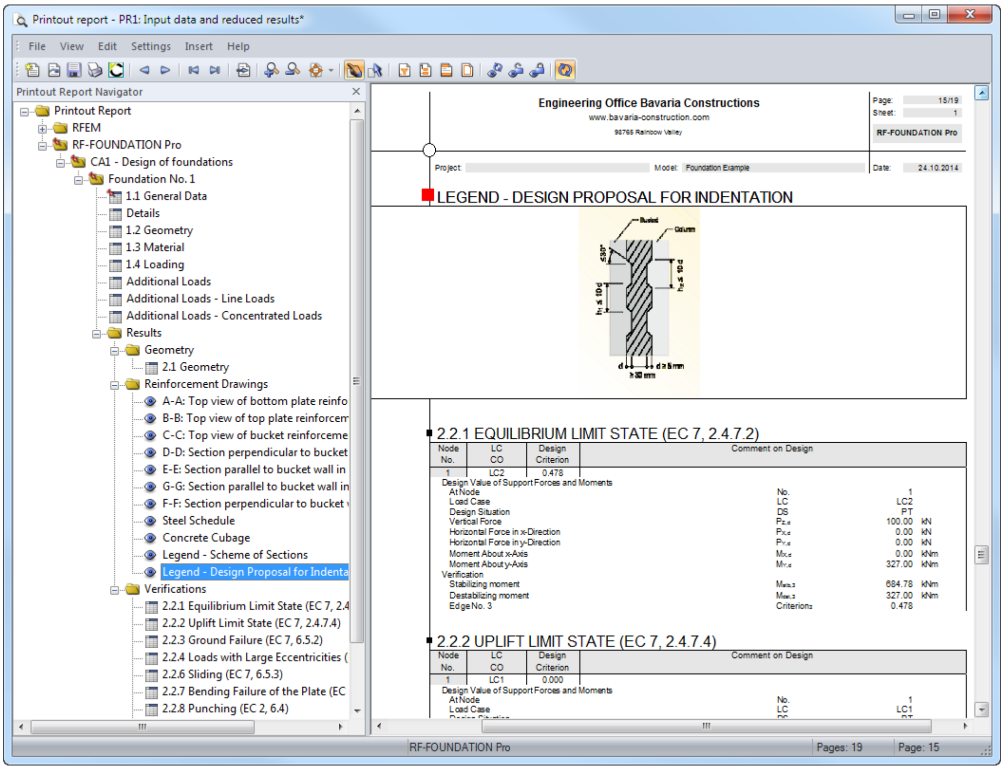


Figure 6.2: Printout for RF-FOUNDATION Pro with reinforcement drawings and designs

6.2 Graphic Printout

Both the graphics of the foundation or reinforcement of the add-on module RF-FOUNDATION Pro (see Figure 5.2, page 54) and the graphics of the RFEM work window (see Figure 5.8, page 59) can be prepared for the printout. Thus, it is possible to document the reinforcements as well as the foundation objects displayed in the RFEM model.

The print function can be accessed with the [Print Graphic] button which opens the following dialog box.

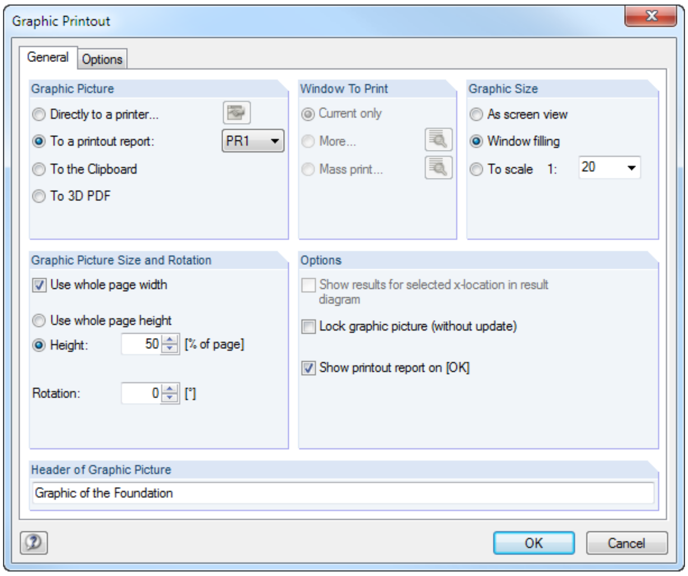


Figure 6.3: Dialog box *Graphic Printout*

The dialog box *Graphic Printout* is described in Chapter 10.2 of the RFEM manual.

7. General Functions

This chapter describes useful menu functions as well as export options for the results of RF-FOUNDATION Pro.

7.1 Design Cases

Design cases allow you to group foundations for the designs, or to handle foundations in different design variants (for example different dimensions or materials).

In case several design cases are used, it is possible to analyze a node number several times. **But a node can be selected only once within the same design case (see also Chapter 2.1, page 10).**

Create a new design case

To create a new design case, use the RF-FOUNDATION Pro menu and select

File → New Case.

The following dialog box appears:

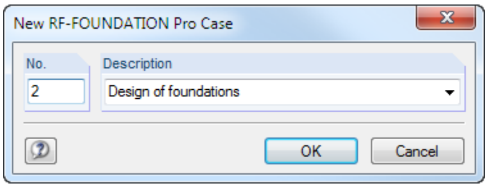


Figure 7.1: Dialog box *New RF-FOUNDATION Pro Case*

In this dialog box, enter a *No.* (one that is still available) for the new design case. An appropriate *Description* will make the selection in the load case list easier.

When you click [OK], module window 1.1 *General Data* opens where you can enter the new design data.

Rename a design case

To change the description of a design case, use the RF-FOUNDATION Pro menu and select

File → Rename Case.

The following dialog box appears:

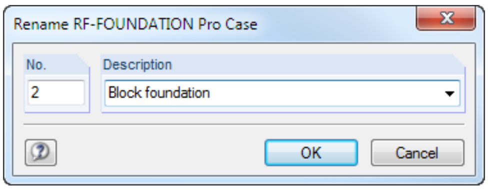


Figure 7.2: Dialog box *Rename RF-FOUNDATION Pro Case*

Here, you can specify a new *Description* as well as a different *No.* for the design case.

Copy a design case

To copy the data entered for the current design case, use the RF-FOUNDATION Pro menu and select

File → Copy Case.

The following dialog box appears:

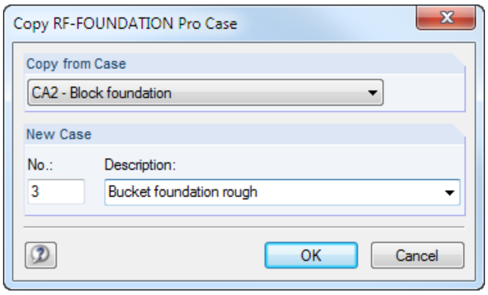


Figure 7.3: Dialog box *Copy RF-FOUNDATION Pro Case*

Define the *No.* and, if necessary, a *Description* for the new case.

Delete a design case

To delete a design case, use the RF-FOUNDATION Pro menu and select

File → Delete Case.

The following dialog box appears:

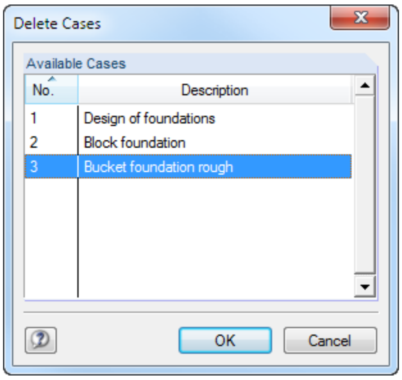


Figure 7.4: Dialog box *Delete Cases*

First, select the design case from the *Available Cases* list. To delete the case, click [OK].

7.2 Units and Decimal Places

The units and decimal places for RFEM and the add-on modules are managed in one common dialog box. To access the dialog box for adjusting the units, use the RF-FOUNDATION Pro menu and click

Settings → **Units and Decimal Places**.

The program opens the following dialog box that you already know from RFEM. RF-FOUNDATION Pro is preset in the list *Program / Module*.

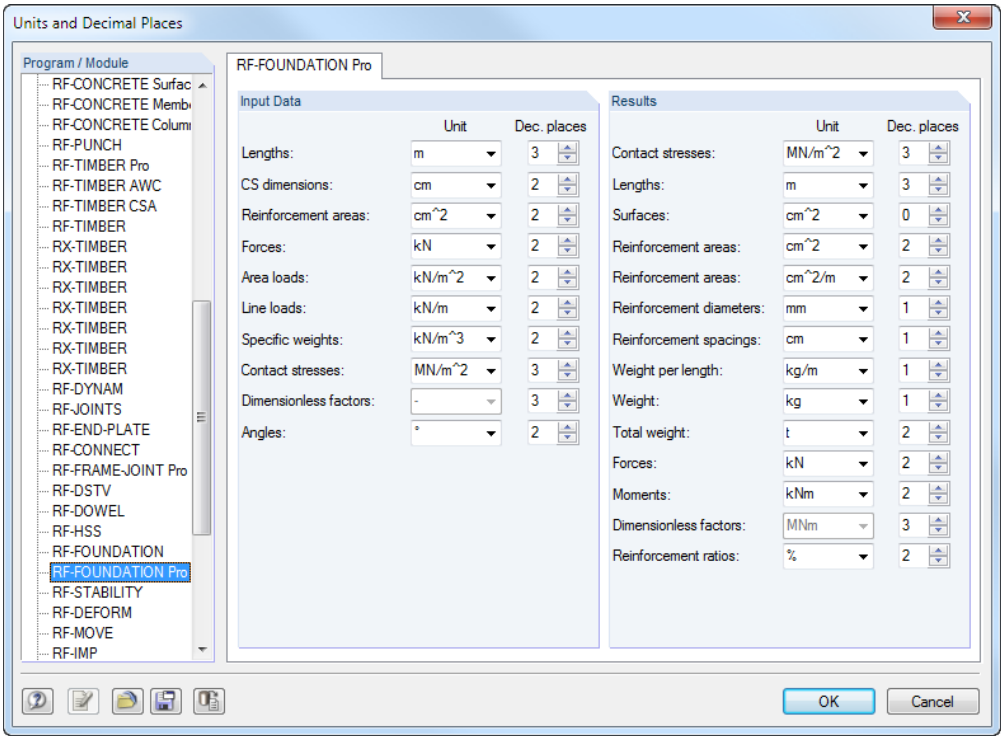
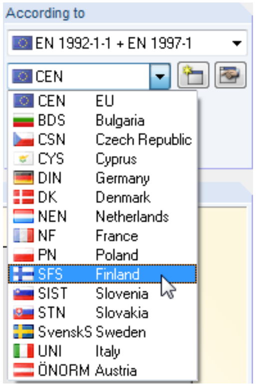


Figure 7.5: Dialog box *Units and Decimal Places*

To reuse the settings in other models, save them as a user-profile. The corresponding functions are described in the RFEM manual, Chapter 11.1.3.

7.3 National Annexes

Selection of national annex



As already described in Chapter 2.1 on page 11, the add-on module RF-FOUNDATION Pro provides different national annexes for the design.

Find a list of the national annexes currently implemented in RF-FOUNDATION Pro also on the web product page: www.dlubal.com/en/foundation-pro-8xx.aspx

National annex in RFEM and RF-FOUNDATION Pro

In RF-FOUNDATION Pro, it is possible to choose a different national annex than in the main program RFEM where the annex is used for the creation of load and result combinations. Both the standard and the National Annex are necessary for the partial safety factors and combination coefficients of the superposition (see Manual for RFEM, Chapter 12.2.1 about creating a model and classifying load cases and combinations).

In case different national annexes are used, make sure that the design-relevant load and result combinations have been created using the correct factors.

Consideration of consequences class

When the load or result combinations are created automatically, it is possible to define the consequences class according to [3], annex B3. The selection of the consequences class, and thus of the factor K_{FI}, also has an influence on the results in RF-FOUNDATION Pro.

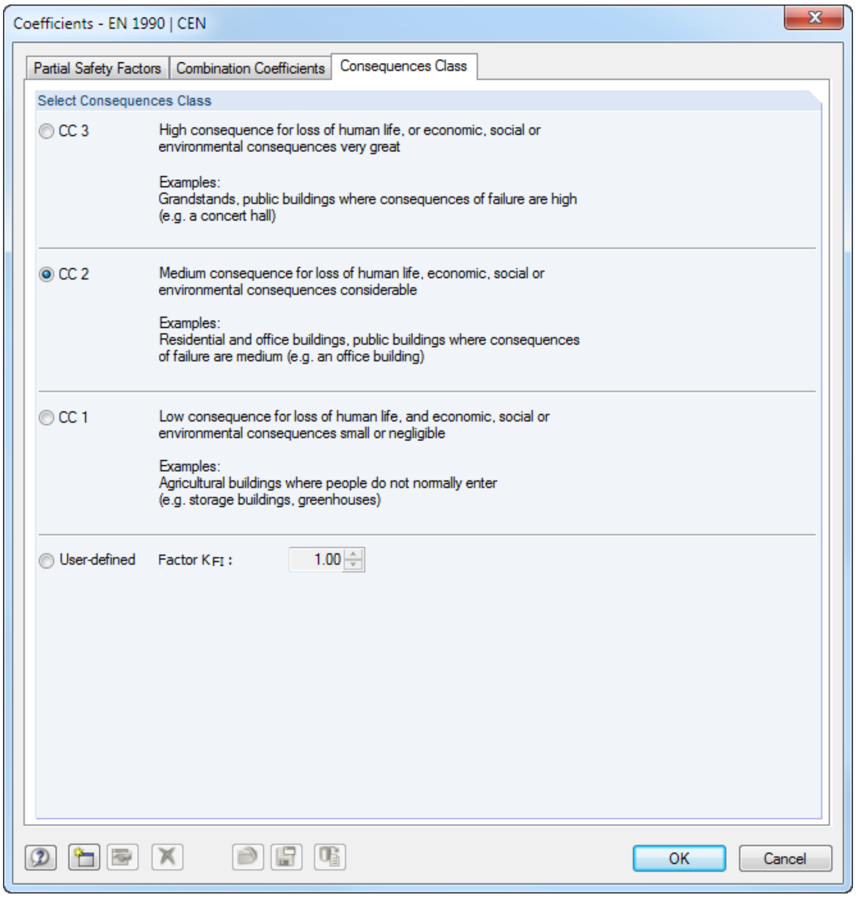


Figure 7.6: RFEM dialog box *Coefficients* for selection of consequences class CC

The consequences class, which is defined in this dialog box, is considered in the add-on module RF-FOUNDATION Pro, too.

The factor K_{FI} affects the design loads that are applied in the add-on module, which are the following:

- Load due to weight of foundation plate
- Load due to self-weight of bucket
- Load due to earth covering
- Load due to additional loading

The factor applicable to actions for reliability differentiation K_{FI} and the consequences class *CC* are documented in the results windows of RF-FOUNDATION Pro. You can look at them under the entry *Resulting Partial Factor*:

Ground failure (EC 7, 6.5.2) ¦ Node 3 ¦ CO1			
⊞ Design Value of Support Forces and Moments			
⊟ Design Value of Ground Failure Action	V'_d/A'	128.6	kN/m²
⊟ Design Value of Effective Vertical Force in the Soil Joint	V'_d	372.26	kN
⊞ Design Value of Self-Weight of Foundation Plate	$G_{p,d}$	40.50	kN
⊞ Design Value of Self-Weight of Bucket	$G_{cal,d}$	40.17	kN
⊟ Design Value of Earth Covering	$G_{cov,d}$	75.32	kN
⊟ Resulting Partial Factor for Permanent, Unfavorable Actions	$\gamma_{G,sup}$	1.350	
⊟ Consequences Class	CC	2	
Factor applicable to actions for reliability differentiation	K_{FI}	1.000	
Partial Factor for Permanent, Unfavorable Actions	$\gamma_{G,sup}$	1.350	
⊟ Characteristic Value of Earth Covering	$G_{cov,k}$	55.79	kN
Height of Earth Covering	c	1.000	m
Characteristic Value of Weight of Earth Covering	$\gamma_{c,k}$	20.00	kN/m³
⊞ Design Value of Surcharge	$P_{s,d}$	62.75	kN
from Column Normal Force	$P_{z,d}$	153.52	kN
⊞ Design Value of Effective Moments in Soil Joint			
⊞ Design Value of Load Eccentricity of Effective Vertical Load			
⊞ Effective Base Area	A'	28942	cm²

Figure 7.7: Output of consequences class in RF-FOUNDATION Pro

If you choose in RF-FOUNDATION Pro a national annex involving a factor K_{FI} that is different from the one specified in RFEM, you are notified before the calculation starts.

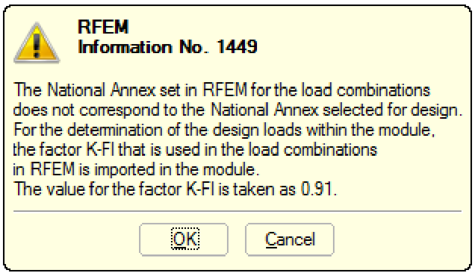


Figure 7.8: RFEM message before calculation

Example :

Standard in RFEM:	EN 1990 + NA for Sweden	=>	K_{FI} = 0.91
Standard in RF-FOUNDATION Pro:	EN 1992-1-1 + EN 1997-1	=>	K_{FI} = 1.00

The factor K_{FI} = 0.91 from RFEM will be used for the designs carried out in RF-FOUNDATION Pro.

7.4 Export of Results

The results of the foundation design can also be used in other programs.

Clipboard

To copy cells selected in the module's results windows to the clipboard, use the keyboard keys [Ctrl]+[C]. To insert the cells, for example in a word processing program, press [Ctrl]+[V]. The headers of the table columns are not transferred.

Printout report

The RF-FOUNDATION Pro data can be printed in the printout report (see Chapter 6.1, page 60) from where they can be exported by selecting

File → **Export to RTF**.

Exporting to VCmaster is also possible. The corresponding functions are described in Chapter 10.1.11 of the RFEM manual.

Excel / OpenOffice

RF-FOUNDATION Pro provides a function used for the direct data export to MS Excel and Open-Office.org Calc or the export in the file format CSV. To access the corresponding function, use the RF-FOUNDATION Pro menu and select

File → **Export Tables**.

The following export dialog box appears.

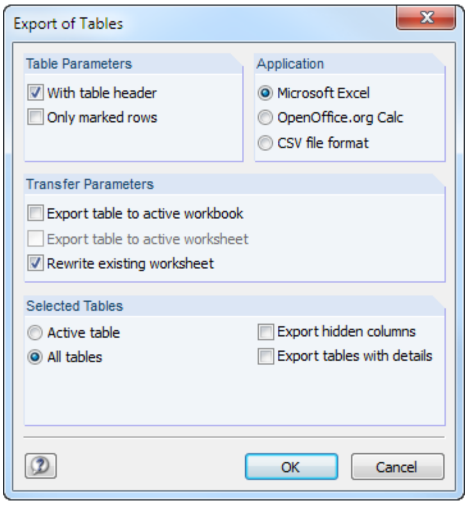
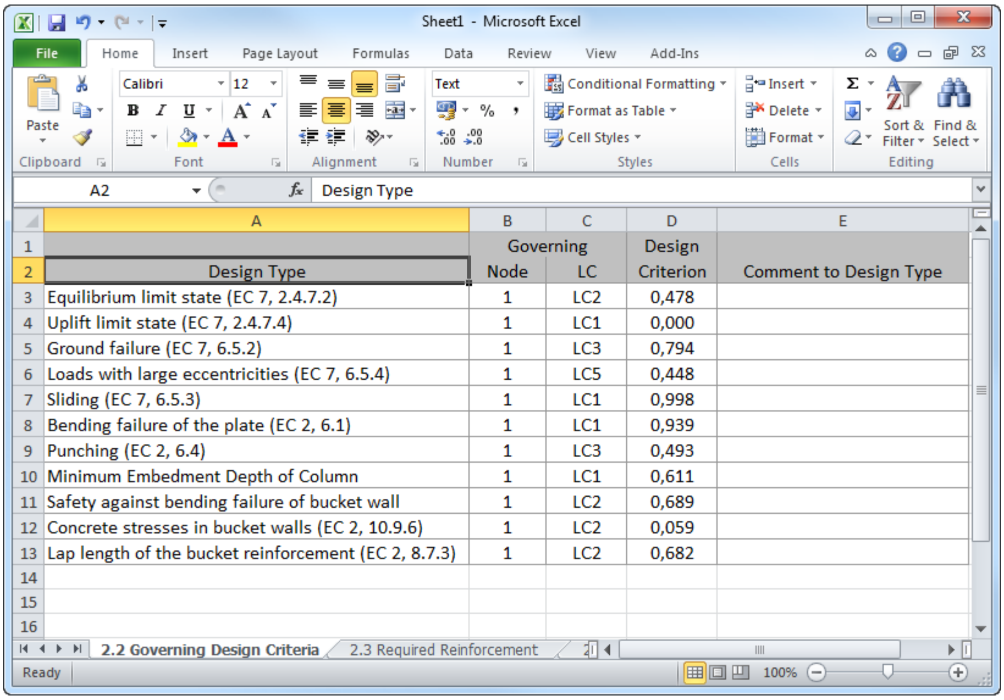


Figure 7.9: Dialog box *Export of Tables*

Having selected the relevant options, you can start the export by clicking [OK]. Excel or Open-Office are started automatically, that is, you do not need to open the programs beforehand (see figure below).



Design Type	Governing Node	Governing LC	Design Criterion	Comment to Design Type
Equilibrium limit state (EC 7, 2.4.7.2)	1	LC2	0,478	
Uplift limit state (EC 7, 2.4.7.4)	1	LC1	0,000	
Ground failure (EC 7, 6.5.2)	1	LC3	0,794	
Loads with large eccentricities (EC 7, 6.5.4)	1	LC5	0,448	
Sliding (EC 7, 6.5.3)	1	LC1	0,998	
Bending failure of the plate (EC 2, 6.1)	1	LC1	0,939	
Punching (EC 2, 6.4)	1	LC3	0,493	
Minimum Embedment Depth of Column	1	LC1	0,611	
Safety against bending failure of bucket wall	1	LC2	0,689	
Concrete stresses in bucket walls (EC 2, 10.9.6)	1	LC2	0,059	
Lap length of the bucket reinforcement (EC 2, 8.7.3)	1	LC2	0,682	

Figure 7.10: Result of export to *Excel*

CAD programs

The reinforcement drawings generated in RF-FOUNDATION Pro can also be used in CAD applications. It is possible to export the drawings as DXF files. To access the corresponding function, use the RF-FOUNDATION Pro menu and select

File → DXF Export of Reinforcement Drawings.

The Windows dialog box *Save As* opens where you enter the directory and name of the DXF file.

Then, you can set the export content including drawings, dimensions and layers in the dialog box *DXF Export of Reinforcement Drawings*.

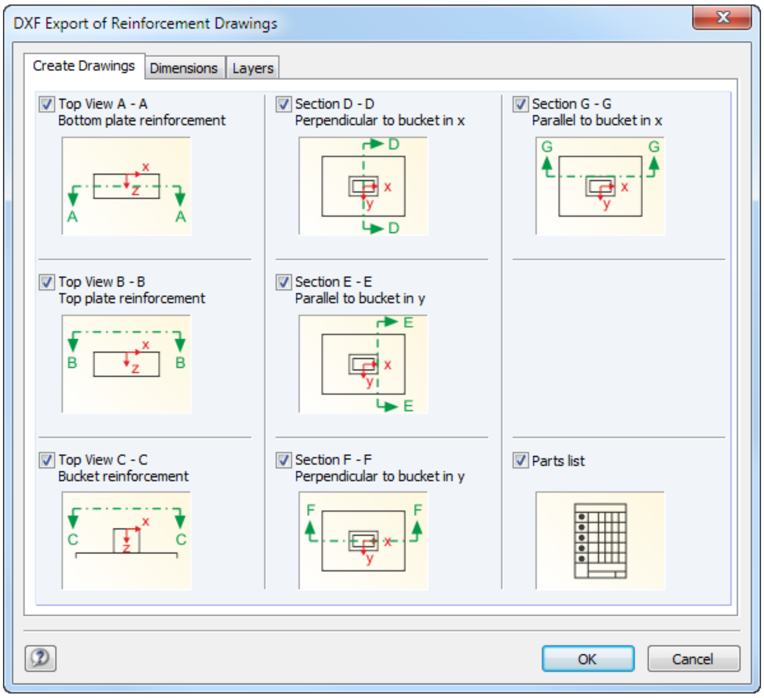


Figure 7.11: Dialog box *DXF Export of Reinforcement Drawings*

8. Examples

8.1 Bucket Foundation

In this example, a reinforced bucket is designed with a rough formwork surface for a group of load cases whose internal forces result in biaxial bending stress. Enclosing links are chosen for the reinforcement.

8.1.1 Support Forces

The support forces for the defined loading is determined in RFEM. The following load cases are governing for the design of a bucket foundation with rough formwork:

Load case **maxHtX** The internal forces of this load case result in the maximum horizontal force in the X-direction.

Load case **maxHtY** The internal forces of this load case result in the maximum horizontal force in the Y-direction.

Load case **minT** The internal forces of this load case lead to the greatest minimum embedment depth of the column in the bucket.

RF-FOUNDATION Pro finds out which load case or combination provides the governing support reactions for the design.

The internal forces of the following load cases are available for the ultimate and the serviceability limit state design:

Load Case	**$P_{Z,d}$ [kN]**	**$P_{X,d}$ [kN]**	**$P_{Y,d}$ [kN]**	**$M_{X,d}$ [kN]**	**$M_{Y,d}$ [kN]**
1	300	-50	20	100	250
2	100	0	0	0	327
3	500	0	0	150	-150

Load Case	**$P_{Z,k}$ [kN]**	**$P_{X,k}$ [kN]**	**$P_{Y,k}$ [kN]**	**$M_{X,k}$ [kN]**	**$M_{Y,k}$ [kN]**
4	215	-35	14	75	175
5	75	0	0	0	235
6	360	0	0	110	-110

8.1.2 Other Settings

The following boundary conditions apply to the design performed in RF-FOUNDATION Pro:

- Foundation type — bucket foundation with rough bucket sides
- Column — rectangle 30 cm / 40 cm
- Standards — EN 1992-1-1, EN 1997-1
- Design section — column center
- Link shape — links enclosing the column
- Concrete — C 35/45
- Reinforcing steel: — B 500 S (A)
- Concrete cover — minimum concrete cover according to standard (exposure class XC2/XC3, concrete cast against prepared ground)

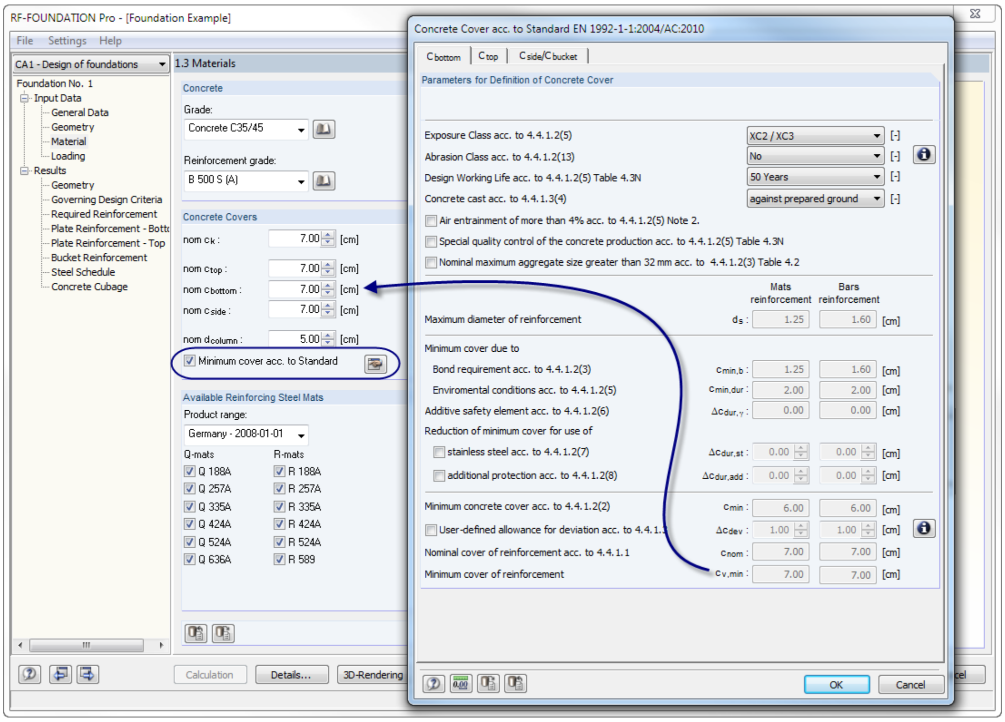


Figure 8.1: Details dialog box for concrete cover

- Eccentricity in x-direction — –30 cm (distance from column center to center of foundation plate)
- Eccentricity in y-direction — none
- Earth covering — 1.00 m with specific weight of earth covering = 20 kN/m^3
- Additional concentrated load — 17 kN
- Distance from support coordinate system
  - in x-direction — -0.5 m
  - in y-direction — 0.5 m
- Additional uniformly distributed load — 10 kN/m
- Distance of distributed load start from support coordinate system
  - in x-direction — 1.5 m
  - in y-direction — 1.5 m

- Distance of distributed load end from support coordinate system
  - in x-direction -2.0 m
  - in y-direction -2.5 m
- Allowable soil stress σ_{Rk} 280 kN/m²
- No consideration of passive earth resistance for design of safety against sliding
- Undrained conditions

8.1.3 Dimensions of Foundation Plate and Bucket

The *Rate* parameters of the foundation plate must be defined as follows:

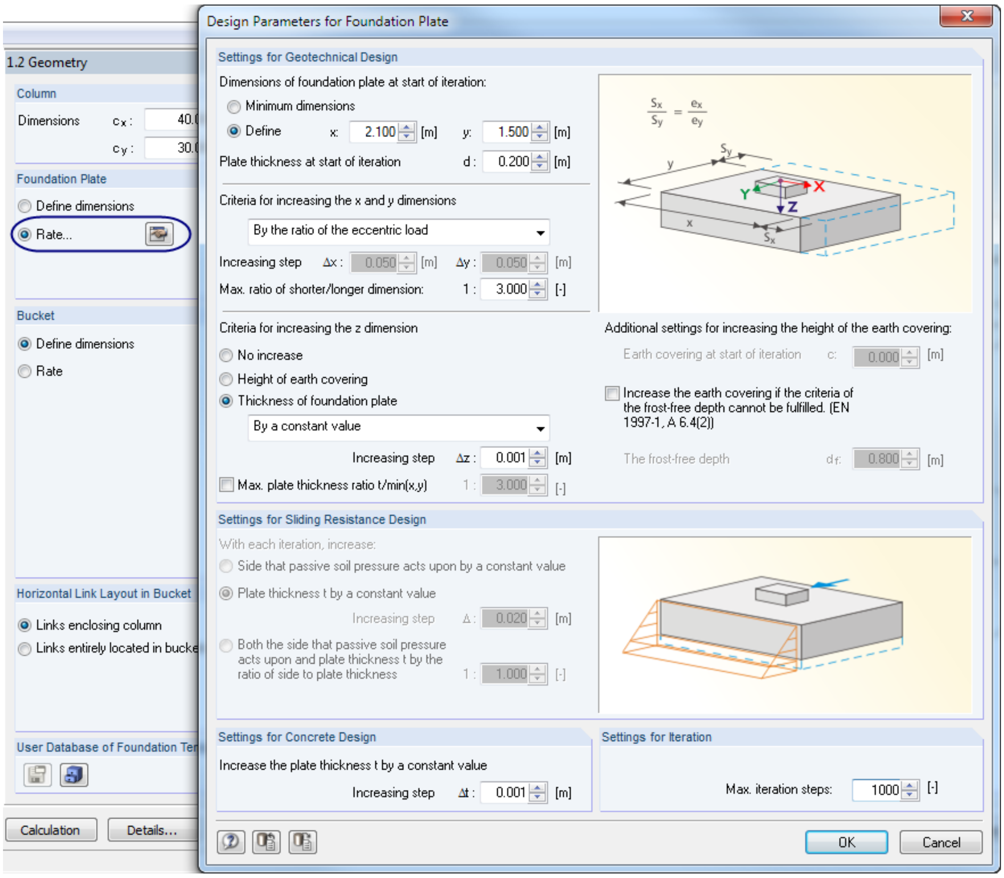


Figure 8.2: Details dialog box for dimensioning of foundation plate

The following dimensions of the foundation plate and the bucket are determined during the iterative calculation:

2.1 Geometry

Description	Symbol	Value	Unit
⊟ Column			
Dimension in x-Direction	c_x	0.400	m
Dimension in y-Direction	c_y	0.300	m
⊟ Eccentricity			
Eccentricity in x-Direction	e_x	-0.300	m
Eccentricity in y-Direction	e_y	0.000	m
⊟ Foundation Plate			
Dimension in x-Direction	x	3.300	m
Dimension in y-Direction	y	2.600	m
Plate Thickness	t	0.360	m
⊟ Bucket			
Bucket Height	h	1.310	m
Column Embedment Depth	d	1.310	m
⊟ Dimension in x-Direction			
⊟ Total Bucket Dimension	d_{kx}	1.140	m
Bucket Wall Thickness Top	t_{tx}	0.270	m
Column Allowance Top	a_{tx}	0.100	m
Bucket Wall Thickness Bott	t_{bx}	0.320	m
Column Allowance Bottom	a_{bx}	0.050	m
Bucket Inclination Inside	α_x	87.81	°
⊟ Dimension in y-Direction			
⊟ Total Bucket Dimension	d_{ky}	1.240	m
Bucket Wall Thickness Top	t_{ty}	0.370	m
Column Allowance Top	a_{ty}	0.100	m
Bucket Wall Thickness Bott	t_{by}	0.420	m
Column Allowance Bottom	a_{by}	0.050	m
Bucket Inclination Inside	α_y	87.81	°
⊟ Earth Covering			
Height of Earth Covering	c	1.000	m

Figure 8.3: Result of dimensioning process

As users expect the dimensions of the foundation to be rounded to centimeters, RF-FOUNDATION Pro provides a button next to the displayed dimensions which you can use to import the calculated dimensions to module window 1.2. Then, you can enter the desired dimensions.

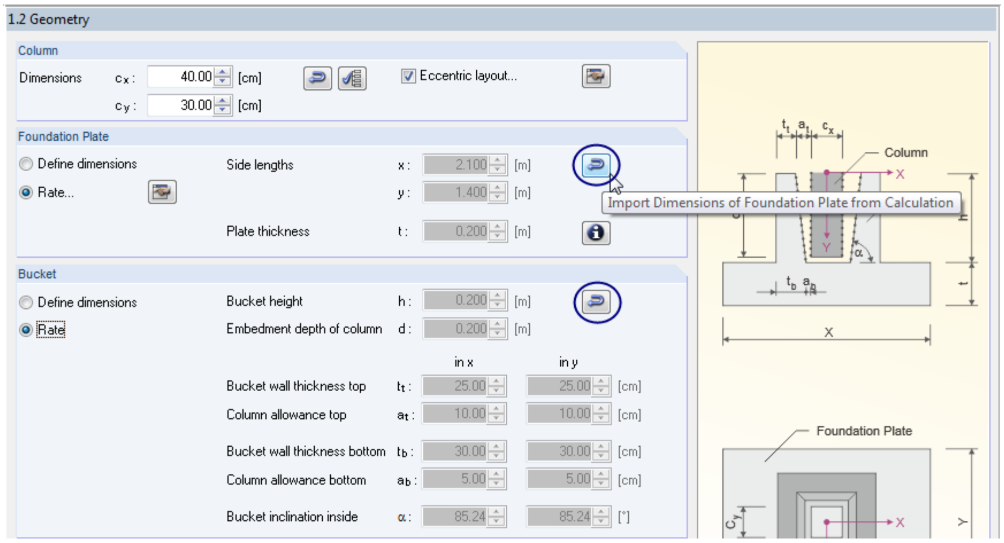


Figure 8.4: Buttons [Import Dimensions]

2.1 Geometry

Description	Symbol	Value	Unit	Message
⊟ Column				
Dimension in x-Direction	c_x	0.400	m	
Dimension in y-Direction	c_y	0.300	m	
⊟ Eccentricity				
Eccentricity in x-Direction	e_x	-0.300	m	
Eccentricity in y-Direction	e_y	0.000	m	
⊟ Foundation Plate				
Dimension in x-Direction	x	3.300	m	
Dimension in y-Direction	y	2.600	m	
Plate Thickness	t	0.360	m	
⊟ Bucket				
Bucket Height	h	1.310	m	
Column Embedment Depth	d	1.310	m	
⊟ Dimension in x-Direction				
⊟ Total Bucket Dimension	d_{kx}	1.140	m	
Bucket Wall Thickness Top	t_{tx}	0.270	m	
Column Allowance Top	a_{tx}	0.100	m	
Bucket Wall Thickness Bott	t_{bx}	0.320	m	
Column Allowance Bottom	a_{bx}	0.050	m	
Bucket Inclination Inside	α_x	87.81	°	
⊟ Dimension in y-Direction				
⊟ Total Bucket Dimension	d_{ky}	1.240	m	
Bucket Wall Thickness Top	t_{ty}	0.370	m	
Column Allowance Top	a_{ty}	0.100	m	
Bucket Wall Thickness Bott	t_{by}	0.420	m	
Column Allowance Bottom	a_{by}	0.050	m	
Bucket Inclination Inside	α_y	87.81	°	
⊟ Earth Covering				
Height of Earth Covering	c	1.000	m	

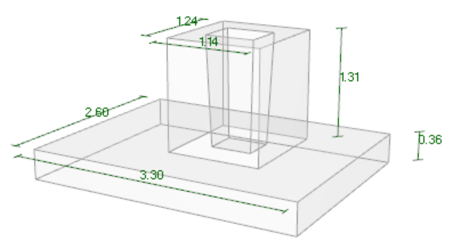


Figure 8.5: Rounded dimensions of foundation

8.1.3.1 Minimum Embedment Depth of Column

The load case LC1 or LC2 (both load cases with $e_x > 2.0$) is governing for the determination of the first embedment depth d_1 of the column embedded in the bucket. The eccentricity *e* is the result of:

$$e_x = \left|\frac{M}{P_z \cdot c}\right| = \frac{250.00}{300.00 \cdot 0.40} = 2.083$$

As 2.0 < 2.083, the required embedment depth *req d* is determined with the following result:

$$\text{req d} = \min T_1 = 2 \cdot c = 2 \cdot 40 = 80 \text{ cm}$$

Minimum Embedment Depth of Column ¦ Node 1 ¦ LC1

⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC1	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	300.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	-50.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	20.00	kN
Moment About x-Axis	$M_{X,d}$	100.00	kNm
Moment About y-Axis	$M_{Y,d}$	250.00	kNm
⊟ Related Load Eccentricity in x-Direction	e_x	2.083	
Column Restraining Moment about Axis y	M_Y	250.00	kNm
Column Width in x-Direction	c_x	0.400	m
⊟ Related Load Eccentricity in y-Direction	e_y	1.111	
Column Restraining Moment about Axis x	M_X	100.00	kN
Column Width in y-Direction	c_y	0.300	m
⊟ Verification			
Provided Embedment Depth	prov d	1.310	m
Required Embedment Depth	req d	0.800	m
Design Criterion	Criterion	0.611	

Figure 8.6: Verification of minimum embedment depth for LC1

Minimum Embedment Depth of Column ¦ Node 1 ¦ LC2			
⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC2	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	100.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	0.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	0.00	kN
Moment About x-Axis	$M_{X,d}$	0.00	kNm
Moment About y-Axis	$M_{Y,d}$	327.00	kNm
⊟ Related Load Eccentricity in x-Direction	e_x	8.175	
Column Restraining Moment about Axis y	M_Y	327.00	kNm
Column Width in x-Direction	c_x	0.400	m
⊟ Related Load Eccentricity in y-Direction	e_y	0.000	
Column Restraining Moment about Axis x	M_X	0.00	kN
Column Width in y-Direction	c_y	0.300	m
⊟ Verification			
Provided Embedment Depth	prov d	1.310	m
Required Embedment Depth	req d	0.800	m
Design Criterion	Criterion	0.611	

Figure 8.7: Verification of minimum embedment depth for LC2

8.1.4 Horizontal Forces on Bucket Walls

As an example, the largest horizontal force in the y-direction is determined as a force acting perpendicular on the bucket wall in the x-direction:

$$\max H_{ty} = \left|\frac{6 \cdot M_X}{5 \cdot t} + \frac{6}{5} \cdot P_Y\right| = \left|\frac{6 \cdot 150}{5 \cdot 1.31} + \frac{6}{5} \cdot 0\right| = 137.40 \text{ kN}$$

In the results window 2.3 *Required Reinforcement*, you find the same value listed among the detailed results. There, you can also see the corresponding horizontal force in the x-direction acting perpendicular on the bucket wall in the y-direction.

Horizontal Bucket Links Lhy (outside, in ydirection) ¦ Pos: 6,9 ¦ Name: Lhy			
⊟ Loading from Maximum Horizontal Force in y-Direction (LC max H_{ty})			
⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC3	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	500.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	0.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	0.00	kN
Moment About x-Axis	$M_{X,d}$	150.00	kNm
Moment About y-Axis	$M_{Y,d}$	-150.00	kNm
Lever	z	1.092	m
Top Horizontal Force in y-Direction	max H_{ty}	137.40	kN
Top Horizontal Force in x-Direction	co H_{tx}	137.40	kN

Figure 8.8: Maximum horizontal force in the y-direction

The next detail entry shows the results of the load case resulting in the largest horizontal force in the x-direction acting perpendicular on the bucket wall in the y-direction. The corresponding horizontal force in the y-direction acting perpendicular on the bucket wall in the x-direction is displayed here, too.

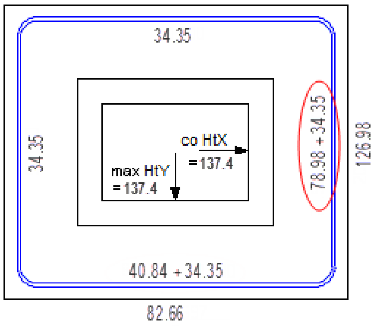
Horizontal Bucket Links Lhy (outside, in ydirection) ¦ Pos: 6,9 ¦ Name: Lhy			
⊞ Loading from Maximum Horizontal Force in y-Direction (LC max H_{ty})			
⊟ Loading from Maximum Horizontal Force in x-Direction (LC max H_{tx})			
⊟ Design Value of Support Forces and Moments			
At Node	No.	1	
Load Case	LC	LC2	
Design Situation	DS	PT	
Vertical Force	$P_{Z,d}$	100.00	kN
Horizontal Force in x-Direction	$P_{X,d}$	0.00	kN
Horizontal Force in y-Direction	$P_{Y,d}$	0.00	kN
Moment About x-Axis	$M_{X,d}$	0.00	kNm
Moment About y-Axis	$M_{Y,d}$	327.00	kNm
Lever	z	1.092	m
Top Horizontal Force in y-Direction	co H_{ty}	0.00	kN
Top Horizontal Force in x-Direction	max H_{tx}	299.54	kN

Figure 8.9: Maximum horizontal force in the x-direction

8.1.5 Tensile Forces of Links and Link Reinforcement

8.1.5.1 Horizontal Bucket Links Lh (outside all sides)

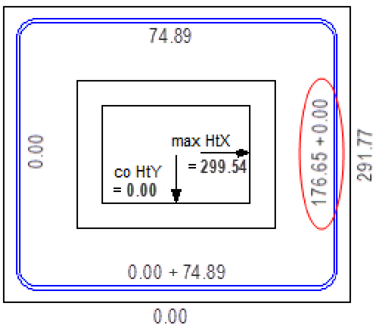
There are the following tensile forces in the load case with the maximum horizontal force in the y-direction:



Horizontal Bucket Links (outside all sides) ¦ Pos: 5,8 ¦ Name: Lh			
⊟ Loading from Maximum Horizontal Force in y-Direction (LC max H_{ty})			
⊞ Design Value of Support Forces and Moments			
Lever	z	1.092	m
Top Horizontal Force in y-Direction	max H_{ty}	137.40	kN
Top Horizontal Force in x-Direction	co H_{tx}	137.40	kN
⊟ Tensile force of this load case for the design of the all-round outside lin	gov T_{Lh} (max H_{ty})	113.33	kN
⊟ From Bending of Bucket Wall in x-Direction			
⊞ Existing Tensile Force in Entire Reinforcement	$T_{Bend,x}$ (max H_{ty})	82.66	kN
Proportional tensile force in all-round outside link due to bending c	$T_{Lh,Bend,x}$ (max H_{ty})	40.84	kN
⊟ From Tension of Bucket Wall in y-Direction			
Proportional tensile force in all-round outside link due to tensile for	$T_{Lh,Tens,y}$ (max H_{ty})	34.35	kN
Top Horizontal Force in x-Direction	H_{tx}	137.40	kN
⊟ From Bending of Bucket Wall in y-Direction			
⊞ Existing Tensile Force in Entire Reinforcement	$T_{Bend,y}$ (max H_{ty})	126.87	kN
Proportional tensile force in all-round outside link due to bending c	$T_{Lh,Bend,y}$ (max H_{ty})	78.98	kN
⊟ From Tension of Bucket Wall in x-Direction			
Proportional tensile force in all-round outside link due to tensile for	$T_{Lh,Tens,x}$ (max H_{ty})	34.35	kN
Top Horizontal Force in y-Direction	H_{ty}	137.40	kN

Figure 8.10: Maximum tensile force in horizontal bucket links – load case with greatest horizontal force in the y-direction

The tensile forces in the load case with the maximum horizontal force in the x-direction are:



Horizontal Bucket Links (outside all sides) ¦ Pos: 5,8 ¦ Name: Lh			
⊟ Tensile force of this load case for the design of the all-round outside lin	gov T_{Lh} (max H_{tx})	176.65	kN
⊟ From Bending of Bucket Wall in x-Direction			
⊞ Existing Tensile Force in Entire Reinforcement	$T_{Bend,x}$ (max H_{tx})	0.00	kN
Proportional tensile force in all-round outside link due to bending c	$T_{Lh,Bend,x}$ (max H_{tx})	0.00	kN
⊟ From Tension of Bucket Wall in y-Direction			
Proportional tensile force in all-round outside link due to tensile for	$T_{Lh,Tens,y}$ (max H_{tx})	74.89	kN
Top Horizontal Force in x-Direction	H_{tx}	299.54	kN
⊟ From Bending of Bucket Wall in y-Direction			
⊞ Existing Tensile Force in Entire Reinforcement	$T_{Bend,y}$ (max H_{tx})	291.77	kN
Proportional tensile force in all-round outside link due to bending c	$T_{Lh,Bend,y}$ (max H_{tx})	176.65	kN
⊟ From Tension of Bucket Wall in x-Direction			
Proportional tensile force in all-round outside link due to tensile for	$T_{Lh,Tens,x}$ (max H_{tx})	0.00	kN
Top Horizontal Force in y-Direction	H_{ty}	0.00	kN

Figure 8.11: Maximum tensile force in horizontal bucket links – load case with greatest horizontal force in the x-direction

On the outside of the bucket, the tensile forces acting on the entire reinforcing steel resulting from the bucket wall's bending are marked out. Above the sketched link, you can see the proportional tensile force due to bending falling upon the horizontal bucket link. The proportional tensile force due to tension of the respective bucket wall is added to this force.

Before the governing tensile force is determined, we want to have a look at the proportional tensile force due to bending in the horizontal bucket link lying outside on all sides. Here, the bending of the bucket wall in the y-direction, which is available in the load case with the largest horizontal force in the x-direction, is regarded.

First, the acting bending moment must be determined.

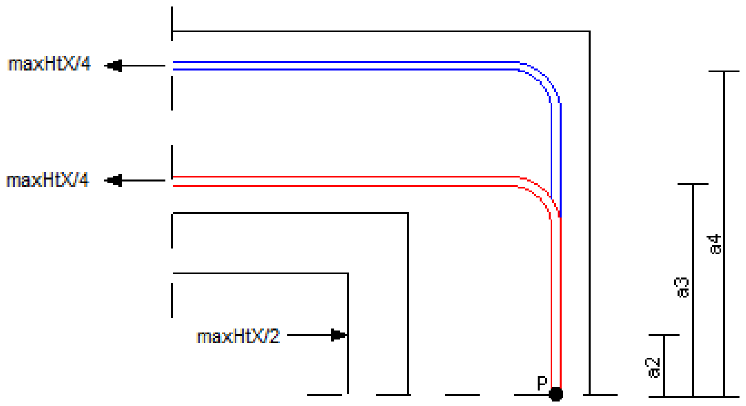


Figure 8.12: Acting bending moment

The lever arms a_2, a_3 and a_4 are determined as follows:

$$a_{2,y} = \frac{c_y}{4} = \frac{30}{4} = 7.5 \text{ cm}$$

$$a_{3,y} = \frac{c_y}{2} + a_{ty} + \text{nom } c_k + \frac{d_s}{2} = \frac{30}{2} + 10 + 7.0 + \frac{1.4}{2} = 32.7 \text{ cm}$$

$$a_{4,y} = \frac{c_y}{2} + a + t_{ty} - \text{nom } c_k - \frac{d_s}{2} = \frac{30}{2} + 10 + 37 - 7 - \frac{1.4}{2} = 54.3 \text{ cm}$$

Now, it is possible to determine the acting moment under the characteristic load around the point P as follows.

$$M_{Ed,y} = \gamma \cdot \left(\frac{\max H_{tx}}{4} \cdot (a_{3,y} + a_{4,y}) - \frac{\max H_{tx}}{2} \cdot a_{2,y} \right)$$

$$= 1.0 \cdot \left(\frac{299.54}{4} \cdot (0.327 + 0.543) - \frac{299.54}{2} \cdot 0.075 \right) = 53.92 \text{ kNm}$$

The following figure shows the parameters of the bending design carried out in the program.

⊟ From Bending of Bucket Wall in y-Direction			
⊟ Existing Tensile Force in Entire Reinforcement	$T_{Bend,y}$ (max H_{tx})	291.77	kN
⊟ Design Value of Acting Bending Moment	$M_{Ed,y}$	53.92	kNm
Lever Arm	$a_{2,y}$	0.075	m
Lever Arm	$a_{3,y}$	0.327	m
Lever Arm	$a_{4,y}$	0.543	m
Required Safety Against Bending Failure	γ	1.000	
⊟ Design Value of Moment Capacity	$M_{Rd,y}$	53.93	kNm
Effective Depth	d	0.210	m
Selected Strength Class		Concrete C3	
Concrete Design Value	f_{cd}	19833.3	kN/m²
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Characteristic Cylinder Compressive Strength	f_{ck}	35000.000	kN/m²
Concrete Partial Safety Factor	γ_c	1.500	
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Concrete Strain	ε_c	3.500	‰
Height of Triangular Concrete Compression Zone Area	h_T	0.017	m
Height of Rectangular Concrete Compression Zone Area	h_R	0.025	m
Width of Concrete Compression Zone Area	w	0.437	m
Area of Concrete Compression Zone	A	147.113	cm²
Design Value of Concrete Compression Force	F_{cd}	291.77	kN
Design Value of Yield Strength	f_{yd}	434783.000	kN/m²
Characteristic Value of Steel Yield Strength	f_{yk}	500000.000	kN/m²
Steel Partial Safety Factor	γ_s	1.150	
Strain of Horizontal Bucket Wall Reinforcement	ε_{zu}	10.470	‰
Minimum Strain of Horizontal Bucket Wall Reinforcement	min ε_{zu}	2.000	‰
Lever Arm of Internal Forces	z	0.185	m

Figure 8.13: Details – horizontal bucket links

The height of the compression zone is composed of a triangular and a rectangular compression zone part. The factor 0.8 from the formula below is omitted above because the height has already been reduced by this factor. The heights of the compression zones result from the design.

Find details about the concrete design in Chapter 8.1.6 describing how the safety against bending failure is determined.

Now, in order to determine the proportional tensile force falling upon the horizontal bucket link, the lever arms a_5 and a_6 must be determined first.

$$a_{5,y} = t_{tx} - \text{nom } c_k - \frac{d_s}{2} - \frac{0.8 \cdot z_{Du}}{4} = t_{tx} - \text{nom } c_k - \frac{d_s}{2} - \frac{0.8 \cdot (h_T + h_R)}{4}$$

$$= 27 - 7 - \frac{1.4}{2} - \frac{1.7 + 2.5}{4} = 18.25 \text{ cm}$$

$$a_{6,y} = \frac{c_y}{8} + a_{ty} + t_{ty} - \text{nom } c_k - \frac{d_s}{2} = \frac{30}{8} + 10 + 37 - 7 - \frac{1.4}{2} = 43.05 \text{ cm}$$

Finally, the load spreading angle θ_1 can be determined.

$$\theta_1 = \arctan\frac{a_5}{a_6} = \arctan\frac{18.25}{43.05} = 22.97$$

By using the angle and the quarter-point of the applied proportional horizontal force max H_{tx}, it is possible to determine the value for the force of the concrete compression strut D1.

$$D1 = \frac{\max H_{tX}}{4 \cdot \sin\theta_1} = \frac{299.54}{4 \cdot \sin 22.97} = 191.89 \text{ kN}$$

The horizontal component of the compression strut force D1 is the proportion of the complete tensile force that results from the bucket wall's bending in the y-direction:

$$T_{Lh,Bend} = D1 \cdot \cos\theta_1 = D1 \cdot \cos\theta_1 = 191.89 \cdot \cos 22.97 = 176.65 \text{kN}$$

This tensile force can also be found in the details of RF-FOUNDATION Pro.

⊟ Geometric Values to Allocate the Tensile Force			
Tangent of load spreading angle υ_1 within bucket wall in the	tan $\upsilon_{1,y}$	0.424	
Load Spreading Angle υ_1 Within Bucket Wall in y-Direction	$\upsilon_{1,y}$	22.97	°
Vertical Cathetus of Concrete Strut within Bucket Wall in y-D	$a_{5,x}$	18.25	cm
Horizontal Cathetus of Concrete Strut within Bucket Wall in y	$a_{6,y}$	43.05	cm
Lever within Bucket Wall in y-Direction	$a_{1,y}$	19.30	cm
Proportional Tensile Force of outside Links in y-Direction	$T_{LhY,Bend,y}$ (	176.65	kN

Figure 8.14: Details – geometric values to allocate the tensile force

Having this background information, it is now possible to understand how the maximum tensile force in the horizontal bucket link is determined. It results from the bucket wall's bending in the y-direction due the maximum horizontal force that is available in the x-direction:

$$\text{gov } T_{Lh} = 176.65 \text{ kN}$$

As we have a steel strain that is beyond the steel strain available on the yield strength, the yield strength is used as the prevailing steel stress for the determination of the required reinforcement area. In the program, it is displayed as follows:

⊟ Required Reinforcement Area			
Governing tensile force for the design of the outside links in the	gov T_{Lh}	176.65	kN
Steel Yield Strength	f_{yk}	500000.0	kN/m^2
Decisive Required Reinforcement Area	gov req $A_{s,Lh}$	4.063	cm^2

Figure 8.15: Details – required reinforcement area for links

The following reinforcement is chosen:

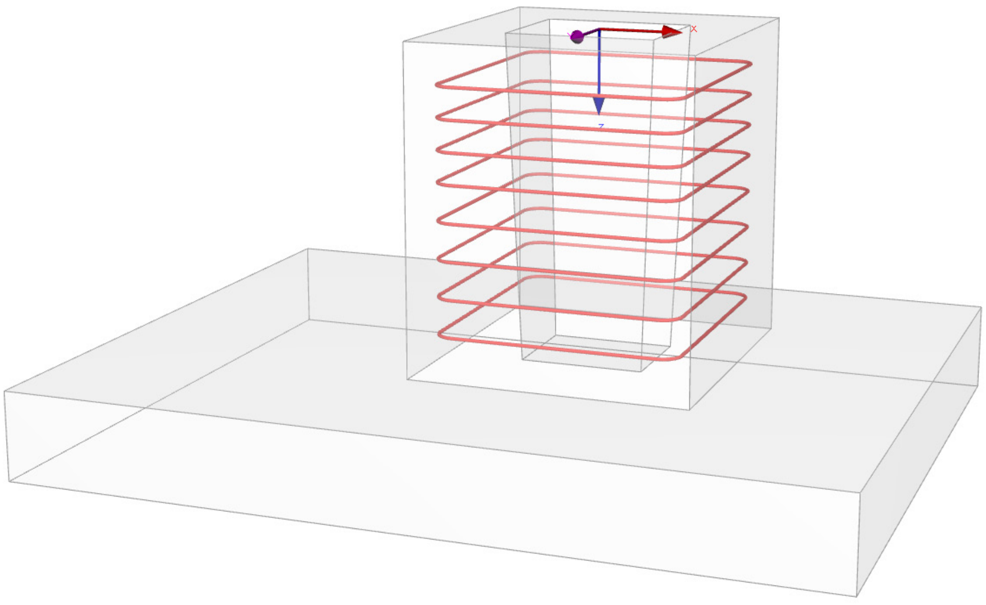


Figure 8.16: Rendering of horizontal bucket links

The table below offers an overview of the reinforcement details.

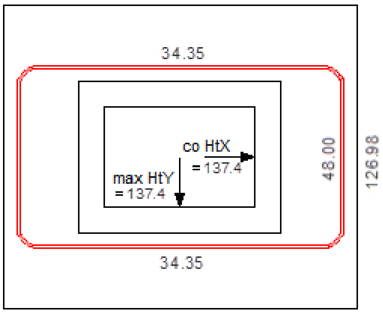
⊟ Details on the Selected Reinforcement			
⊟ Top Links			
Existing Reinforcement Area	prov $A_{s,LhX}$	4.618	cm^2
Selected Link Diameter	$d_{s,LhX}$	14	mm
Selected Number of Links	n_{LhX}	3	
Statically Required Number of Links	req n_{LhX}	3	
Number of Links Constructionally Possible	poss n_{LhX}	3	
⊟ Link Spacing	s_{LhX}	125	mm
⊟ Max. length of reinforced zone	$l_{max,LhX}$	261	mm
Layout width	$l_{layout,LhX}$	437	mm
Minimum distance from the top bucket side	$z_{min,LhX}$	175	mm
⊟ Bottom Links			
Bucket with rough bucket sides: Reinforcement only constructional			
Existing Reinforcement Area	prov $A_{s,LhX}$	7.697	cm^2
Selected Link Diameter	$d_{s,LhX}$	14	mm
Selected Number of Links	n_{LhX}	5	
Statically Required Number of Links	req n_{LhX}	0	
Number of Links Constructionally Possible	poss n_{LhX}	5	
⊟ Link Spacing	s_{LhX}	150	mm
⊟ Max. length of reinforced zone	$l_{max,LhX}$	714	mm
Layout width	$l_{layout,LhX}$	873	mm
Minimum distance from the bottom bucket side	$z_{min,LhX}$	159	mm

Figure 8.17: Details – selected reinforcement (links Lh)

8.1.5.2 Horizontal Bucket Links LhY (in y-direction outside)

The tensile force in the links lying on the outside of the bucket walls in the y-direction is to be determined in the same way.

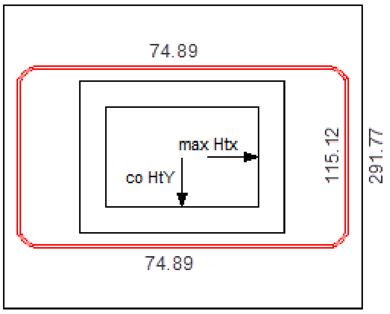
There are the following tensile forces in the load case with the maximum horizontal force in the y-direction:



⊟ Tensile force of this load case for the design of the outside links in the	gov T_{LhY} (max H_{ty})	48.00	kN
⊟ From Bending of Bucket Wall in y-Direction			
⊟ Existing Tensile Force in Entire Reinforcement	$T_{Bend,y}$ (max H_{ty})	126.98	kN
⊞ Design Value of Acting Bending Moment	$M_{Ed,y}$	24.73	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,y}$	24.73	kNm
⊞ Geometric Values to Allocate the Tensile Force			
Proportional Tensile Force of outside Links in y-Direction	$T_{LhY,Bend,y}$ (max H	48.00	kN
⊟ From Tension of Bucket Wall in x-Direction			
Proportional Tensile Force of outside Links in y-Direction	$T_{LhY,Tens,x}$ (max H	34.35	kN
Top Horizontal Force in x-Direction	H_{tx}	137.40	kN

Figure 8.18: Maximum tensile force in link lying outside (y-direction) – load case with greatest horizontal force in the y-direction

There are the following tensile forces in the load case with the maximum horizontal force in the x-direction:



⊟ Tensile force of this load case for the design of the outside links in	gov T_{LhY} (max H_{tx})	115.12	kN
⊟ From Bending of Bucket Wall in y-Direction			
⊟ Existing Tensile Force in Entire Reinforcement	$T_{Bend,y}$ (max H_{tx})	291.77	kN
⊞ Design Value of Acting Bending Moment	$M_{Ed,y}$	53.92	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,y}$	53.93	kNm
⊞ Geometric Values to Allocate the Tensile Force			
Proportional Tensile Force of outside Links in y-Direction	$T_{LhY,Bend,y}$ (max H_{tx})	115.12	kN
⊟ From Tension of Bucket Wall in x-Direction			
Proportional Tensile Force of outside Links in y-Direction	$T_{LhY,Tens,x}$ (max H_{tx})	74.89	kN
Top Horizontal Force in x-Direction	H_{tx}	299.54	kN

Figure 8.19: Maximum tensile force in link lying outside (y-direction) – load case with greatest horizontal force in the x-direction

The largest tensile force occurs due to the bending of the bucket wall in the y-direction, which is available in the load case of the maximum horizontal force in the x-direction:

$$\text{gov } T_{LhY} = 115.12 \text{ kN}$$

Then, the following reinforcement area for the links LhY is determined:

⊟ Required Reinforcement Area			
Governing tensile force for the design of the outside links in the y-c	gov T_{LhY}	115.12	kN
Steel Yield Strength	f_{yk}	500000.0	kPa
Decisive Required Reinforcement Area	gov req $A_{s,LhY}$	2.648	cm^2

Figure 8.20: Details – required reinforcement area for links LhY

The following reinforcement has been chosen:

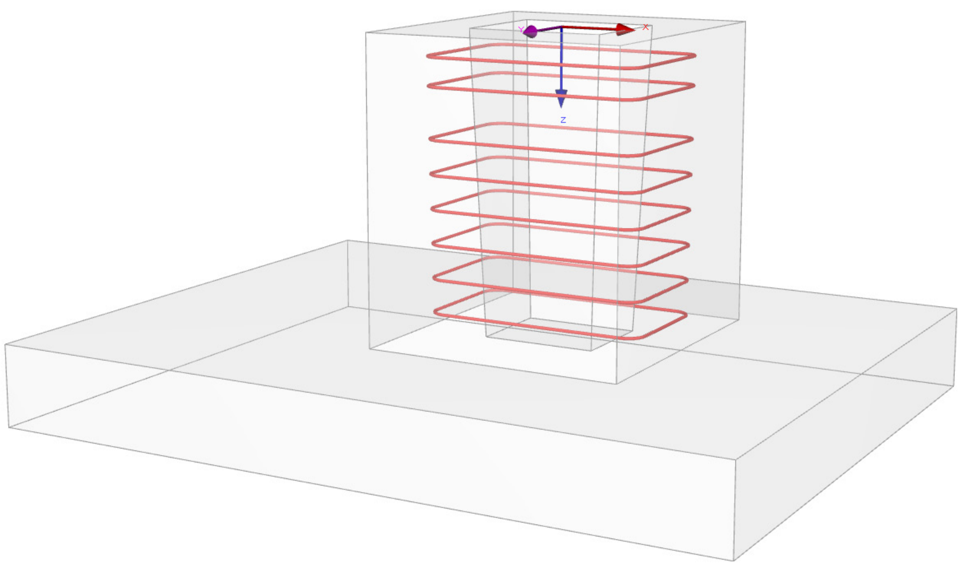


Figure 8.21: Rendering of link reinforcement LhY

The following design specifications can be found in the reinforcement details.

Details on the Selected Reinforcement			
Top Links			
Existing Reinforcement Area	prov $A_{s,LhY}$	3.079	cm^2
Selected Link Diameter	$d_{s,LhY}$	14	mm
Selected Number of Links	n_{LhY}	2	
Statically Required Number of Links	req n_{LhY}	2	
Number of Links Constructionally Possible	poss n_{LhY}	3	
Link Spacing	s_{LhY}	125	mm
Max. length of reinforced zone	$l_{max,LhY}$	317	mm
Layout width	$l_{layout,LhY}$	437	mm
Minimum distance from the top bucket side	$z_{min,LhY}$	120	mm
Bottom Links			
Bucket with rough bucket sides: Reinforcement only constructional			
Existing Reinforcement Area	prov $A_{s,LhY}$	9.236	cm^2
Selected Link Diameter	$d_{s,LhY}$	14	mm
Selected Number of Links	n_{LhY}	6	
Statically Required Number of Links	req n_{LhY}	0	
Number of Links Constructionally Possible	poss n_{LhY}	6	
Link Spacing	s_{LhY}	150	mm
Max. length of reinforced zone	$l_{max,LhY}$	782	mm
Layout width	$l_{layout,LhY}$	873	mm
Minimum distance from the bottom bucket side	$z_{min,LhY}$	91	mm

Figure 8.22: Details – selected reinforcement (links LhY)

8.1.5.3 Horizontal Bucket Links LhX (in x-direction outside)

The link reinforcement lying outside in the x-direction is determined in a similar way.

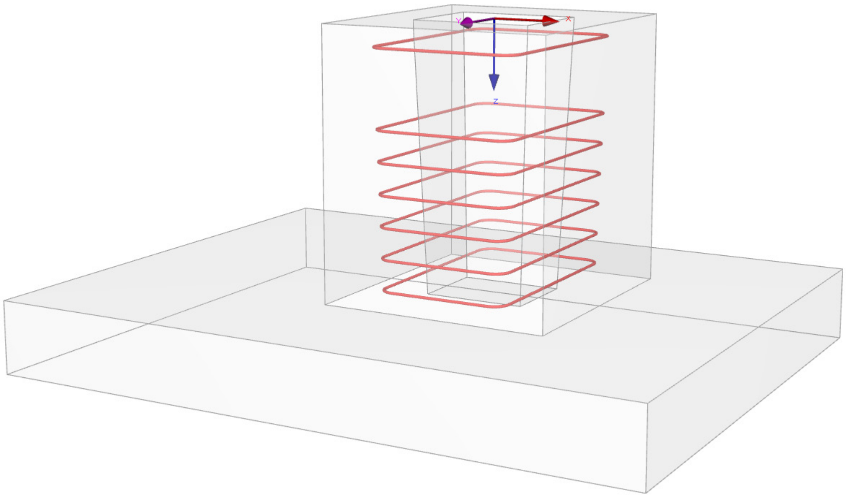


Figure 8.23: Rendering of link reinforcement LhX

Details on the Selected Reinforcement			
Top Links			
Existing Reinforcement Area	prov $A_{s,LhX}$	1.539	cm^2
Selected Link Diameter	$d_{s,LhX}$	14	mm
Selected Number of Links	n_{LhX}	1	
Statically Required Number of Links	req n_{LhX}	1	
Number of Links Constructionally Possible	poss n_{LhX}	3	
Link Spacing	s_{LhX}	125	mm
Max. length of reinforced zone	$l_{max,LhX}$	331	mm
Layout width	$l_{layout,LhX}$	437	mm
Minimum distance from the top bucket side	$z_{min,LhX}$	106	mm
Bottom Links			
Bucket with rough bucket sides: Reinforcement only constructional			
Existing Reinforcement Area	prov $A_{s,LhX}$	9.236	cm^2
Selected Link Diameter	$d_{s,LhX}$	14	mm
Selected Number of Links	n_{LhX}	6	
Statically Required Number of Links	req n_{LhX}	0	
Number of Links Constructionally Possible	poss n_{LhX}	6	
Link Spacing	s_{LhX}	150	mm
Max. length of reinforced zone	$l_{max,LhX}$	796	mm
Layout width	$l_{layout,LhX}$	873	mm
Minimum distance from the bottom bucket side	$z_{min,LhX}$	77	mm

Figure 8.24: Details – selected reinforcement (links LhX)

8.1.5.4 Vertical Bucket Links Lvx

To determine the vertical edge reinforcement of the bucket wall in the x-direction, the load case resulting in the maximum horizontal force in the x-direction is considered.

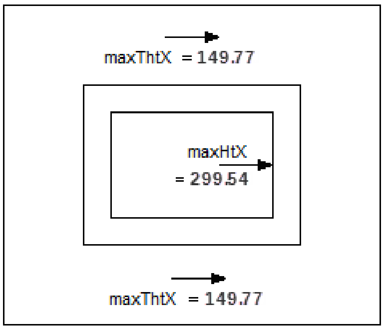


Figure 8.25: Distribution of horizontal force to bucket walls

The horizontal force is uniformly distributed to both bucket walls:

$$\max T_{ht,x} = 149.77 \text{ kN}$$

The inclination of the concrete compression strut running diagonally across the bucket wall in the x-direction is determined as follows:

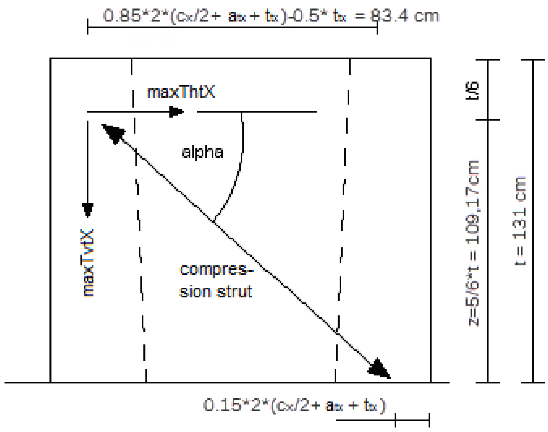


Figure 8.26: Model of forces for determination of vertical side tensile force

$$\tan\alpha = \frac{109.17}{83.4} = 1.309$$

Now, the side tensile force can be determined:

$$\max T_{vt,x} = \tan\alpha \cdot \max T_{ht,x} = 1.309 \cdot 149.77 = 196.04 \text{ kN}$$

Then, the total reinforcement area required for the absorption of the tensile forces is determined.

$$\text{req As} = \frac{\max T_{vt,x}}{f_{yd}} = \frac{196.04}{43.4783} = 4.509 \text{ cm}^2$$

$$f_{yd} = \frac{500000 \text{ kPa}}{1.15} = 43.4783 \text{ kN/cm}^2$$

Now, if the total reinforcement area is divided by twice the area of a vertical link, we get the required number of vertical links.

Thus, links with a diameter of ø 12 mm are chosen.

$$\text{req } n = \frac{\text{req As}}{2 \cdot As_{links}} = \frac{4.509}{2 \cdot 1.13} = 1.99$$

There are two links selected for each side of the bucket wall in the x-direction. So we get the following reinforcement:

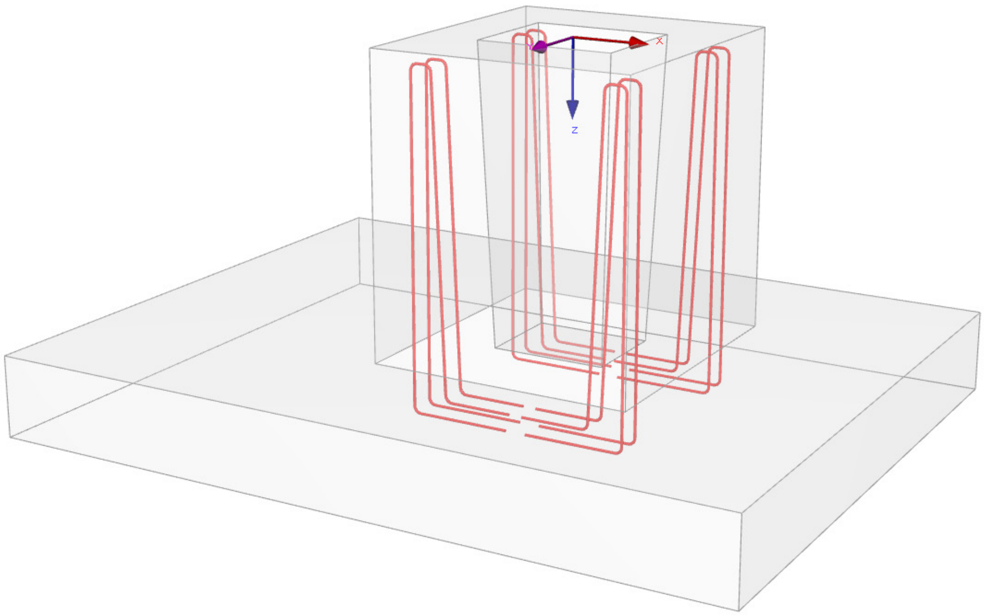


Figure 8.27: Rendering of link reinforcement Lvx

In the tables, the reinforcement is displayed as shown below:

⊟ Details on the Selected Reinforcement			
Existing Reinforcement Area	prov $A_{s,Lvx}$	4.524	cm^2
Selected Link Diameter	$d_{s,Lvx}$	12.0	mm
Selected Number of Links per Side	sel n_{Lvx}	2	
Statically Required Number of Links per Edge	req n_{Lvx}	2	
Number of Links Constructionally Possible per Side	poss n_{Lvx}	2	
Link Spacing	s_{Lvx}	116	cm

Figure 8.28: Details – selected reinforcement (links Lvx)

8.1.5.5 Vertical Bucket Links Lvy and Bucket Wall Reinforcement

The edge reinforcement for the bucket wall in the y-direction is determined in the same way. The result is the following:

Details on the Selected Reinforcement			
Existing Reinforcement Area	prov $A_{s,Lvy}$	2.262	cm²
Selected Link Diameter	$d_{s,Lvy}$	12.0	mm
Selected Number of Links per Side	n_{Lvy}	1	
Statically Required Number of Links per Edge	req n_{Lvy}	1	
Number of Links Constructionally Possible per Side	poss n_{Lvy}	1	
Link Spacing	s_{Lvy}	10.0	cm

Figure 8.29: Details – selected reinforcement (links Lvy)

The edge reinforcements are coupled with the bending reinforcement of the foundation plate. Thus, the determination of the statically required reinforcement is complete.

For structural reasons, it is now necessary to insert in each wall as many links as allowed by the spacing of 20 cm selected in module window 2.6 *Bucket Reinforcement* for the bucket wall reinforcement in the x- and y-direction.

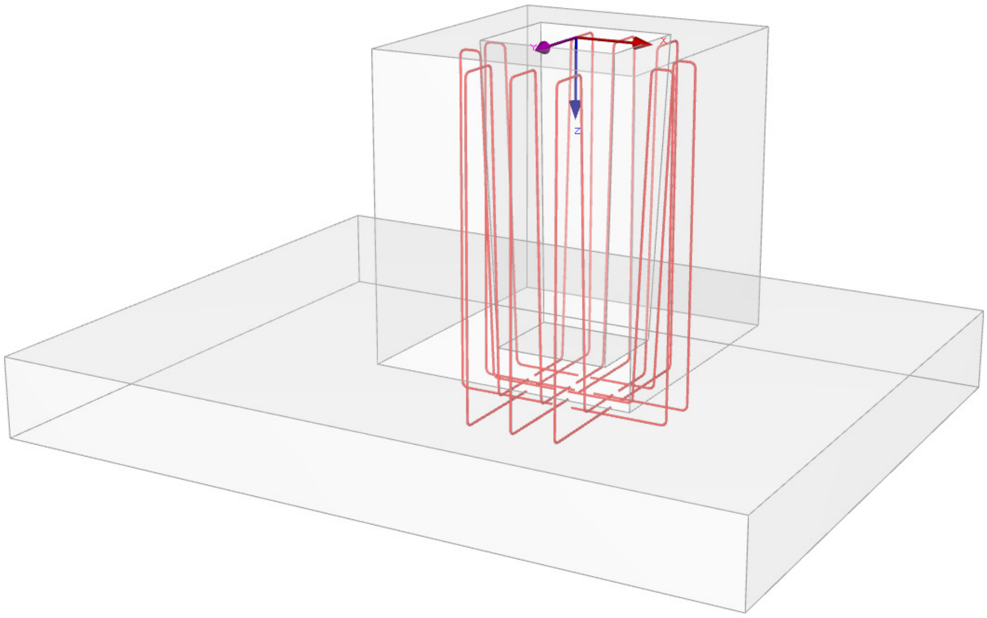


Figure 8.30: Rendering of bucket wall reinforcement in the x- and y-direction

8.1.6 Safety Against Bending Failure of Bucket Wall

The following chapters describe further design details.

Acting moment M

The acting moment under characteristic load is M = 53.92 kNm for the bending of the bucket wall in the y-direction due to the maximum horizontal force in the x-direction.

Ultimate moment M_{Ed}

The calculated load moment corresponds to the ultimate moment M_{Ed} = 53.92 kNm.

Moment capacity M_{Rd}

Shortening on the inner side and elongation on the outside of the bucket wall in the y-direction are changed iteratively until the forces in the steel and in the concrete coming along with these deformations form together with their distance an internal moment M_{Rd} that is larger than the ultimate moment M_{Ed}.

After specifying a reinforcement area, it is once again possible to determine an internal moment M_{Rd}. Starting from the state of ultimate strain at failure, the deformation of steel and concrete is changed until an equilibrium of forces is established in both materials. Now, we want to determine this moment capacity M_{Rd} for the selected reinforcement.

At the end of the iterations, there is the following result:

Bucket Wall in y-Direction	Criterion	0.884	
Design Value of Support Forces and Moments			
Design Value of Acting Bending Moment	$M_{Ed,y}$	53.92	kNm
Design Value of Moment Capacity	$M_{Rd,y}$	61.01	kNm
Effective Depth	d	0.210	m
Selected Strength Class		Concrete C35/45	
Concrete Design Value	f_{cd}	19833.3	kN/m²
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Characteristic Cylinder Compressive Strength	f_{ck}	35000.000	kN/m²
Concrete Partial Safety Factor	γ_c	1.500	
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Concrete Strain	ε_c	3.500	‰
Height of Triangular Concrete Compression Zone Area	h_T	0.017	m
Height of Rectangular Concrete Compression Zone Area	h_R	0.030	m
Width of Concrete Compression Zone Area	w	0.437	m
Area of Concrete Compression Zone	A	168.857	cm²
Design Value of Concrete Compression Force	F_{cd}	334.90	kN
Characteristic Value of Steel Yield Strength	f_{yk}	500000.000	kN/m²
Steel Partial Safety Factor	γ_s	1.150	
Steel Modulus of Elasticity	E_s	2.00000E+08	kN/m²
Strain of Horizontal Bucket Wall Reinforcement	ε_{zu}	8.990	‰
Total Reinforcement Area	prov A_s	7.697	cm²
Reinforcement Area of all-round outside Links	prov $A_{s,li}$	4.618	cm²
Reinforcement Area of Outside Links in y-Direction	prov $A_{s,LhY}$	3.079	cm²
Minimum Strain of Horizontal Bucket Wall Reinforcement	min ε_{zu}	2.000	‰
Existing Steel Stress	σ_s	434783.000	kN/m²
Lever Arm of Internal Forces	z	0.182	m

Figure 8.31: Moment capacity $M_{Rd,y}$

The following two sketches illustrate the parameters of the moment capacity M_{Rd}.

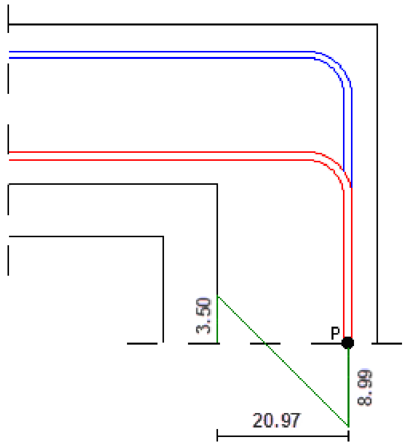


Figure 8.32: State of strain when internal forces are balanced

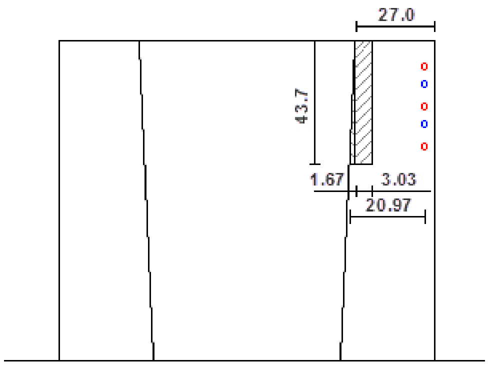


Figure 8.33: Shape of compression zone (section through bucket wall with view in the y-direction)

If the moment capacity M_{Rd} = 61.01 kNm is divided by the previously determined design moment M_{Ed}=53.92 kNm, we get the safety against bending failure that is available with the selected reinforcement.

⊞ Design Value of Acting Bending Moment	$M_{Ed,y}$	53.92	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,y}$	61.01	kNm
⊟ Verification			
Provided Safety Against Bending Failure	prov γ	1.131	
Required Safety Against Bending Failure	req γ	1.00	
Design Criterion	Criterion	0.884	

Figure 8.34: Determination of safety against bending failure

The provided safety against bending failure can be further increased if the number of the links outside in the y-direction is increased from 2 to 3 links which are structurally possible. The internal moment M_{Rd} and the provided safety against bending failure are the following after performing the recalculation:

⊞ Design Value of Acting Bending Moment	$M_{Ed,y}$	53.92	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,y}$	71.64	kNm
⊟ Verification			
Provided Safety Against Bending Failure	prov γ	1.329	
Required Safety Against Bending Failure	req γ	1.00	
Design Criterion	Criterion	0.753	

Figure 8.35: Safety against bending failure after changed reinforcement

8.1.7 Concrete Stresses in Bucket Walls

The design of concrete stresses in the bucket walls is performed by a comparison of the stresses $\sigma_{c,top}$ with the design value of the concrete compression strength f_{cd} for the concrete of the foundation. The design is carried out according to [1] 10.9.6.

The following figures illustrate the correlations.

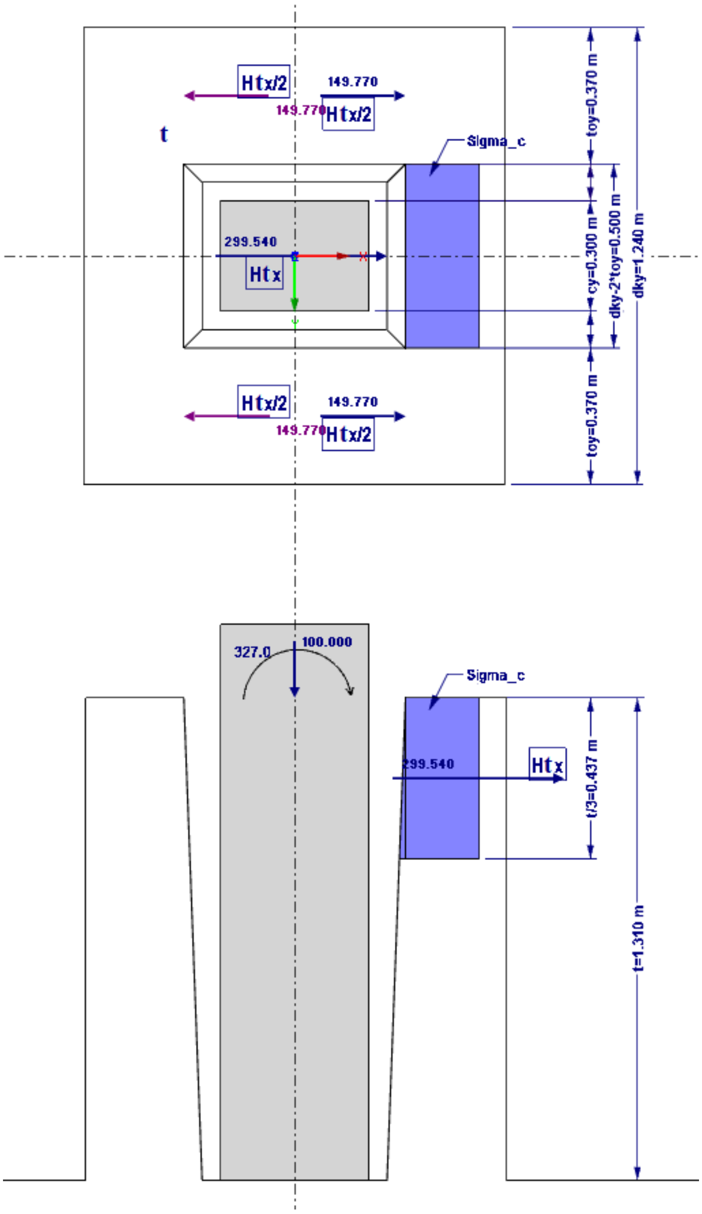


Figure 8.36: Impact of horizontal forces on bucket walls

$$\sigma_{c,t,x} = \frac{H_{t,x}}{\frac{t}{3}\cdot\left(d_{ky} - 2\cdot t_{ty}\right)} = \frac{299.54}{\frac{1.31}{3}\cdot(1.24 - 2\cdot 0.37)} = 1371.9\text{ kPa}$$

$$\left|\sigma_{c,t,x}\right| \leq \left|f_{cd}\right|$$

$$1371.9\text{ kPa} \leq 19833.3\text{ kPa}$$

$$\text{Criterion:}\quad \frac{1371.9}{19833.3} = 0.069 < 1$$

8.1.8 Lap Length of Bucket Reinforcement

In particular cases, the governing bucket height can be determined by the lap length design according to [1] 8.7.3. Here, this design is performed by using the governing load in the x-direction from LC 2.

Distance of column longitudinal reinforcement:

$$z_x = MIN[0.9 \cdot (c_x - d_c); c_x - 2 \cdot d_c] = MIN[0.9 \cdot (400 - 50); 400 - 2 \cdot 50] = 300mm$$

Moment:

$$M_{ED,x} = |My| + P_z \cdot \left(\frac{c_x}{2} - d_c\right) = 327 + 100 \cdot \left(\frac{0.4}{2} - 0.05\right) = 342 \text{ kNm}$$

Column tension force:

$$F_{t,x} = \frac{M_{ED,x}}{z_x} - P_z = \frac{342}{0.3} - 100 = 1040 \text{ kN}$$

Column compression force:

$$F_{p,x} = -\left(\frac{M_{ED,x}}{z_x}\right) = -\left(\frac{342}{0.3}\right) = -1140 \text{ kN}$$

$$F_x = MAX(F_{t,x}; F_{p,x}) = MAX(1040; -1140) = 1040 \text{ kN}$$

Design value of concrete tension strength:

$$f_{ctd} = \alpha_{ct} \cdot f_{ctk0,05} \cdot \frac{1}{\chi_c} = 1 \cdot 2200 \cdot \frac{1}{1.5} = 1466.7 \text{ kPa}$$

Design value of ultimate bond stress according to [1] 8.4.2:

$$f_{bd} = 2.25 \cdot \eta_1 \cdot \eta_2 \cdot f_{ctd} = 2.25 \cdot 1 \cdot 1 \cdot 1466.7 = 3300 \text{ kPa}$$

where

$\eta_1 = 1.0$	quality of bond conditions and position of bars during concreting - "good" bond conditions
$\eta_2 = 1.0$	factor for taking account of bar diameter – Ø ≤ 32 mm

Column tension force in reinforcement L_{Vx}:

$$F_{s,x} = F_x \cdot \frac{z_x}{z_x + d_c + a_{tx} + \frac{t_{tx}}{2}} = 1040 \cdot \frac{0.3}{0.3 + 0.05 + 0.1 + \frac{0.27}{2}} = 533.33 \text{ kN}$$

Available steel stress:

$$\sigma_x = \frac{F_{s,x}}{A_{sx}} = \frac{533.33}{0.001219} = 437.54 \text{ MPa}$$

The required basic value of the anchorage length $l_{b,rqd}$ used to anchor the force $A_s \cdot \sigma_{sd}$ of a straight member, under the assumption of a constant bond stress f_{bd}, results from:

$$l_{b,rqd,x} = \frac{\phi_x}{4} \cdot \frac{\sigma_x}{f_{bd}} = \frac{0.012}{4} \cdot \frac{43754}{3300} = 0.398 \text{ m}$$

Minimum lap length:

$$l_{0,min,x} = MAX(0.3 \cdot \alpha_{6,x} \cdot l_{b,rqd,x}; 15 \cdot \phi_x; 0.2) = MAX(0.3 \cdot 1.5 \cdot 0.398; 15 \cdot 0.012; 0.2) = 0.20\ m$$

Lap length:

$$l_{0,x} = \alpha_1 \cdot \alpha_6 \cdot l_{b,rqd,x} = 1.0 \cdot 1.5 \cdot 0.398 = 0.597\ m$$

where

$\alpha_1 = 1.0$

$\alpha_6 = 1.5$ (percentage of lapped bars relative to total area of reinforcing steel > 50%)

Design of lap length:

$$l_{0,x} \geq l_{0,min,x}$$

$$0.597\ m \geq 0.20\ m$$

Required embedment depth in the x-direction:

$$t_{min,x} = c_k + \frac{t_{tx}}{2} + l_{0,x} + \frac{\phi_x}{2} + a_{tx} + 2 \cdot d_c = 0.07 + \frac{0.27}{2} + 0.597 + \frac{0.012}{2} + 0.1 + 2 \cdot 0.05 = 1.008\ m$$

8.1.9 Soil-Mechanical Designs

For the soil-mechanical designs we determine the resulting loads in the soil joint, which is the transition zone between the ground and the concrete below the foundation, without support forces.

First, the volume of the bucket is calculated.

$$V_{bucket} = (c_x + 2 \cdot (t_{tx} + a_{tx})) \cdot (c_y + 2 \cdot (t_{ty} + a_{ty})) \cdot h$$
$$= (0.40 + 2 \cdot (0.27 + 0.10)) \cdot (0.30 + 2 \cdot (0.37 + 0.10)) \cdot 1.31 = 1.8518\ m^3$$

Now, the bucket's self-weight can be determined.

$$G_{cal,d} = 25 \cdot 1.8518 = 46.30\ kN$$

Then, the weight of the earth covering, which is on the contact area of the bucket, must be calculated.

$$G_{cov,d} = \left(x \cdot y - (c_x + 2 \cdot (t_{tx} + a_{tx})) \cdot (c_y + 2 \cdot (t_{ty} + a_{ty}))\right) \cdot c \cdot \gamma$$
$$= \left(3.3 \cdot 2.6 - (0.40 + 2 \cdot (0.27 + 0.10)) \cdot (0.30 + 2 \cdot (0.37 + 0.10))\right) \cdot 1.0 \cdot 20 = 143.33\ kN$$

In this context, we want to clarify how the resultant of an additional load that is uniformly distributed is determined: You specify the start and end of the uniformly distributed load. Then, RF-FOUNDATION Pro determines the part of the load lying on the foundation plate when the dimensioning is done. The following sketch demonstrates this principle.

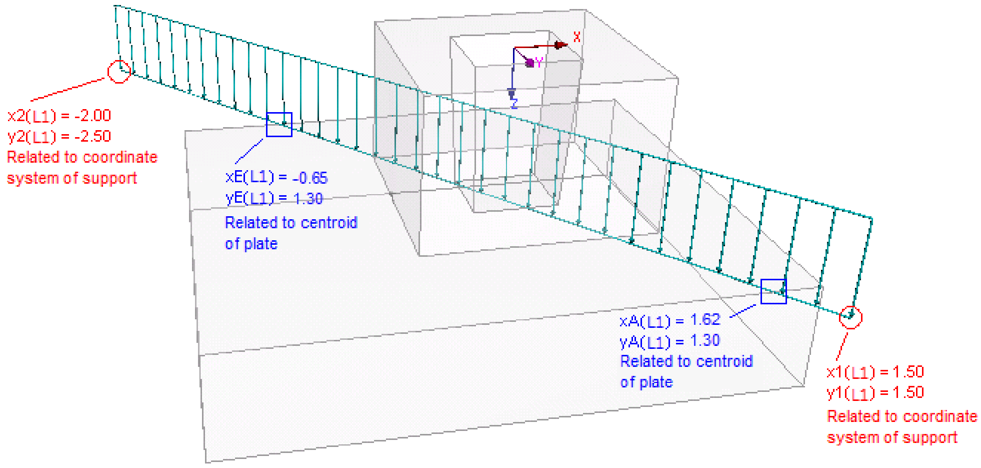


Figure 8.37: Uniformly distributed load across foundation plate

The uniformly distributed load cuts the edges of the foundation plate, stressing only a part of the foundation. The length of this load component can be calculated by means of the coordinates of the start and end point. Then, the value is multiplied by the distributed load per meter (10 kN/m). Thus, the resultant force of 34.55 kN is the result.

The design details of RF-FOUNDATION Pro are shown below.

⊟ 1. Line Load	$M_{x,L1,d}$	-22.74	kNm
Partial Factor for Permanent, Unfavorable Actions	$\gamma_{G,sup}$	1.350	
Resulting Load from the Line Load Component on the Foundation P	$G_{L1,k}$	34.55	kN
Line Load per Meter	l_1	10.00	kN/m
⊟ Line Cuts the Plate			
⊟ Start of Line Load			
Coordinate x (rel. to Support Node)	x_1 (L1)	1.500	m
Coordinate y (rel. to Support Node)	y_1 (L1)	1.500	m
⊟ End of Line Load			
Coordinate x (rel. to Support Node)	x_2 (L1)	-2.000	m
Coordinate y (rel. to Support Node)	y_2 (L1)	-2.500	m
⊟ Start of the Line Load Component on the Foundation Plate			
Coordinate x (rel. to Plate Centroid)	x_A(L1)	-0.650	m
Coordinate y (rel. to Plate Centroid)	y_A(L1)	-1.300	m
⊟ End of the Line Load Component on the Foundation Plate			
Coordinate x (rel. to Plate Centroid)	x_E(L1)	1.625	m
Coordinate y (rel. to Plate Centroid)	y_E(L1)	1.300	m
⊟ Center of gravity of the line load component on the foundation plate			
Coordinate x (rel. to Plate Centroid)	x_S(L1)	0.488	m
Coordinate y (rel. to Plate Centroid)	y_S(L1)	0.000	m

Figure 8.38: Details - determination of resultant force of an additional uniformly distributed load

In the details, the loads are summarized as follows:

⊞ Design Value of Self-Weight of Foundation Plate	$G_{p,d}$	77.22	kN
⊞ Design Value of Self-Weight of Bucket	$G_{cal,d}$	46.30	kN
⊞ Design Value of Earth Covering	$G_{cov,d}$	143.33	kN
⊞ Design Value of Additional Single Loads	$P_{N,d}$	17.00	kN
⊞ Design Value of Additional Line Loads	$P_{L,d}$	34.55	kN

Figure 8.39: Details - resulting loads in soil joint from permanently acting loads

After those preliminary calculations, it is possible to perform the soil-mechanical designs.

8.1.9.1 Proof of Safety for Uplift Limit State

There are no lifting column axial forces available. Therefore, the design according to [2] 2.4.7.4 is not carried out.

8.1.9.2 Proof of Safety for Ground Failure

The load combination CO3 is governing for ground failure analysis according to [2] 6.5.2. The resulting vertical force in the soil joint is determined from the column axial force and the already determined permanent loads with:

$$V`_d = 929.83 \text{ kN}$$

The resulting moment in the soil joint for the reinforcement running in the x-direction is determined from the loads represented in Figure 8.40.

$$\begin{aligned} \text{res } M_{x,d} &= M_{Y,d} - P_{X,d} \cdot (d+h) - \Sigma P_{N,d} \cdot x_N - \Sigma P_{L,d} \cdot x_L - ex \cdot (P_{Z,d} + G_{cal,d} - \Delta G_{cov,d} - R_p) \\ &= -150.00 - 0.00 \cdot (0.36 + 1.31) - 17 \cdot 1.35 \cdot (-0.2) - 34.55 \cdot 1.35 \cdot 0.488 \\ &\quad - 0.30 \cdot (500 + 46.30 \cdot 1.35 - 28.272 \cdot 1.35) \\ &= -325.45 \text{ kNm} \end{aligned}$$

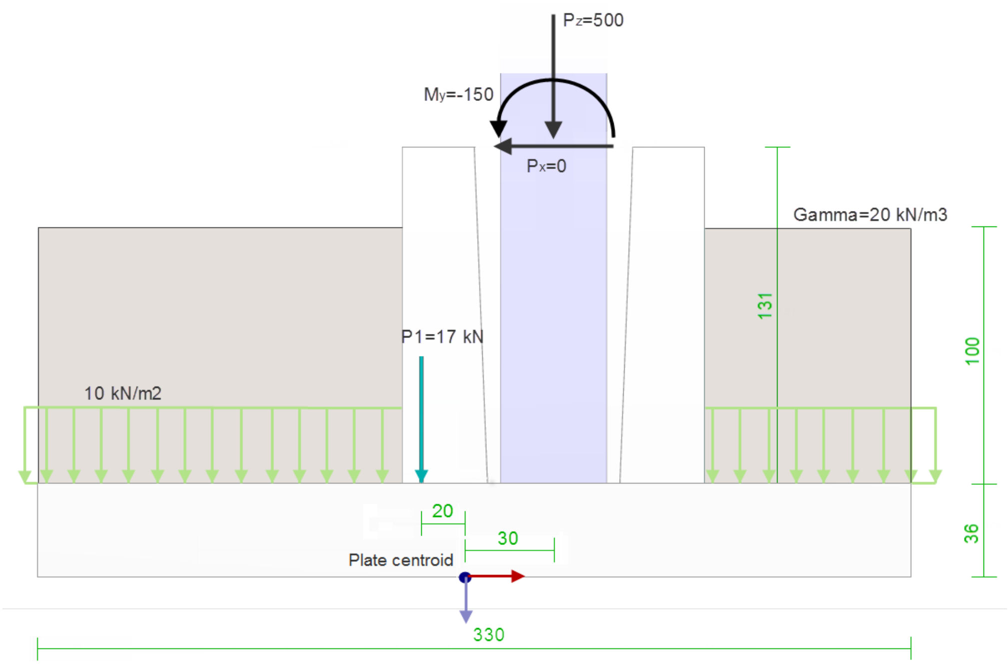


Figure 8.40: Loads and resulting moment in soil joint

The moment in the soil joint for the reinforcement in the y-direction is calculated as follows:

$$\begin{aligned} \text{res } M_{y,d} &= M_y + P_{Y,d} \cdot (d+h) - \Sigma P_{N,d} \cdot y_N - \Sigma P_{L,d} \cdot y_L - e_y \cdot (P_{Z,d} + G_{cal,d} - \Delta G_{cov,d} - R_p) \\ &= 150.00 + 17 \cdot 1.35 \cdot 0.5 + 34.55 \cdot 1.35 \cdot 0 = 161.48 \text{ kNm} \end{aligned}$$

Based on both moments in the soil joint, it is possible to determine the eccentricity of the resulting vertical force in the respective directions.

$$e_x = -\frac{\text{res } M_{x,d}}{V_d} = -\frac{-325.45}{929.83} = 35.0 \text{ cm}$$

$$e_y = \frac{\text{res } M_{y,d}}{V_d} = \frac{161.48}{929.83} = 17.37 \text{ cm}$$

The eccentricities are used to calculate the effective foundation side lengths.

$$L`=x-2\cdot|e_x|=3.3-2\cdot|0.35|=2.60\ \text{m}$$

$$B`=y-2\cdot|e_y|=2.6-2\cdot|0.174|=2.252\ \text{m}$$

This results in an effective foundation area A_{eff} of:

$$A`=L`\cdot B`=2.60\cdot 2.253=5.857\ \text{m}^2$$

Now, we can determine the provided soil contact pressure.

$$\sigma_{prov}=\frac{V`_d}{A`}=\frac{929.83}{5.857}=158.8\ \text{kN/m}^2$$

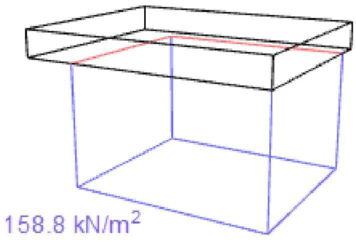


Figure 8.41: Provided soil stress

The design of the allowable soil stress is fulfilled:

$$\sigma_{Rd}=\frac{\sigma_{Rk}}{\gamma_{R,v}`}=\frac{280}{1.4}=200.0\ \text{kN/m}^2$$

$$\sigma_{prov}\leq\sigma_{Rd}$$

$$158.8\,\text{kN/m}^2\leq 200.0\,\text{kN/m}^2$$

Thus we obtain the following design criterion:

Criterion: $\frac{\sigma_{prov}}{\sigma_{Rd}}=\frac{158.8}{200.0}=0.794<1$

8.1.9.3 Proof of Safety for Loads with Large Eccentricities

The load case LC5 is governing for the design according to [2] 6.5.4. The resulting vertical force in the soil joint is determined from the column axial force in connection with the already determined permanent loads as follows:

$$\text{res } V_k = 393.39 \text{ kN}$$

Thus, the resulting moment in the soil joint for the reinforcement running in the x-direction results from the following loading:

$$\begin{aligned} \text{res } M_{x,k} &= M_y - P_x \cdot (d+h) - \Sigma P_{N,d} \cdot x_N - \Sigma P_{L,d} \cdot x_S - e_x \cdot (P_z + G_{cal,d} - \Delta G_{cov,d} - R_p) \\ &= 235.00 - 17 \cdot (-0.2) - 34.55 \cdot 0.4875 - 0.30 \cdot (75 + 46.30 - 28.27) \\ &= 193.65 \text{ kNm} \end{aligned}$$

The moment in the soil joint for the reinforcement in the y-direction is calculated as follows:

$$\begin{aligned} \text{res } M_{y,k} &= M_x + P_y \cdot (d+h) + \Sigma P_{N,d} \cdot y_N + \Sigma P_{L,d} \cdot y_S + e_y \cdot (P_z + G_{cal,d} - G_{cov,d} - R_p) = 17 \cdot 0.5 \\ &= 8.50 \text{ kNm} \end{aligned}$$

The eccentricities of the resulting vertical force in the respective directions are:

$$e`_x = \frac{\text{res } M_{x,k}}{\text{res } V_k} = -\frac{193.65}{393.39} = 0.492 \text{ m}$$

$$e`_y = \frac{\text{res } M_{y,k}}{\text{res } V_k} = \frac{8.50}{393.39} = 0.022 \text{ m}$$

The maximum eccentricity must not exceed:

$$e_{all} = \frac{1}{3} \cdot B = \frac{1}{3} \cdot 330 \text{ cm} = 110 \text{ cm}$$

The following figure shows the position of the resulting vertical force in the soil joint:

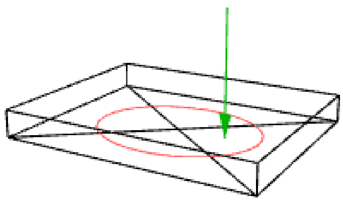


Figure 8.42: Position of resultant

The design for the loads with large eccentricities is fulfilled:

$$e`_x \le e_{all}$$

$$0.492 \le 1.1$$

Thus we obtain the following design criterion:

Criterion: $\frac{e`_x}{e_{all}} = \frac{0.492}{1.1} = 0.447$

8.1.9.4 Proof of Safety for Sliding

The load case LC1 is governing for the sliding design according to [2] 6.5.3. The shear force, which is governing for the design under undrained subsoil conditions, is:

$$H_{x,d} = 50\text{ kN}$$

The soil resistance is determined as follows:

$$R_s = A`\cdot c_{u,d} = 5.51\cdot 10 = 55.1\text{kN}$$

Thus, we obtain the following design criterion for the governing x-direction.

$$\text{Criterion:}\qquad \frac{H_{x,d}}{R_{x,d}} = \frac{50.0}{\frac{55.1}{1.1}} = 0.998$$

8.1.9.5 Proof of Equilibrium Limit State

The load case LC2 is governing for the equilibrium limit state design according to [2] 2.4.7.2.

The resulting moments on the four edges of the soil joint are determined from the column axial force together with the already determined permanent loads. Here, it is necessary to consider the effect which comes from the moments:

- Destabilizing effect
- Stabilizing effect

In load case 2, only the following moment is acting in a **destabilizing** way on edge 3:

$$M_{dst,3} = M_{y,d} = 327.00\text{kN}$$

The moments acting in a **stabilizing** way are reduced by partial safety factors.

Moment from RFEM:

$$M_{x,RSTAB,d} = P_{z,d}\cdot\left(\frac{x}{2}+e_x\right) = 100\cdot(1.65+0.3) = 195.0\text{kN}$$

Moment from plate weight:

$$M_{x,p,d} = G_{p,d}\cdot\frac{x}{2}\cdot\gamma_{G,stb} = (3.3\cdot 2.6\cdot 0.36\cdot 25)\cdot 1.65\cdot 0.9 = 114.67\text{kN}$$

Moment from bucket self-weight:

$$M_{x,cal,d} = (G_{cal,d}\cdot(x/2+e_x))\cdot\gamma_{G,stb} = (1.14\cdot 1.24\cdot 1.31\cdot 25\cdot(1.65+0.3))\cdot 0.9 = 81.25\text{kN}$$

Moment from cover:

$$\begin{aligned} M_{x,cov,d} &= (x\cdot y\cdot c\cdot\gamma_{c,k}\cdot x/2) - (d_{kx}\cdot d_{kz}\cdot c\cdot\gamma_{c,k}\cdot(x/2+e_x))\cdot\gamma_{G,stb} \\ &= ((3.3\cdot 2.6\cdot 1\cdot 20\cdot 1.65) - (1.14\cdot 1.24\cdot 1\cdot 20\cdot(1.65+0.3)))\cdot 0.9 = 205.21\text{kN} \end{aligned}$$

Design value of moment from additional single loads:

$$M_{x,N,d} = (G_{Z,1}\cdot(x/2+(x_{N1}+e_x)))\cdot\gamma_{G,stb} = (17\cdot(1.65+(-0.5+0.3)))\cdot 0.9 = 22.185\text{kN}$$

Design value of moment from additional line loads:

$$M_{x,L,d} = (G_{L,1}\cdot(x/2+x_{S(L1)}))\cdot\gamma_{G,stb} = (34.55\cdot(1.65+0.4875))\cdot 0.9 = 66.46\text{kN}$$

Stabilizing moment acting on edge 3:

$$M_{stb,3} = M_{x,RSTAB,d} + M_{x,p,d} + M_{x,cal,d} + M_{x,cov,d} + M_{x,N,d} + M_{x,L,d}$$
$$= 195.0 + 114.67 + 81.25 + 205.21 + 22.185 + 66.46$$
$$= 684.78 \text{ kNm}$$

Thus we obtain the following design criterion:

$$\text{Criterion}_3 = \frac{M_{dst,3}}{M_{stb,3}} = \frac{327.0}{684.78} = 0.478$$

8.1.10 Design of Internal Stability

8.1.10.1 Safety Against Bending Failure of Foundation Plate

The foundation plate has top and bottom reinforcement for each direction. So, four different safeties against bending failure must be designed.

Safety against bending failure from bottom reinforcement in x-direction

First, it is necessary to determine the design moments for the bending design of the foundation plate from the governing soil contact pressure. The load case LC1 is governing for the bottom reinforcement in the x-direction.

The resulting vertical force in the soil joint is determined from the column axial force in connection with the already determined permanent loads as follows:

$$\text{res } V_{max} = 729.83 \text{ kN}$$

Thus, the resulting moment in the soil joint for the reinforcement running in the x-direction results from the following loading:

$$\text{res } M_{x,d} = M_y - P_x \cdot (d+h) - \Sigma P_{N,d} \cdot x_N - \Sigma P_L \cdot x_S - e_x \cdot (P_z + G_{cal,d} - \Delta G_{cov,d} - R_p)$$
$$= 250.00 - (-50.00) \cdot (0.36 + 1.31) - 17 \cdot 1.35 \cdot (-0.2) - 34.55 \cdot 1.35 \cdot 0.4875$$
$$- 0.30 \cdot (300 + 46.30 \cdot 1.35 - 28.27 \cdot 1.35) = 218.05 \text{ kNm}$$

The moment in the soil joint for the reinforcement in the y-direction is calculated as follows:

$$\text{res } M_{y,d} = M_x + P_y \cdot (d+h) + \Sigma P_{N,d} \cdot y_N + \Sigma P_L \cdot y_S + e_y \cdot (P_z + G_{cal,d} - \Delta G_{cov,d} - R_p)$$
$$= 100 + 20.00 \cdot (0.36 + 1.31) + 17 \cdot 1.35 \cdot 0.5 = 144.88 \text{ kNm}$$

The eccentricities of the resulting vertical force in the respective directions are:

$$e_x = -\frac{\text{res } M_{x,d}}{\text{res } V_{max}} = -\frac{218.05}{729.83} = -29.88 \text{ cm}$$

$$e_y = \frac{\text{res } M_{y,d}}{\text{res } V_{max}} = \frac{144.88}{729.83} = 19.85 \text{ cm}$$

Iteratively, the following distribution of compression stress is the result. The value and position of the resultant corresponds to the resulting vertical force in the soil joint.

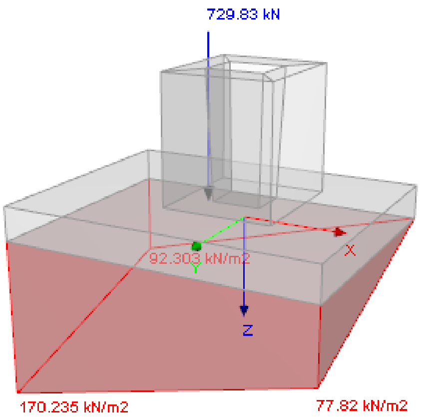


Figure 8.43: Distribution of compressive stress

⊟ Distribution of Compressive Stress			
Case of Stress Distribution acc. Manual	Case	Case 1	
Compressive Stress at Corner Node CI	CI	0.000	kN/m²
Compressive Stress at Corner Node CII	CII	77.820	kN/m²
Compressive Stress at Corner Node CIII	CIII	170.235	kN/m²
Compressive Stress at Corner Node CIV	CIV	92.303	kN/m²
Compressive Stress Beneath Center of Foundation Plate	D0	85.062	kN/m²
⊟ Distribution of Gaping Joint			
x-Coordinate Start Point	x_{C1}	1.646	m
y-Coordinate Start Point	y_{C1}	-1.300	m
x-Coordinate Start Point	x_{C2}	1.650	m
y-Coordinate Start Point	y_{C2}	-1.296	m

Figure 8.44: Distribution of compressive stress displayed in table

Now, the volume of the partial compressive stress object and its distance to the center of gravity is determined by the user-defined design section. The product of both values provides the moment due to the compression stress.

The figure below illustrates the design section indicated by arrows showing in the direction of the partial compressive stress object by which the moment due compression stress has been determined. The moment $M_{C,x,plus}$ = 121.90 kNm in the positive x-direction results from this compressive stress block.

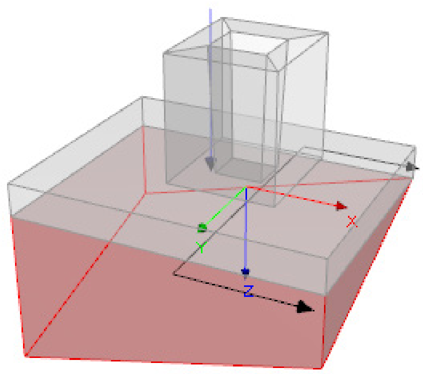


Figure 8.45: Moment from compressive stress block in the positive x-direction

Figure 8.46 shows the design section for the moment from compressive stress in the negative x-direction, providing the moment $M_{C,x,minus}$ = 558.74 kNm.

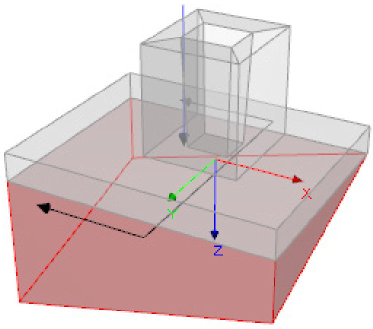


Figure 8.46: Moment from compressive stress block in the negative x-direction

In the *Details* dialog box, the design section was placed into the **column center** according to the specification on page 70.

Next, we have to subtract the component causing no bending of the plate from both moments. It is composed of the foundation plate's self-weight and the earth covering (see the following figures).

In Figure 8.47, the distance from the design section to the plate edge in the x-direction is 1.35 m. Thus, the moment from self-weight and earth covering is calculated with:

$$M_{A,x,plus} = \frac{1.35^2}{2} \cdot 2.6 \cdot \gamma_G \cdot (d \cdot \gamma_{concrete} + cov \cdot \gamma_{cov}) = \frac{1.35^2}{2} \cdot 2.6 \cdot 1.35 \cdot (0.36 \cdot 25 + 1 \cdot 20) = 92.76\ \text{kNm}$$

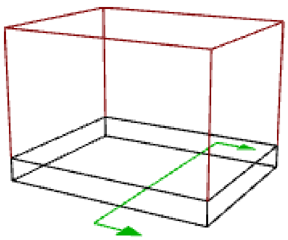


Figure 8.47: Moment from area load in the positive x-direction

In Figure 8.48, the distance from the design section to the negative plate edge in the x-direction is 1.95 m. Thus, the self-weight and the earth covering are calculated with:

$$M_{A,x,minus} = \frac{1.95^2}{2} \cdot 2.6 \cdot \gamma_G \cdot (d \cdot \gamma_{concrete} + cov \cdot \gamma_{cov}) = \frac{1.95^2}{2} \cdot 2.6 \cdot 1.35 \cdot (0.36 \cdot 25 + 1 \cdot 20) = 193.53\ \text{kNm}$$

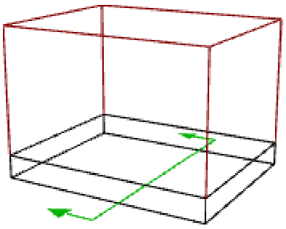


Figure 8.48: Moment from area load in the negative x-direction

Consequently, the following design moments are available in the respective section directions:

$$M_{bottom,x,plus} = M_{C,xplus} + M_{G,xplus} = 121.90 - 92.76 = 29.14 \text{ kNm}$$

$$M_{bottom,x,minus} = M_{C,xminus} + M_{G,xminus} = 558.74 - 193.53 = 365.21 \text{ kNm}$$

This is the direction where the plate gets tension on the bottom side. Thus, a bottom bending reinforcement is required. The design moment in the positive x-direction is governing for the design of a bottom bending reinforcement.

$$M_{x,b} = M_{bottom,x,minus} = 365.21 \text{ kNm}$$

Now, the foundation plate is subdivided into eight strips of the same width in the x-direction. Using the following quotient, we find out how large is the proportion of the design moment that is allocated to each plate strip.

$$Q_x = \frac{c_x + 2 \cdot (a_{tx} + t_{tx})}{x} = \frac{0.40 + 2 \cdot (0.10 + 0.27)}{3.3} = 0.35$$

As the quotient is larger than 0.3, the design moment is uniformly distributed to all eight plate strips. Thus, the distribution factor α is 0.125.

The proportional design moment for the plate strip No. 4 is:

$$M_{Ed,x,4} = \alpha \cdot M_{x,b} = 0.125 \cdot 365.21 = 45.65 \text{ kNm}$$

RF-FOUNDATION Pro uses the following parameters to determine the moment capacity M_{Rd}:

⊞ Design Value of Acting Bending Moment	$M_{Ed,x,4}$	45.65	kNm
⊟ Design Value of Moment Capacity	$M_{Rd,x,4}$	49.87	kNm
⊟ Design Value of Concrete Compression Force	$F_{cd,4}$	151.49	kN
⊟ Concrete Design Value	f_{cd}	19833.3	kN/m²
Characteristic Cylinder Compressive Strength	f_{ck}	35000.0	kN/m²
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Concrete Partial Safety Factor	γ_c	1.500	
⊟ Height of Compression Zone	x_4	0.040	m
Concrete Strain	$\varepsilon_{c,4}$	3.500	‰
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Width of Foundation Plate Strip	y_{strip}	0.412	m
⊟ Design Value of Reinforcement Tension Force	$F_{Sd,4}$	193.50	kN
⊟ Provided Reinforcement	prov $A_{x,4}$	3.34	cm²
Width of Foundation Plate Strip	y_{strip}	0.325	m
Provided x Reinforcement per Meter	prov a_x	10.27	cm²/m
⊟ Provided Steel Stress	$\sigma_{s,4}$	452142.	kN/m²
Provided Steel Strain	$\varepsilon_{s,4}$	20.401	‰
Characteristic Value of Steel Yield Strength	f_{yk}	500000.	kN/m²
Characteristic Value of Steel Tensile Strength for the Design	$f_{tk,cal}$	525000.	kN/m²
Steel Partial Safety Factor	γ_s	1.150	
Steel Modulus of Elasticity	E_s	2.00000	kN/m²
⊟ Lever of Internal Forces	z_4	0.258	m
⊟ Effective Depth	d_4	0.273	m
Distance of Reinforcement Centroid from Bottom Plate Edge	$d_{iz,4}$	0.087	m
Distance of Reinforcement Centroid from Bottom Reinforcement Edg	$d_{icent,4}$	0.017	m
Nominal Value of Concrete Cover Bottom	nom c_b	0.070	m
Main Reinforcement Direction of Bottom Reinforcement	Main Reinf.	X	
Existing Safety Against Bending Failure	$\gamma_{x,4}$	1.065	

Figure 8.49: Details - parameters for determination of moment capacity

The required steel of this plate strip is determined based on the required reinforcement tension force and the provided steel stress for the given state of strain.

$$\text{req}A_{x,4} = \frac{F_{sd}}{\sigma_s} = \frac{193.50}{45.214} = 4.280 \text{ cm}^2$$

Now, the amount of steel is related to one meter of standard length.

$$\text{req}\,a_{X,4} = \frac{\text{req}\,A_{X,4}}{y_{\text{strip}}} = \frac{4.280}{0.325} = 13.17 \text{ cm}^2/\text{m}$$

This required reinforcement can be covered most efficiently by using bars of ø 10 mm placed in a distance of 80 mm and a mesh reinforcement of Q 335A.

Details on the Selected Reinforcement			
Required Reinforcement per Meter	req $a_{x,I}$ (per m)	13.161	cm²/m
Provided Reinforcement per Meter	prov $a_{x,I}$ (per m)	13.167	cm²/m
Defined Width of Reinforcement Area I	y_I (defined)	2.600	m
Designed Width of Reinforcement Area I	y_I (designed)	2.240	m
Selected Basic Mat	Description	Q 335A	
Provided Mat Reinforcement	prov $a_{x,Mat}$	3.350	cm²/m
Selected Reinforcement Bar	d_s	10	mm
Rebar Spacing	s	80	cm
Reinforcement Area of Rebars	prov a (Bar)	9.817	cm²/m

Figure 8.50: Details - reinforcement specifications for bottom zone in the x-direction

In module window 2.4, the reinforcement is changed manually to bars of ø 16 mm with a spacing of 200 mm:

Details on the Selected Reinforcement			
Required Reinforcement per Meter	req $a_{x,I}$ (per m)	13.161	cm²/m
Provided Reinforcement per Meter	prov $a_{x,I}$ (per m)	13.403	cm²/m
Defined Width of Reinforcement Area I	y_I (defined)	2.600	m
Designed Width of Reinforcement Area I	y_I (designed)	2.400	m
Selected Basic Mat	Description	Q 335A	
Provided Mat Reinforcement	prov $a_{x,Mat}$	3.350	cm²/m
Selected Reinforcement Bar	d_s	16	mm
Rebar Spacing	s	200	cm
Reinforcement Area of Rebars	prov a (Bar)	10.053	cm²/m

Figure 8.51: Details - changed reinforcement specifications for bottom zone in the x-direction

In addition to the mat Q 335A, the rendering represents these rebars inserted in the x- and y-direction as follows:

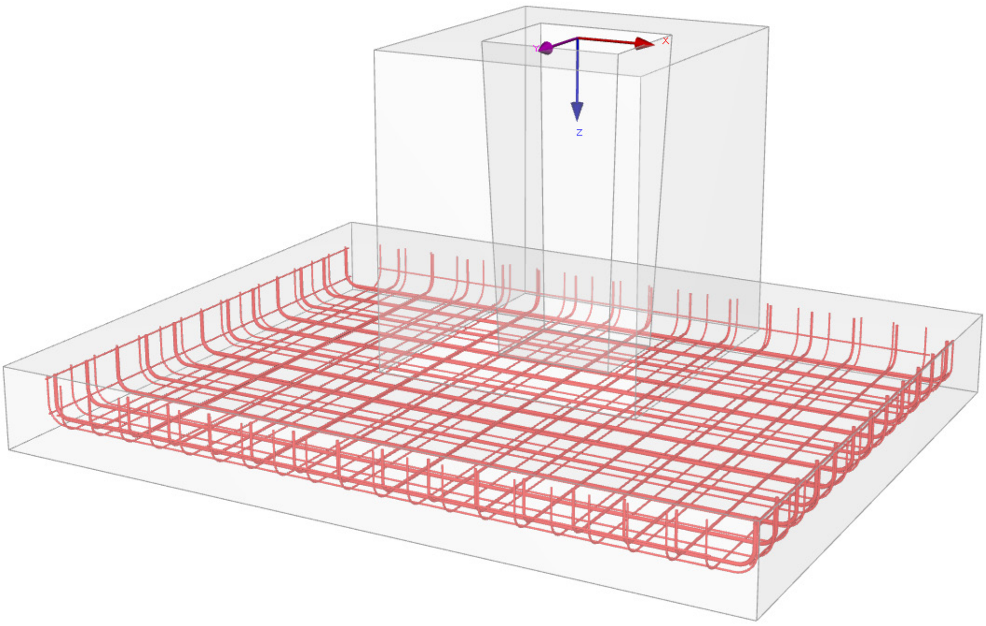


Figure 8.52: Rendering of bottom reinforcement

As the quantity and the position of the inserted reinforcement area is known, the moment capacity M_{Rd} is again determined. The result is the following:

Bending failure of the plate (EC 2, 6.1) ¦ Node 1 ¦ LC1			
⊟ Design Value of Moment Capacity	$M_{Rd,x,4}$	50.19	kNm
⊟ Design Value of Concrete Compression Force	$F_{cd,4}$	196.71	kN
⊟ Concrete Design Value	f_{cd}	19833.3	kN/m²
Characteristic Cylinder Compressive Strength	f_{ck}	35000.0	kN/m²
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Concrete Partial Safety Factor	γ_c	1.500	
⊟ Height of Compression Zone	x_4	0.041	m
Concrete Strain	$\varepsilon_{c,4}$	3.500	‰
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Width of Foundation Plate Strip	y_{strip}	0.325	m
⊞ Design Value of Reinforcement Tension Force	$F_{Sd,4}$	196.71	kN
⊟ Lever of Internal Forces	z_4	0.255	m
⊟ Effective Depth	d_4	0.271	m
Distance of Reinforcement Centroid from Bottom Plate Edge	$d_{iz,4}$	0.089	m
Distance of Reinforcement Centroid from Bottom Reinforcement Edg	$d_{i\,cent,4}$	0.019	m
Nominal Value of Concrete Cover Bottom	nom c_b	0.070	m
Main Reinforcement Direction of Bottom Reinforcement	Main Reinf.	X	
Existing Safety Against Bending Failure	$\gamma_{x,4}$	1.100	
⊟ Verification			
Governing Safety Against Bending Failure	$\gamma_{x,4}$	1.100	
Required Safety Against Bending Failure	req γ	1.00	
Design Criterion	Criterion	0.909	

Figure 8.53: Details - parameters for determination of moment capacity

With the changed reinforcement we get the following existing safety against bending failure:

$$\text{exis}\ \gamma_{x,4} = \frac{M_{Rd,x,4}}{M_{Ed,x,4}} = \frac{50.19}{45.65} = 1.10$$

Thus, the design criterion for the design of the plate's safety against bending failure for the bottom reinforcement in the x-direction is the following:

$$\text{Criterion:} \quad \frac{\text{req}\ \gamma}{\text{exis}\ \gamma_{x,4}} = \frac{1.0}{1.10} = 0.909$$

Safety against bending failure from bottom reinforcement in y-direction

The calculation steps are the same as for designing the safety against bending failure from the bottom reinforcement in the x-direction.

The most efficient reinforcement proposal includes the mesh reinforcement Q 335A and rebars of ø 12 mm with a spacing of 220 mm. This rebar spacing is changed to 200 mm in module window 2.4. So, we get the following design result:

⊟ Bottom Reinforcement in y-Direction	Criterion	0.809	
⊞ Design Value of Support Forces and Moments			
⊞ Design Moment in y-Direction	$M_{y,b}$	273.76	kNm
⊟ Safety Against Bending Failure of Design Strip	Criterion	0.809	
⊞ Design Value of Acting Bending Moment	$M_{Ed,y,4}$	34.22	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,y,4}$	42.28	kNm
⊟ Verification			
Governing Safety Against Bending Failure	$\gamma_{y,4}$	1.236	
Required Safety Against Bending Failure	req γ	1.00	
Design Criterion	Criterion	0.809	

Figure 8.54: Details - safety against bending failure from bottom reinforcement in the y-direction

Safety against bending failure from top reinforcement in x-direction

The design is carried out as already described above. A particular case, however, is the determination of the design moment. In the governing load case LC2, the following compressive stress block from the maximum moment is formed below the plate:

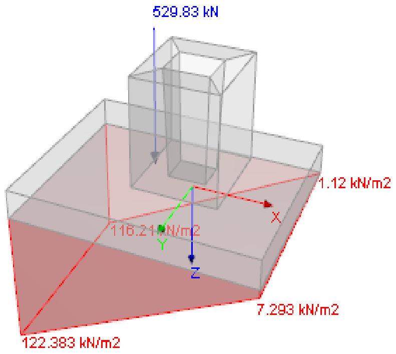


Figure 8.55: Distribution of compressive stress

The moment from the compressive stress block part in the positive x-direction is $M_{C,x,plus} = 35.48$ kNm. The moment from the area load in the positive x-direction is $M_{A,x,plus} = -92.76$ kNm.

Furthermore, we have to consider the resultant of the additional single or line loads running across the plate. This resultant force lies beyond the design section in the positive x-direction.

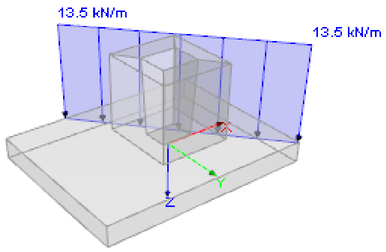


Figure 8.56: Additional uniformly distributed loads

So, we get a top bending moment of $M_{Z,x,plus} = -7.98$ kNm from the additional loading.

The design moment for the top reinforcement in the x-direction is determined from the sum of these moments:

$$M_{x,t} = M_{C,x,plus} + M_{A,x,plus} + M_{Z,x,plus} = 35.48 - 92.76 - 7.98 = -65.26\,\text{kNm}$$

For the top reinforcement the design moment is uniformly distributed to the eight design strips. Thus, the following reinforcement is the result:

⊟ Design Strip			
⊟ Design Value of Acting Bending Moment	$M_{Ed,x}$	-8.16	kNm
Design Moment in x-Direction	$M_{x,t}$	-65.26	kNm
Distribution Number of this Design Strip	α_y	0.125	
⊞ Design Value of Moment Capacity	$M_{Rd,x}$	-8.17	kNm
⊟ Verification			
⊞ Required Reinforcement	req A_x,	0.705	cm^2
⊞ Provided Reinforcement	prov A_x	0.835	cm^2
Design Criterion	Criterion	0.843	
⊟ Details on the Selected Reinforcement			
Required Reinforcement per Meter	req a_x (per m)	2.168	cm^2/m
Provided Reinforcement per Meter	prov a_x (per m)	2.570	cm^2/m
Defined Width of Reinforcement Area	y_l (defined)	2.600	m
Designed Width of Reinforcement Area	y_l (designed)	2.500	m
Selected Basic Mat	Description	Q 257A	
Provided Mat Reinforcement	prov $a_{x,Mat}$	2.570	cm^2/m
Selected Reinforcement Bar	d_s	0	mm
Rebar Spacing	s	0	cm
Reinforcement Area of Rebars	prov a (Bar)	0.000	cm^2/m

Figure 8.57: Details – top reinforcement in the x-direction

On the basis of this reinforcement, the design of the safety against bending failure is performed.

⊟ Safety against bending failure of design strip			
⊞ Design Value of Acting Bending Moment	$M_{Ed,x}$	-8.16	kNm
⊞ Design Value of Moment Capacity	$M_{Rd,x}$	-10.66	kNm
⊟ Verification			
Provided Safety Against Bending Failure	prov γ	1.307	
Required Safety Against Bending Failure	req γ	1.00	
Design Criterion	Criterion	0.765	

Figure 8.58: Details - safety against bending failure from top reinforcement in the x-direction

Safety against bending failure from top reinforcement in y-direction

The safety against bending failure in the y-direction is determined in the same way. However, as there is no bending moment available, reinforcement is not required.

8.1.10.2 Punching Resistance of Foundation Plate

For the punching shear design according to [1] 6.4 it is necessary to determine the shear force transferring area, first.

The expected distance from the bucket edge to the perimeter was user-defined with the value $l_{w,def} = 1.0 \cdot d = 26$ cm for the determination of the foundation's minimum dimensions. In addition, the iterative calculation of the critical perimeter was set. The factor used to consider the favorably acting soil stresses within the perimeter is set with $k_{red} = 1.00$. This means that 100 % of the soil stresses within the perimeter have been considered as favorably acting for the determination of the resulting applied shear force $V_{Ed,red}$.

All three load cases lead to similar design criteria. Two different types of verification are relevant:

- Double-sided edge column: shear force design for LC2
- Interior column: punching shear design for LC1 and LC3

In order to analyze the results in the results windows of the add-on module separately for the different types of verification, you can use the result filter mentioned in Chapter 4.2. For example, if LC2 is selected, the design is displayed as *Double-sided edge column*, even if the design criterion is not governing for this design.

Double-sided edge column: shear force design for LC2

In the course of the iterative calculation, the distance from the column edge to the perimeter is determined with $l_{w,crit} = 68.40$ cm.

On both sides, the perimeter lies outside of the foundation edge in the y-direction. Therefore, the design is carried out as a shear force design.

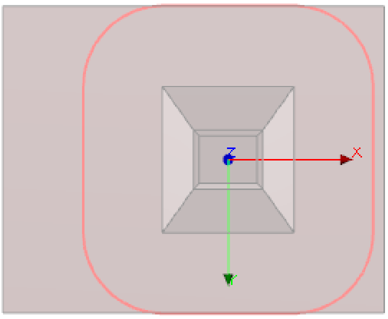
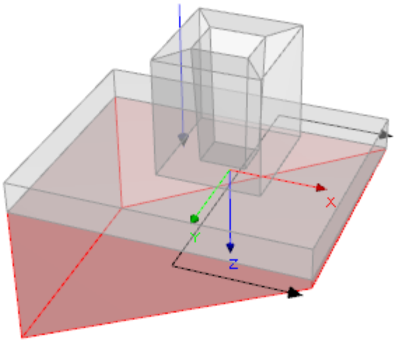


Figure 8.59: Critical perimeter for double-sided edge column – shear force design

The shear force V_{Ed} to be transferred is calculated as the difference between the shear force due to compressive stress and the shear force due to surface load.



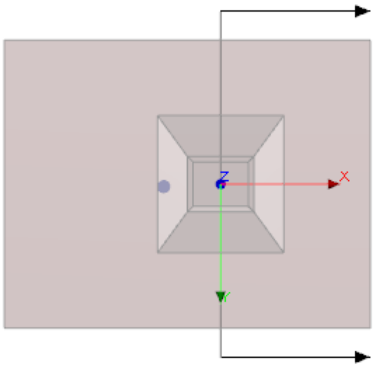


Figure 8.60: Compressive stress block and position of design section

The shear force to be transferred in the negative x-direction is:

$$V_{Ed,x,n} = V_{D,x,n} - V_{G,x,n} = 432.43 - 274.16 = 158.27 \text{ kN}$$

For the allowable shear stress it is first necessary to determine the mean surface reinforcement of the bottom plate reinforcement from both directions. The longitudinal reinforcement ratio is calculated with:

$$\rho_l = \frac{A_{sl}}{d \cdot b_w} = \frac{34.848 \text{ cm}^2}{26 \text{ cm} \cdot 260 \text{ cm}} = 0.515\%$$

The longitudinal reinforcement ratio was calculated with the reinforcement Q355 + ø16-20 for the bottom reinforcement in the x-direction defined in the previous paragraph.

This ratio of longitudinal reinforcement must be less than 2 %.

The safety factor $C_{Rd,c}$ is calculated according to the following formula:

$$C_{Rd,c} = \frac{0.18}{\gamma_c} = \frac{0.18}{1.5} = 0.12$$

The scaling factor of the static depth is:

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{260}} = 1.877$$

The following applies to the design value of the shear force resistance:

$$V_{Rd,c} = \left(C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}} + k_1 \cdot \sigma_{cd} \right) \cdot b_w \cdot d \geq V_{Rd,c,min}$$

$$V_{Rd,c} = \left(0.12 \cdot 1.877 \cdot (100 \cdot 0.0052 \cdot 35)^{\frac{1}{3}} + 0.15 \cdot 0 \right) \cdot 2.6 \cdot 0.26 = 0.3994 \text{ MN}$$

[1] specifies a minimum shear force resistance v_{min} which may lead to larger load bearing capacities in case of minor reinforcement ratios in connection with very high concrete strengths. It is determined as follows:

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{ck}^{\frac{1}{2}} = 0.035 \cdot 1.877^{\frac{3}{2}} \cdot 35^{\frac{1}{2}} = 0.5325\,\text{MPa}$$

$$V_{Rd,c,min} = \left(\nu_{min} + k_1 \cdot \sigma_{cp}\right) \cdot b_w \cdot d = (532.5 + 0.15 \cdot 0) \cdot 2.6 \cdot 0.26 = 359.97\,\text{kN}$$

Thus, the design value of the shear force resistance is larger than the minimum load bearing capacity:

$$V_{Rd,c} = 399.4\text{ kN} > V_{Rd,c,min} = 359.97\text{ kN}$$

So, the criterion for the shear force design from the maximum vertical force is fulfilled:

$$\text{Criterion} = \frac{V_{Ed,x,p}}{V_{Rd,c}} = \frac{158.27}{399.4} = 0.396 \leq 1$$

Interior column: punching shear design for LC1

In the course of the iterative calculation, the distance from the column edge to the perimeter is determined with $l_{w,crit}$ = 49.0 cm. Therefore, the design is carried out as a punching shear design.

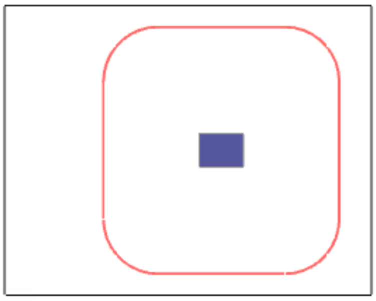


Figure 8.61: Critical perimeter for interior column – punching shear design

As the complete bucket is effective for a bucket foundation with rough bucket sides, the bucket's external dimensions are relevant for the circumference of the governing perimeter.

$$u_{it} = 2 \cdot \left(d_{kx} + d_{ky}\right) + 2 \cdot \pi \cdot l_{w,crit} = 2 \cdot (1.14 + 1.24) + 2 \cdot 3.1416 \cdot 0.49 = 7.839\ \text{m}$$

Factor β:

$$\beta = 1 + \sqrt{\left(k_x \frac{M_{Ed,x,sl}}{V_{Ed}} \cdot \frac{u_{it}}{W_{1,x}}\right)^2 + \left(k_y \frac{M_{Ed,y,sl}}{V_{Ed}} \cdot \frac{u_{it}}{W_{1,y}}\right)^2}$$

$$= 1 + \sqrt{\left(0.576 \frac{218.05}{226.06} \cdot \frac{7.839}{5.994}\right)^2 + \left(0.609 \frac{144.88}{226.06} \cdot \frac{7.839}{6.169}\right)^2} = 1.879$$

The shear force to be transferred from the maximum vertical force is calculated with:

$$v_{Ed} = \beta \cdot \frac{V_{Ed}}{u_i \cdot d} = 1.879 \cdot \frac{226.06}{7.839 \cdot 0.245} = 221.2\,\text{kPa}$$

The following value is applied as the mean longitudinal reinforcement ratio:

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} = \sqrt{0.516 \cdot 0.392} = 0.450$$

The scaling factor of the effective depth is:

$$k = 1 + \sqrt{\frac{200}{d}} = 1 + \sqrt{\frac{200}{245}} = 1.904$$

The punching resistance without punching reinforcement is calculated as follows:

- Basic punching shear resistance according to (6.50):

$$v_{Rd,c,calc,1} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{\frac{1}{3}} \cdot \frac{2 \cdot d}{l_{w,crit}} =$$

$$0.120 \cdot 1.904 \cdot (100 \cdot 0.00449 \cdot 35)^{\frac{1}{3}} \cdot \frac{2 \cdot 0.245}{0.490} = 572.3\,\text{kPa}$$

- Minimum punching shear resistance according to [1] formula (6.50):

$$v_{Rd,c,calc,2} = v_{min} \cdot \frac{2 \cdot d}{l_{w,crit}} = 0.5438 \cdot \frac{2 \cdot 0.245}{0.49} = 543.8\,\text{kPa}$$

where

$$v_{min} = 0.035 \cdot k^{\frac{3}{2}} \cdot f_{ck}^{\frac{1}{2}} = 0.035 \cdot 1.904^{\frac{3}{2}} \cdot 35^{\frac{1}{2}} = 0.5438\,\text{MPa}$$

Thus, the punching shear resistance is the following:

$$v_{Rd,c} = MAX(v_{Rd,c,calc,1}; v_{Rd,c,calc,2}) = MAX(572.3; 543.8) = 572.3\,\text{kPa}$$

So, the design for safety against punching is fulfilled.

$$\text{Criterion} = \frac{v_{Ed}}{v_{Rd,c}} = \frac{221.2}{572.3} = 0.387 \leq 1$$

8.2 Block Foundation

At last, we design a block foundation with rough bucket sides. The loading as well as the geotechnical position are the same as for the bucket foundation described in the previous example.

In this example, we do without the load determination and the geotechnical designs. Instead, it is described how RF-FOUNDATION Pro calculates the bucket reinforcement of the block foundation.

8.2.1 Dimensions of Foundation

Module window 2.1 *Geometry* manages the dimensions of the column, the foundation plate and the bucket.

2.1 Geometry

Description	Symbol	Value	Unit	Message
⊟ Column				
Dimension in x-Direction	c_x	0.400	m	
Dimension in y-Direction	c_y	0.300	m	
⊟ Eccentricity				
Eccentricity in x-Direction	e_x	-0.300	m	
Eccentricity in y-Direction	e_y	0.000	m	
⊟ Foundation Plate				
Dimension in x-Direction	x	2.950	m	
Dimension in y-Direction	y	2.700	m	
Plate Thickness	t	0.840	m	
⊟ Bucket				
Bucket Height	h	0.600	m	
Column Embedment Depth	d	0.600	m	
⊟ Dimension in x-Direction				
Column Allowance Top	a_{tx}	0.100	m	
Column Allowance Bottom	a_{bx}	0.050	m	
Bucket Inclination Inside	α_x	85.24	°	
⊟ Dimension in y-Direction				
Column Allowance Top	a_{ty}	0.100	m	
Column Allowance Bottom	a_{by}	0.050	m	
Bucket Inclination Inside	α_y	85.24	°	
⊟ Earth Covering				
Height of Earth Covering	c	1.000	m	

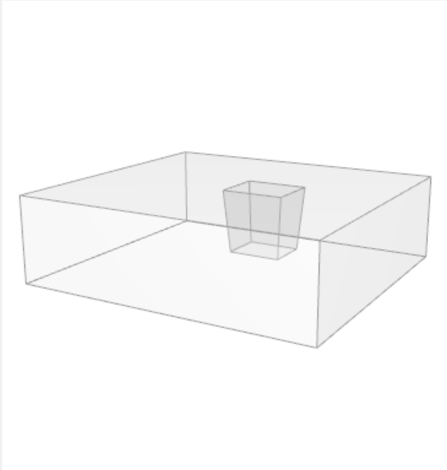


Figure 8.62: Dimensions of block foundation

8.2.2 Reinforcement in Block Foundation

8.2.2.1 Vertical Reinforcement in x-Direction

First, the number and diameter of the vertical rebars running in the x-direction are determined. The support forces of load case LC2 are governing for the design.

The governing moment for the design is the following:

$$\text{gov}\, M_y = M_y + h \cdot P = 327.00 + 0.74 \cdot 0 = 327.00\ \text{kNm}$$

The width of an equivalent beam is:

$$b = c_y + h = 0.30 + 0.74 = 1.04\ \text{m}$$

Then, the moment capacity M_{Rd} which is larger than the ultimate moment is determined.

The following table shows the parameters of the moment determination carried out in RF-FOUNDATION Pro.

⊟ Required Reinforcement Area	req $A_{s,Lvx}$	10.42	cm^2
⊞ Design Value of Acting Bending Moment	$M_{Ed,y}$	327.00	kNm
⊟ Design Value of Moment Capacity	$M_{Rd,y}$	328.63	kNm
Effective Depth	d	0.740	m
Selected Strength Class		Concrete C3	
Concrete Design Value	f_{cd}	19833.30	kN/m^2
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Characteristic Cylinder Compressive Strength	f_{ck}	35000.00	kN/m^2
Concrete Partial Safety Factor	γ_c	1.500	
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Concrete Strain	ε_c	1.420	‰
Height of Compression Zone	x	0.044	m
Width of Concrete Compression Zone Area	w	1.040	m
Design Value of Concrete Compression Force	F_{cd}	453.06	kN
Design Value of Yield Strength	f_{yd}	434783.00	kN/m^2
Characteristic Value of Steel Yield Strength	f_{yk}	500000.00	kN/m^2
Steel Partial Safety Factor	γ_s	1.150	
Provided Steel Strain	ε_s	22.500	‰
Lever Arm of Internal Forces	z	0.725	m

Figure 8.63: Moment capacity $M_{Rd,y}$

Thus, the required reinforcement area req $A_{s,Lvx}$ is determined with:

$$\text{req } A_{s,Lvx} = \frac{F_{cd}}{f_{yd}} = \frac{453.06}{43.478} = 10.42 \text{ cm}^2$$

We select a reinforcement of 6 ø 16 mm with a spacing of 75 mm with A_s = 12.06 cm².

In the calculation details, checking the lap length of the bucket reinforcement according to [1] 8.7.3 is activated by default. **In this example, however, the check of the bucket reinforcement's lap length has been deactivated.** If this option was activated in this example (see Chapter 3.1.4, page 32), a higher percentage of reinforcement with a smaller steel diameter would be required.

8.2.2.2 Vertical Reinforcement in y-Direction

The support forces of the load case LC3 are governing for the determination of the number and diameter of the vertical rebars running in the y-direction.

The governing moment for the design is the following:

$$\text{gov } M_x = M_x + h \cdot P = 150.00 + 0.724 \cdot 0 = 150.00 \text{ kNm}$$

The width of an equivalent beam is:

$$w = c_x + h = 0.40 + 0.724 = 1.124 \text{ m}$$

The following table shows the parameters used to determine the moment capacity M_{Rd}:

⊟ Required Reinforcement Area	req $A_{s,Lvy}$	4.82	cm^2
⊞ Design Value of Acting Bending Moment	$M_{Ed,x}$	150.00	kNm
⊟ Design Value of Moment Capacity	$M_{Rd,x}$	150.44	kNm
Effective Depth	d	0.724	m
Selected Strength Class		Concrete C3	
Concrete Design Value	f_{cd}	19833.30	kN/m^2
Coefficient to Consider Long-Term Effects	α_{cc}	0.850	
Characteristic Cylinder Compressive Strength	f_{ck}	35000.00	kN/m^2
Concrete Partial Safety Factor	γ_c	1.500	
Ultimate Compressive Strain in the Concrete	ε_{cu}	3.500	‰
Concrete Strain	ε_c	0.600	‰
Height of Compression Zone	x	0.019	m
Width of Concrete Compression Zone Area	w	1.124	m
Design Value of Concrete Compression Force	F_{cd}	209.61	kN
Design Value of Yield Strength	f_{yd}	4334783.00	kN/m^2
Characteristic Value of Steel Yield Strength	f_{yk}	5600000.00	kN/m^2
Steel Partial Safety Factor	γ_s	1.150	
Provided Steel Strain	ε_s	22.500	‰
Lever Arm of Internal Forces	z	0.718	m

Figure 8.64: Moment capacity $M_{Rd,x}$

Then, the required area of reinforcement req $A_{s,Lvy}$ is determined with:

$$\text{req } A_{s,Lvy} = \frac{F_{cd}}{f_{yd}} = \frac{209.61}{43.478} = 4.82 \text{ cm}^2$$

A reinforcement of 3 ø 16 mm with a spacing of 200 mm with $A_s = 6.03$ cm² is selected.

8.2.2.3 Horizontal Reinforcement (Shear Reinforcement for Bucket)

The required steel area of the horizontal links corresponds to the larger value of the reinforcements that has been determined for both vertical directions.

We select a reinforcement with three surrounding links of ø 16 mm with a spacing of 200 mm with $A_s = 12.06$ cm².

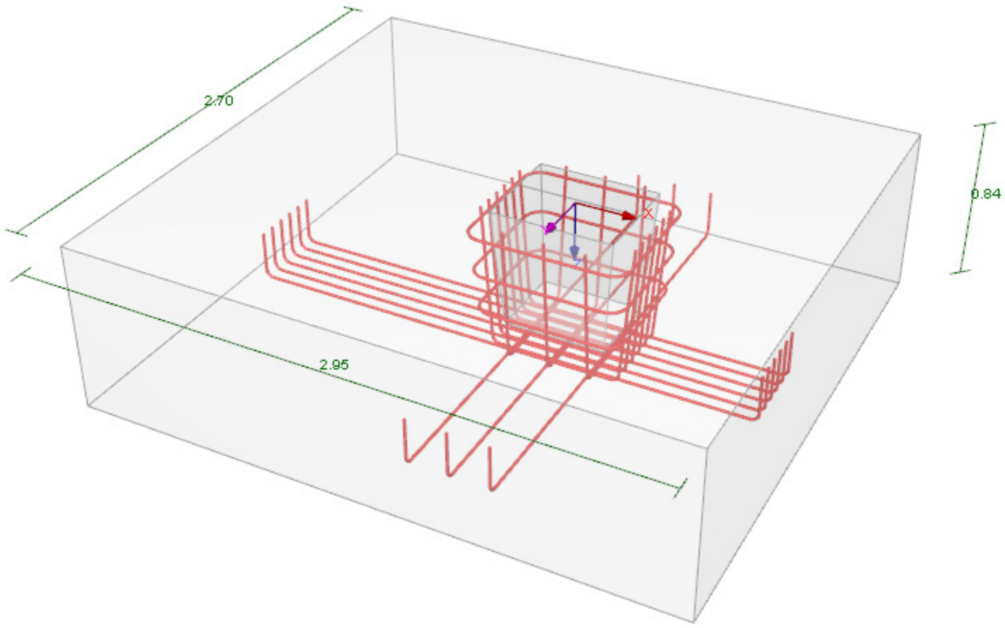


Figure 8.65: Rendering of selected reinforcement

A Literature

[1] DIN EN 1992-1-1 + AC:2010: Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken – Teil 1-1: Allgemeine Bemessungsregeln und Regeln für den Hochbau, 2005

[2] DIN EN 1997-1: Entwurf, Berechnung und Bemessung in der Geotechnik Teil1: Allgemeine Regeln, 2008

[3] DIN EN 1990: Grundlagen der Tragwerksplanung, 2010

[4] Steinle, A. Hohn, V.: Bauen mit Fertigteilen im Hochbau. Beton-Kalender 1988/2, Berlin: Ernst und Sohn.

[5] Leonhardt, F.: Vorlesungen über Massivbau, Teil Zwei: Sonderfälle der Bemessung im Stahlbetonbau. Dritte Auflage, Springer-Verlag, Berlin 1986

[6] Leonhardt, F.: Vorlesungen über Massivbau, Dritter Teil: Grundlagen zum Bewehren im Stahlbetonbau. Dritte Auflage, Springer-Verlag, Berlin, Heidelberg, New York 1983

[7] DAfStb-Heft 240: Grasser, E; Thielen, G: Hilfsmittel zur Berechnung der Schnittgrößen und Formänderungen von Stahlbetontragwerken, Ausgabe Juli 1988. 3. Auflage. Berlin, Köln: Beuth Verlag 1991

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