Dlubal

Version
April 2015

Add-on Module

RF-PUNCH

Punching Shear Design of Surfaces
According to EN 1992-1-1:2010

Program
Description

© Dlubal Software GmbH
Am Zellweg 2   D-93464 Tiefenbach

Tel.: +49 9673 9203-0
Fax: +49 9673 9203-51
E-Mail: info@dlubal.com
Web: www.dlubal.com

Contents

1. Introduction

1.1 About RF-PUNCH

The RFEM add-on Module RF-PUNCH analyzes the safety of concrete slabs against punching due to concentrated loads. You can design according to the following standards:

- EN 1992-1-1:2004/AC:2010 with National Annexes
- DIN 1045-1: 2008-08
- DIN 1045: 1988-07

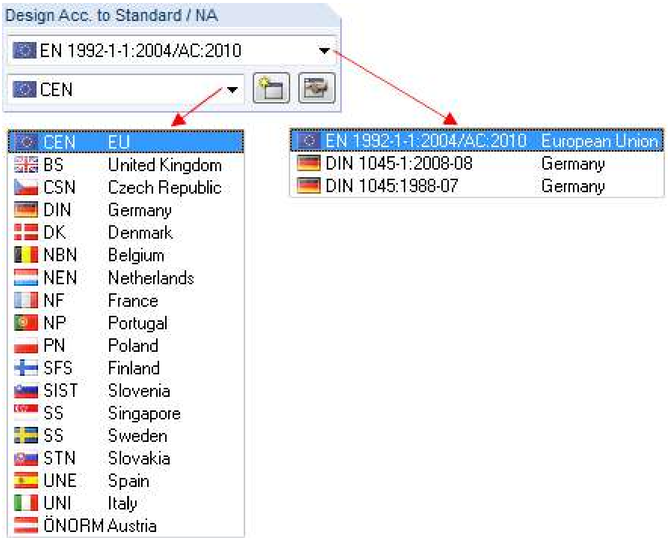


Figure 1.1: Design according to Standard / NA

The longitudinal reinforcement can be defined and checked, or else laid out by the program. The required punching reinforcement is, if necessary, determined quantitatively.

Furthermore, RF-PUNCH allows you to access the design software of the producer of shear rails DEHA/HALFEN.

We hope you enjoy working with RF-PUNCH.

Your DLUBAL Team

1.2 RF-PUNCH Team

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

Program coordination

Dipl.-Ing. Georg Dlubal
Dipl.-Ing. (FH) Alexander Meierhofer
Dipl.-Ing. (FH) Younes El Frem

Programming

Ing. Michal Balvoň
Ing. Ivana Váňová
Mgr. Jaroslav Krul
Ing. Václav Rek

Program design, dialog figures, and icons

Dipl.-Ing. Georg Dlubal
MgA. Robert Kolouch
Ing. Jan Miléř

Program development and supervision

Ing. Jan Fráňa
Dipl.-Ing. (FH) Alexander Meierhofer
Ing. Bohdan Šmid

Localization, manual

Ing. Fabio Borriello
Ing. Dmitry Bystrov
Eng. Rafael Duarte
Ing. Jana Duníková
Ing. Lara Freyer
Bc. Chelsea Jennings
Ing. Ladislav Kábrt
Ing. Aleksandra Kociołek
Ing. Roberto Lombino
Eng.º Nilton Lopes
Mgr. Ing. Hana Macková
Ing. Téc. Ind. José Martínez
Dipl.-Ing. (FH) Alexander Meierhofer
Dipl.-Ü. Gundel Pietzcker
MA Translation Anton Mitleider
Mgr. Petra Pokorná
Ing. Zoja Rendlová
Ing. Bohdan Šmíd
Ing. Marcela Svitáková
Dipl.-Ing. (FH) Robert Vogl
Ing. Marcin Wardyn

Technical support

M.Eng. Cosme Asseya
Dipl.-Ing. (BA) Markus Baumgärtel
Dipl.-Ing. Moritz Bertram
Dipl.-Ing. (FH) Steffen Clauß
Dipl.-Ing. (FH) René Flori
Dipl.-Ing. (FH) Stefan Frenzel
Dipl.-Ing. (FH) Walter Fröhlich
Dipl.-Ing. (FH) Paul Kieloch
Dipl.-Ing. (FH) Ulrich Lex
Dipl.-Ing. (BA) Sandy Matula
Dipl.-Ing. (FH) Alexander Meierhofer
M.Eng. Dipl.-Ing. (BA) Andreas Niemeier
M.Eng. Dipl.-Ing. (FH) Walter Rustler
M.Sc. Dipl.-Ing. (FH) Frank Sonntag
Dipl.-Ing. (FH) Lukas Sühnel
Dipl.-Ing. (FH) Robert Vogl

2. Theoretical Background

2.1 Determining Punching Load

With the program RF-PUNCH, you can check if a reinforced concrete slab can resist a concentrated load with or without a punching shear reinforcement. For the individual design standards, you can lay out the longitudinal and, if necessary, the punching shear reinforcement in terms of efficiency.

The following concentrated loads can be considered in the program RFEM:

- Support forces of nodal supports
- Nodal loads
- Axial forces in members connecting rectangularly to the slab

When checking the punching resistance, it is crucial to know which surface (side) of the slab is loaded and which is not. It depends on whether the reinforcement mesh of the bottom surface of the slab or of the top side of the slab is used to determine the punching shear resistance. In RFEM, the bottom surface of the slab is the one that is oriented in the direction of the positive z-axis of the local coordinate system of the slab.

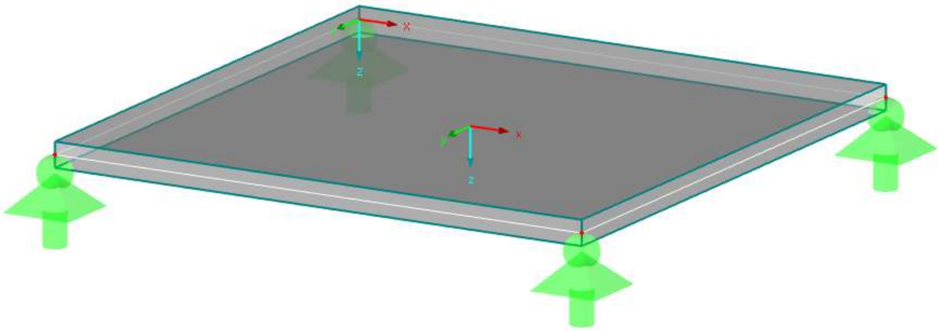


Figure 2.1: Local slab coordinate system

For the orientation of the local coordinate system of the slab shown in the figure, the following surface sides are referred to as top surface and bottom surface:

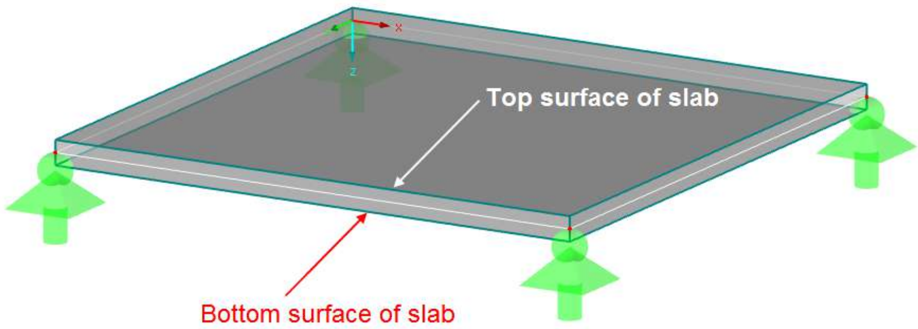


Figure 2.2: Top surface and bottom surface

In this manual, when referring to the top or bottom surface of a slab, you can always identify the relevant surface by means of the local coordinate system of the slab.

If you need to model the structural connection between a single support, a column, or a concentrated load, a common node between the concentrated load transfer and the slab is required. In this way, you can determine all locations with a concentrated load transfer by simply selecting a node.

Once the location of the concentrated load transfer is obtained, the direction and the magnitude of the load are to be determined to obtain the governing punching load. The punching load of a load case, load combination, or result combination represents the greatest concentrated load acting perpendicular to the slab surface. Here, it is important that the program searches for the greatest punching load for each surface side of the slab: It is possible that the concentrated load transfer shows changing signs of the acting load on a node. Changing signs mean that the loaded area is one time the top surface and the other the bottom surface that is subjected to a compression force. It can also mean that the load always acts on one side of a slab, but acts one time as a compression and the other as a tension force. A tension force is transferred through an according reinforcement to the other side of the slab. From there, it results in, quasi like a compression force, the formation of the "compression strut vault."

If the determination of the forces at a node gives two governing punching loads, one of which is trying to punch the slab to its bottom while the other tries to punch it to the top surface, then it is necessary to carry out two separate punching shear designs. The mutual influence of the results will be described after we introduce the designs of the respective standard. First, however, we will look into how the governing punching load for each side is determined for the different possibilities of the concentrated load transfer.

2.1.1 Punching Load From Nodal Support

There is a nodal support at a common node with the slab be supported. It is important to know that each support has its own coordinate system (X',Y',Z') whose orientation determines the magnitude and direction of the support forces.

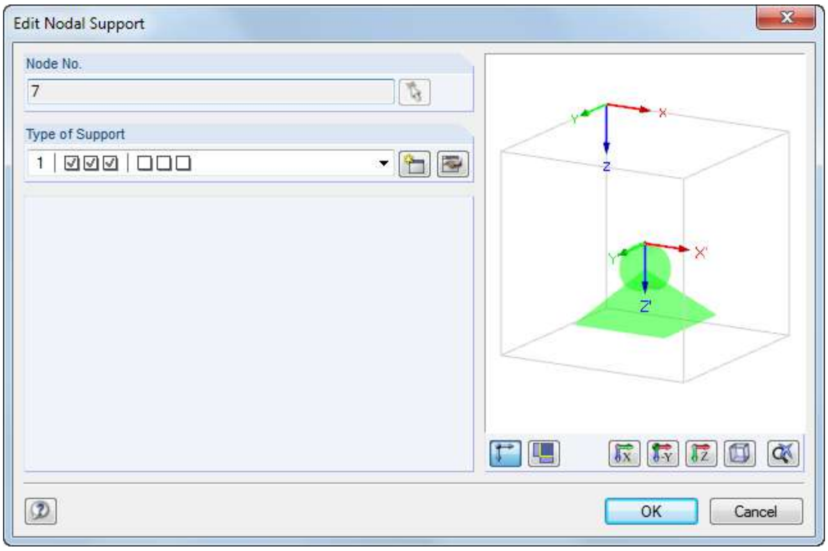


Figure 2.3: Dialog box *Edit Nodal Support*

To open the dialog box shown in the figure above, right-click a nodal support, and then select *Edit Nodal Supports* from the context menu. The graphic in the dialog box shows the global coordinate system. If you add a new nodal support, the axes of the support's coordinate system have the same orientation as the axes of the global coordinate system. You can, however, adjust the direction of the axes of the support's coordinate system. To do this, click [Edit] (see the following figure).

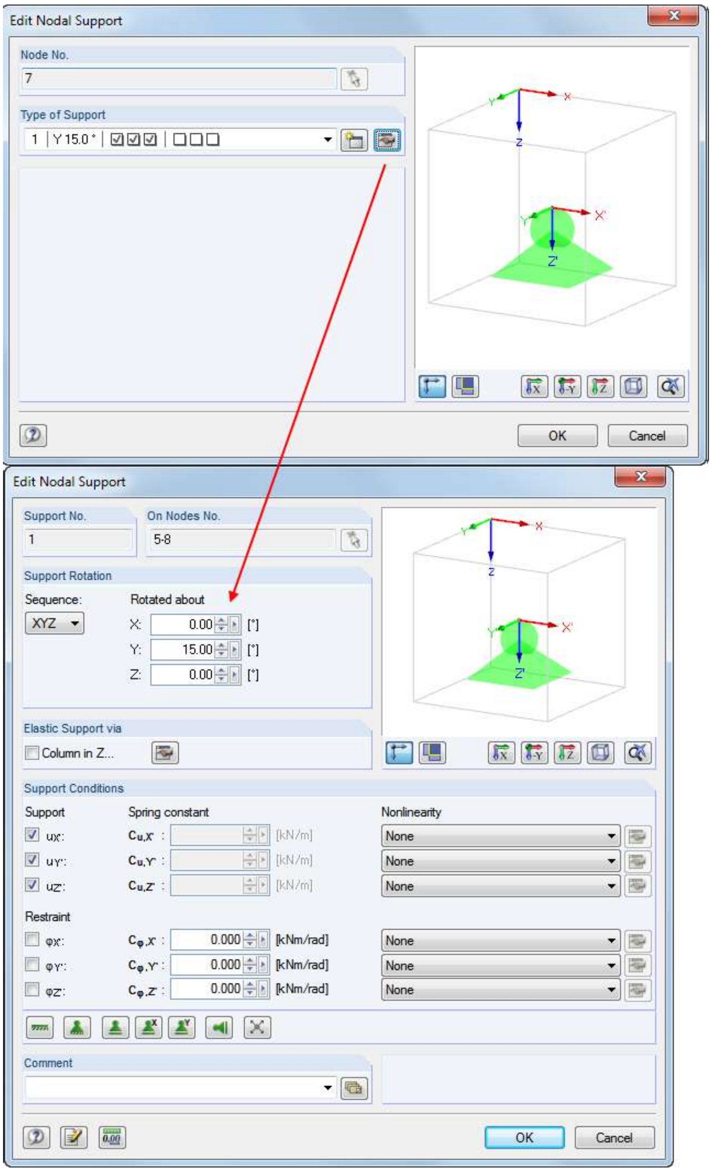


Figure 2.4: Dialog box *Edit Nodal Supports* with adjusted display of supports

If the coordinate system of the support is not rotated (if it has the same orientation as the global coordinate system), then the global support forces and the local support forces are identical.

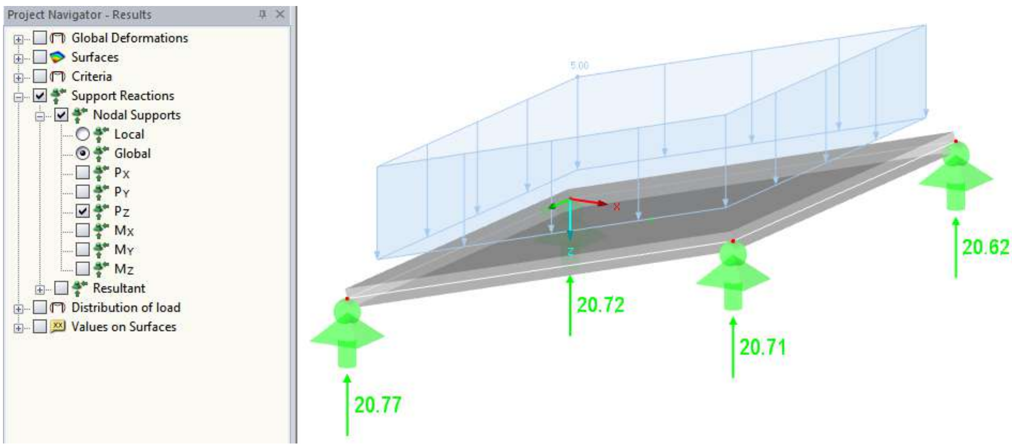


Figure 2.5: Global support forces

If, however, you rotate the support's coordinate system, the local support forces change.

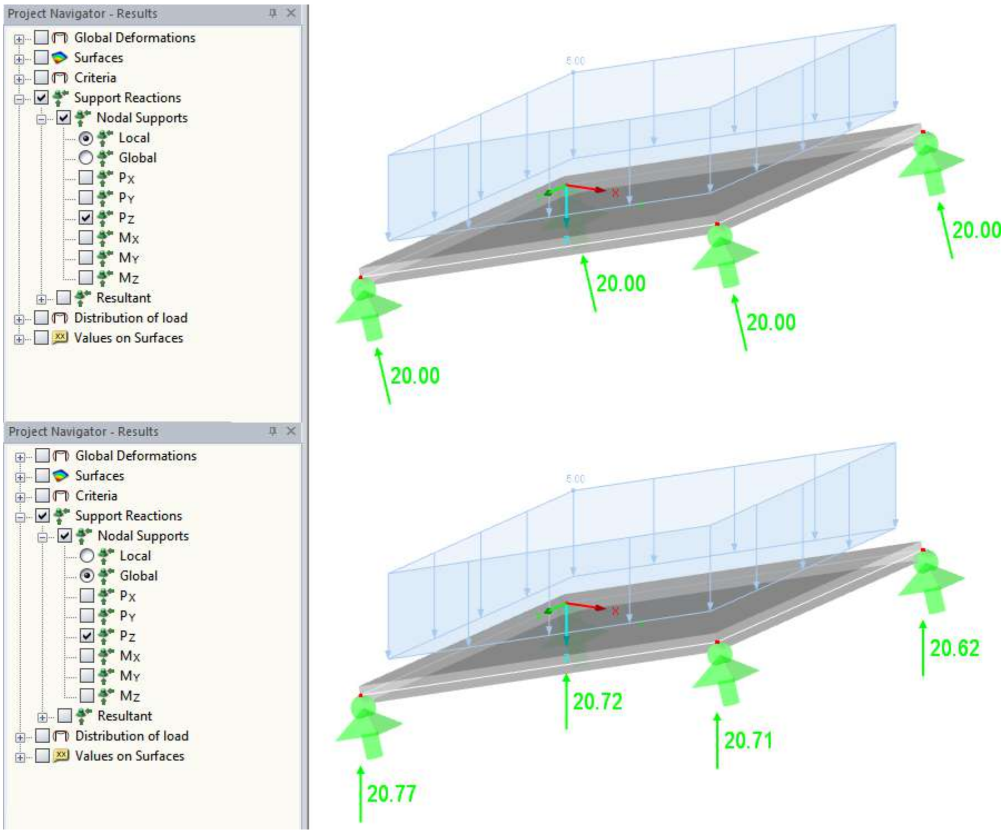


Figure 2.6: Local and global support forces in rotated coordinate system

The forces given in the 4.1 *Nodes - Support Forces* table are also controlled by the settings in the Project Navigator (*Local* or *Global*).

4.1 Nodes - Support Forces

Node No.	A Support Forces [kN] Px	B Py	C Pz	D Support Moments [kNm] Mx	E My	F Mz
5	-0.06	-3.42	20.72	0.00	0.00	0.00
6	0.33	3.11	20.62	0.00	0.00	0.00
7	-0.25	3.69	20.77	0.00	0.00	0.00
8	-0.02	-3.38	20.71	0.00	0.00	0.00
Σ Forces	0.00	0.00	82.82			
Σ Loads	0.00	0.00	82.82			

Results - Summary | Nodes - Support Forces | Nodes - Deformations | Surfaces - Local Deformations | Surfaces - Global Deformations

Figure 2.7: Table 4.1 *Nodes - Support Forces* showing the global support forces

These values represent forces that are transferred into the support. The RFEM graphic, however, shows the support reaction forces, that is, those forces that the support has to provide to resist the loading. The support forces (values in the table) have a positive sign if they are oriented as global support forces in the direction of the global coordinate system. The support reaction forces in the graphic have a positive sign; the vectors point in the direction in which the forces act.

The following two pictures show the global support forces and the support reaction forces for reversed sings of the loading.

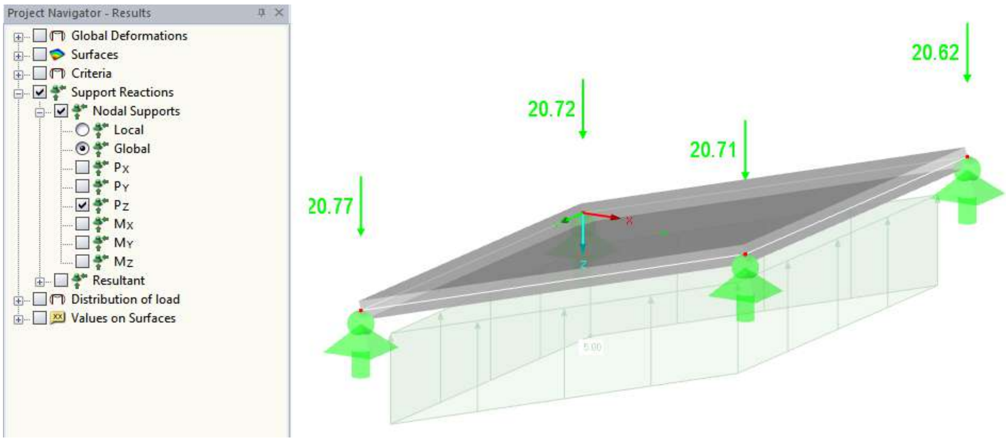
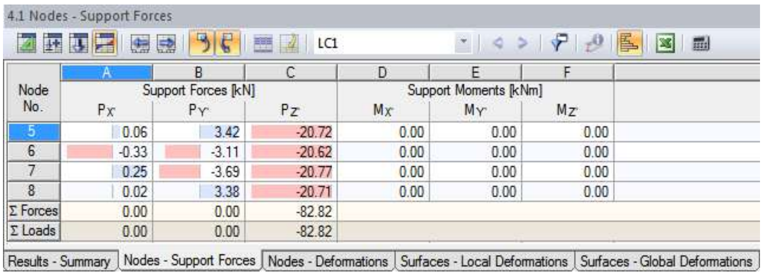


Figure 2.8: Global support reaction forces for negative loading



4.1 Nodes - Support Forces

Node No.	A Support Forces [kN] Px'	B Py'	C Pz'	D Support Moments [kNm] Mx'	E My'	F Mz'
5	0.06	3.42	-20.72	0.00	0.00	0.00
6	-0.33	-3.11	-20.62	0.00	0.00	0.00
7	0.25	-3.69	-20.77	0.00	0.00	0.00
8	0.02	3.38	-20.71	0.00	0.00	0.00
Σ Forces	0.00	0.00	-82.82			
Σ Loads	0.00	0.00	-82.82			

Results - Summary | Nodes - Support Forces | Nodes - Deformations | Surfaces - Local Deformations | Surfaces - Global Deformations

Figure 2.9: Global support forces for negative loading

Which support reaction force is now exported as load to RF-PUNCH? To answer this question, it is important to consider the orientation of the axes.

If the axes of the local coordinate system of the slab run in the <u>same</u> directions as the axes of the global coordinate system, then the exported punching load corresponds to the global support reaction force in the Z-direction of the global coordinate system.

In the following example, RF-PUNCH is subjected to a governing punching load of Q = 20.00 kN. The unloaded surface is the top surface of the slab.

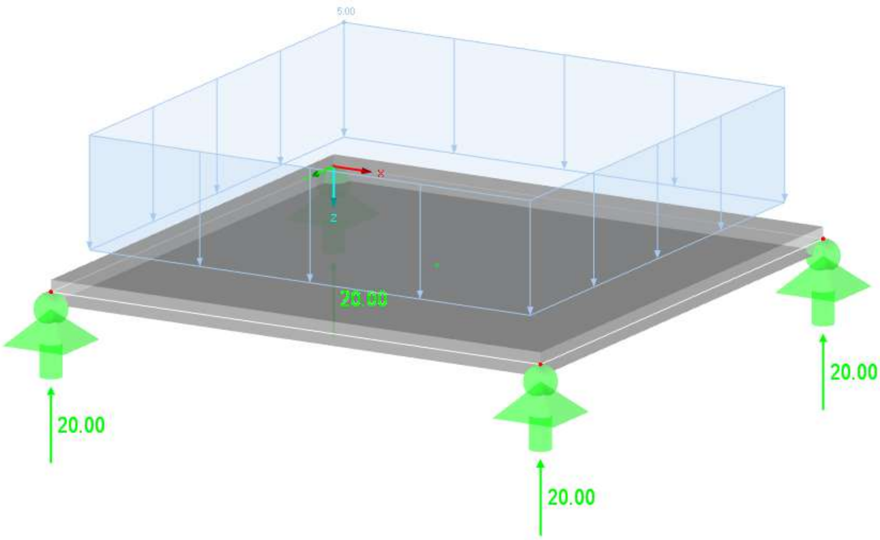


Figure 2.10: Punching load – support's coordinate system showing same orientation as global coordinate system

If the signs of the loading are opposite, a governing punching load of Q = 20.00 kN is exported to RF-PUNCH as well. The unloaded surface, however, is the bottom surface of the slab.

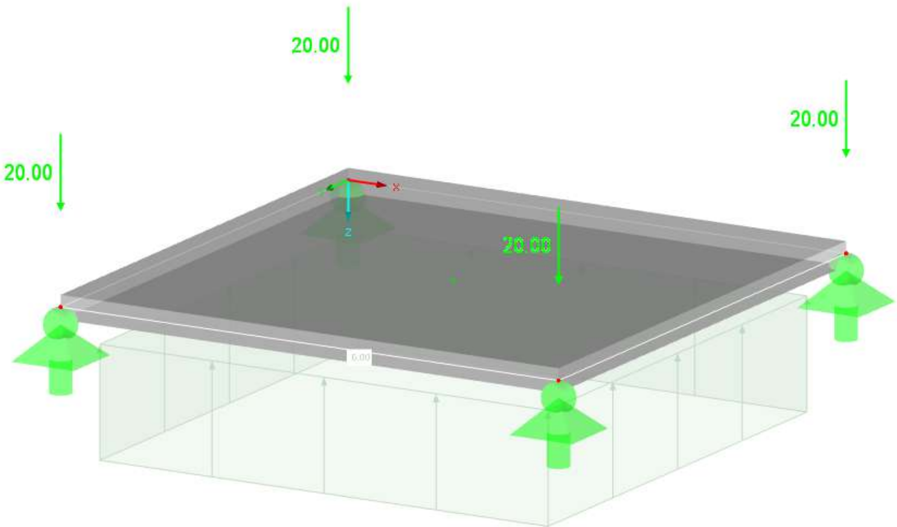


Figure 2.11: Punching load in case of negative loading

If there is no parallelism between the axes of the global coordinate system and the support coordinate system but the axes of the support coordinate system and the local slab coordinate system are parallel, then the punching load of the local support reaction force in the Z-direction of the support coordinate system is exported. In the following example, RF-PUNCH is subjected to the governing punching load Q = 20.00 kN for the right frontal support. The unloaded surface is the top surface of the slab.

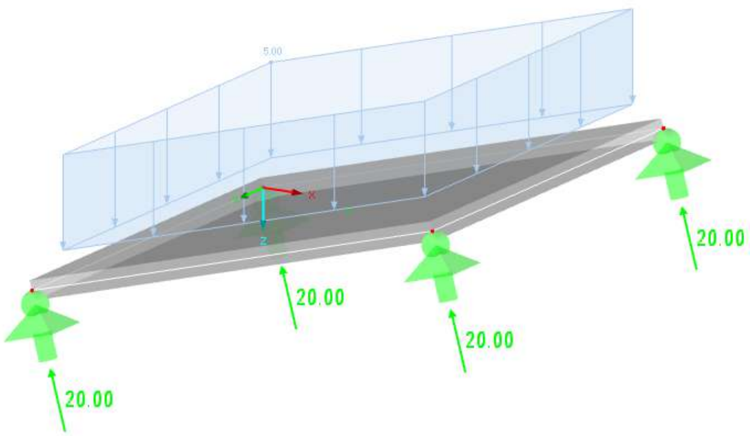


Figure 2.12: Punching load - support coordinate system with same orientation as surface coordinate system

The cases shown above are likely to be the largest part of the designs in your daily work. You can view the punching load in RFEM. The loaded and unloaded surface sides can be seen at once: The bottom surface of the slab is the loaded surface if the support reaction arrow shows in the opposite direction to the z-axis of the slab's coordinate system.

How is the governing punching load determined when there is no parallelism between the coordinate systems?

To determine the punching load, the values of the forces that are transmitted into the support are used. To obtain the support reaction forces, the signs are swapped. Then the forces are transformed in the direction of the local coordinate system of the slab, because only that force component is to be considered as punching load that acts perpendicularly to the slab.

Having determined the forces orientated on the local coordinate system of the slab, we can now decide, based on the sign of the load, which surface of the plate is loaded and which is not: The bottom surface of the slab is loaded if the vector of the transformed support reaction force in the Z-direction points in the opposite direction of the vector of the z-axis of the slab's coordinate system.

In the following example, a governing punching load of Q = 20.00 kN is applied to the right frontal support. The unloaded surface is the top surface of the slab.

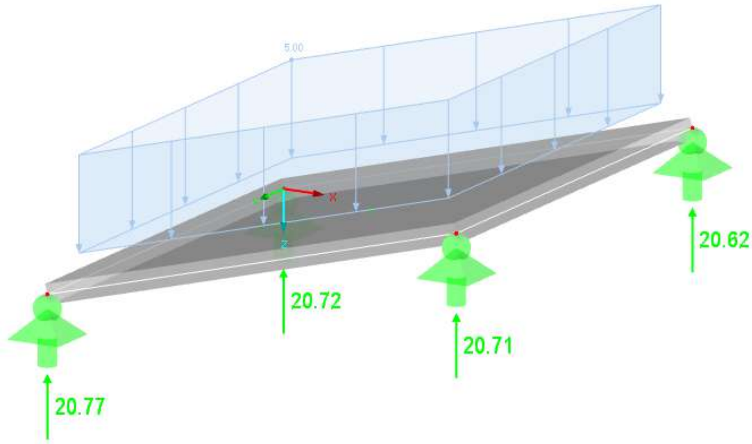


Figure 2.13: Punching load - support coordinate system with different orientation than surface coordinate system

If the plane is inclined by 15°, the punching load is determined as follows:

$$Q = P_Z \cdot \cos 15° = 20.71 \cdot \cos 15° = 20.00 \text{ kN}$$

Load cases and load combinations result in a single support force. For a result combination, the maximum and minimum value is to be determined for each internal force of the support. If one of the two values is not zero and if both values have also different signs, the punching shear design is carried out using this maximum and minimum values (see chapter 2.2 *Punching Shear Design Acc. to EN 1992-1-1*).

2.1.2 Punching Load from Nodal Load

Nodal loads are concentrated loads on a node located on the surface to be analyzed for punching.

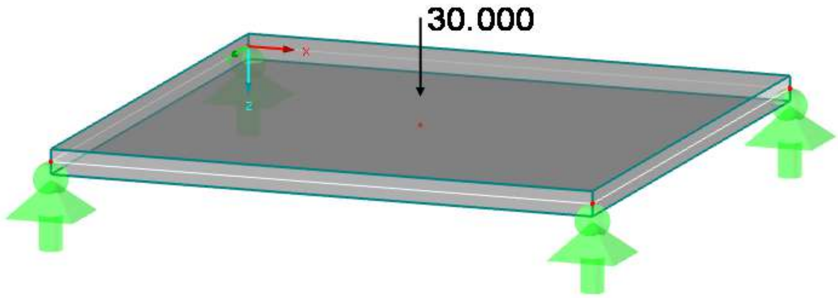


Figure 2.14: Nodal load

The direction and positive definition of a nodal load is described by means of the global coordinate system: A nodal load is positive if it acts in the direction of one of the axes of the global coordinate system. If the local coordinate system of the slab does not have the same orientation as the global coordinate system, the same applies as for the support reaction forces (see previous chapter): It is necessary to determine the force component of the nodal load whose vector runs parallel to the z-axis of the slab's coordinate system.

If several nodal loads act on the same node in a load case, the components from the forces in the respective axes must be added to obtain the punching load.

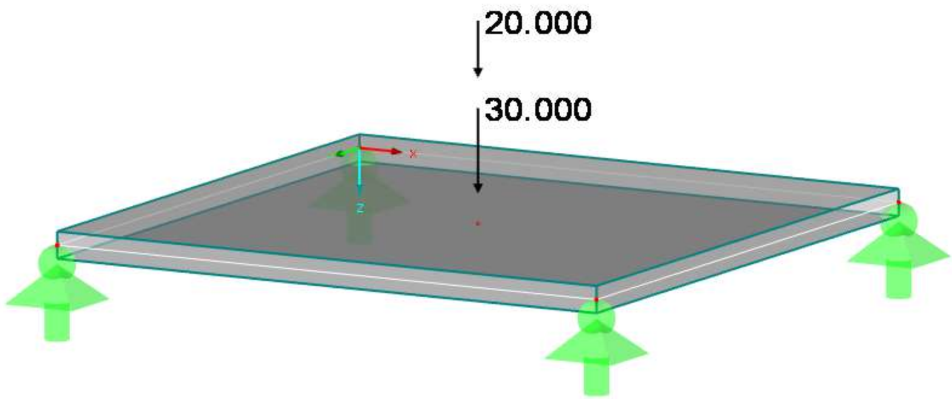


Figure 2.15: Two nodal loads on the same node

In these cases, we first obtain the sum of the nodal loads that run parallel to one of the axes of the global coordinate system. With this sum, the transformation in the direction of the z-axis of the slab coordinate system is carried out.

If several **load cases** are selected for design in RF-PUNCH, then those two load cases are determined whose sum of the nodal load in the Z-direction of the local slab coordinate system result in the greatest punching load in the direction of the bottom of the slab and in the greatest punching load in the direction of the top surface of the slab, respectively.

In case of a **load combination**, the loads of the load cases are summed under consideration of the load case factors. Then, the internal forces are determined for the load combinations. For the nodal loads, this means that the resulting nodal loads of the individual load cases are summed up under consideration of the load case factors.

A **Result combination** differs from a load combination in that the actions don't have to be only load cases, but may also contain load combinations and result combinations. Besides the additive superposition, you can also use the alternative combination with the "or" criterion. The crucial difference, however, is the following: The program doesn't combine the loading to obtain the sum of loads for the determination of internal forces but superimposes the results in the form of internal forces.

If we look at a structural analysis in such a way that we first determine the internal forces from a loading and then analyze a structural component with these forces, then for the punching shear analysis the step of determining the internal forces is to be determined, because the loading is identical with the internal force. Therefore, the governing punching load for each slab surface from the load cases, load combinations, and result combinations of this result combination are used.

2.1.3 Punching Load from Member Axial Force

The governing punching load of a member that connects to a common node is determined from the member axial force.

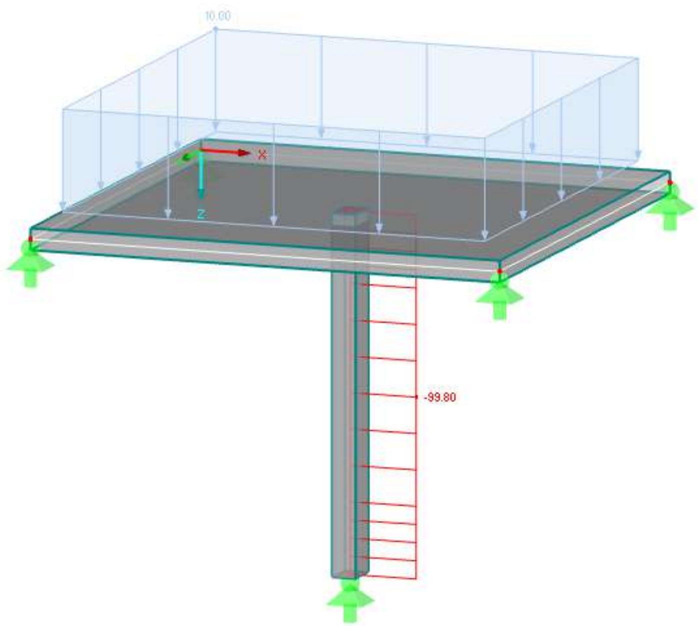


Figure 2.16: Axial force in connecting member

In RFEM, the axial force as the compression force is shown in red. This force receives a negative sign. The signs and the direction of the internal forces are defined by the local coordinate system of the member.

If the column connects to the lower side of the slab and a compression force is effective, the punching effect acts in the direction of the top side of the slab. If the connecting side is the same but the tension force is in the column, the punching effect goes in the direction of the bottom side of the slab.

We also want to look at the case of a column extending over several stories, which is frequently occurring in practice (see the following figure).

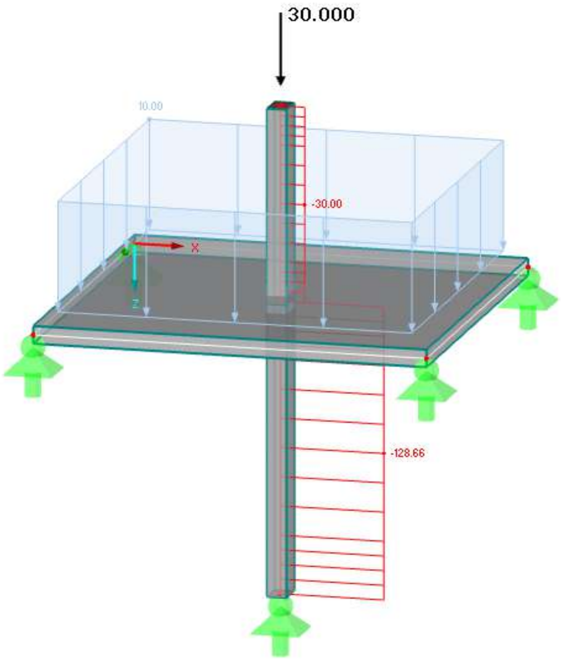


Figure 2.17: Punching load for continuous column members

If there are compression forces in the columns in the same load case or the same load combination, then they cancel out their respective punching effect. Therefore, only the differential force is applied as governing punching load. The direction of the punching effect is obtained depending on which slab surface the column with the greatest amount of axial force is. The direction of punching is then assumed in the direction of the slab surface which lies opposite to the connecting side of this column.

If the signs of the column axial forces are different, the absolute values of the forces are added. The direction is obtained from the signs and the connecting location of the individual columns.

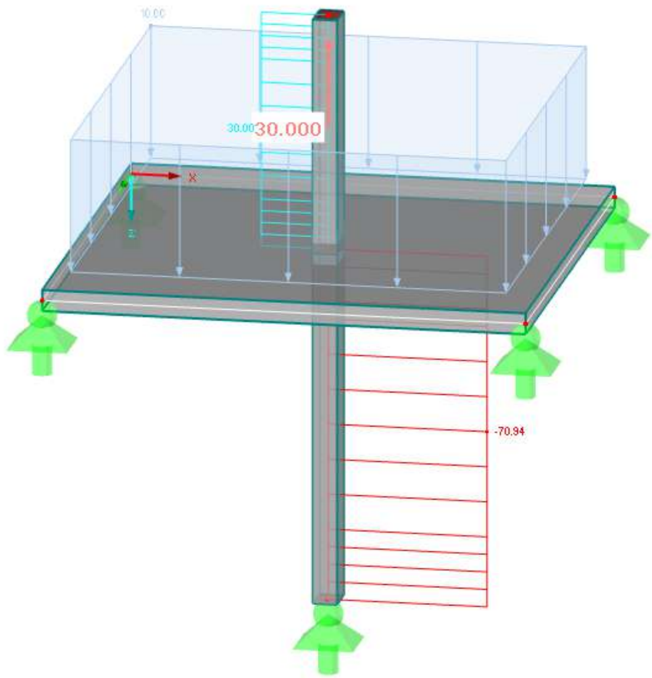


Figure 2.18: Punching load for different signs in connecting members

This also applies without restrictions for axial forces that come from the same load cases or load combinations. For internal forces of result combinations, however, the sum or the difference of the column axial forces can only be obtained if these forces come from the same load cases or load combinations. At the current state of program development, it cannot be documented which actions lead to the maximum and minimum internal forces. Therefore, the design of result combinations is omitted. Otherwise, we have to accept that the maximum or minimum axial forces of both columns are to be applied, though they do not necessarily occur for the same loading. This is because RFEM combines other load cases or load combinations as governing. The design of result combinations is therefore on the save side; however, it sometimes results in uneconomical solutions.

2.2 Punching Shear Design Acc. to EN 1992-1-1

2.2.1 General Features

Punching can occur due to concentrated loads or support reactions that act on a relatively small loaded area A_{load} on floor slabs or foundations.

For the punching shear design at the ULS, EN 1992-1-1 uses the design model shown in the following figure.

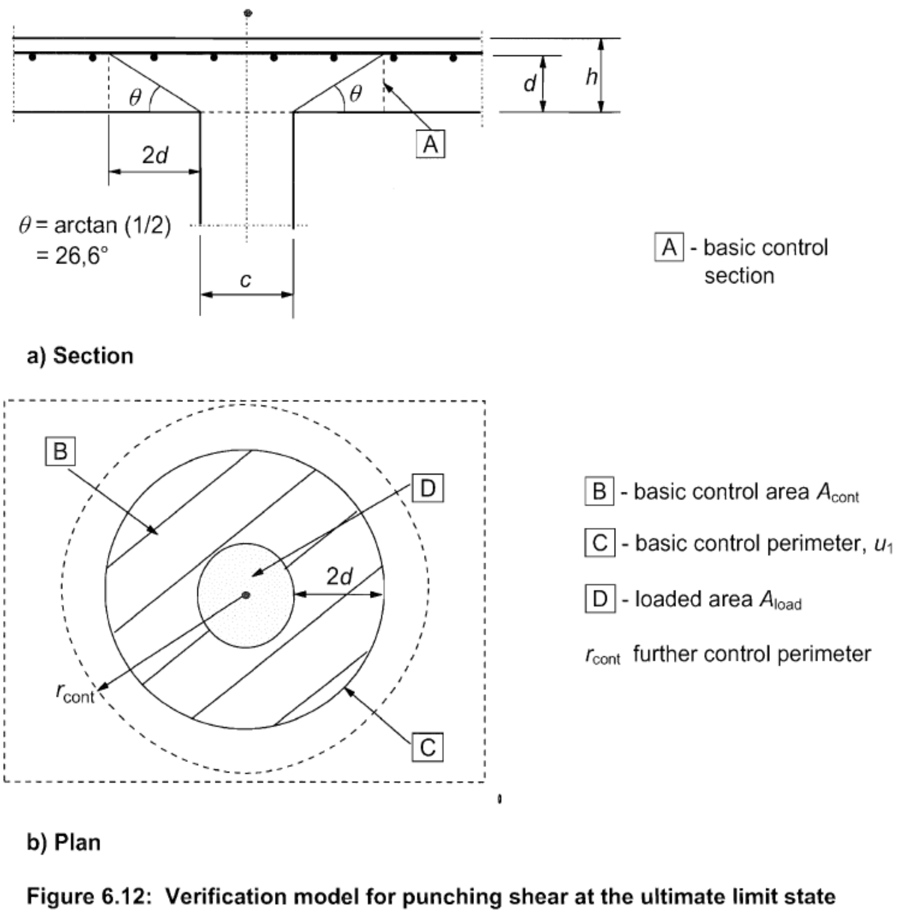


Figure 2.19: Design model with control perimeter for internal column

According to EN 1992-1-1 CEN, the following checks should be carried out:

Check for slabs without punching shear reinforcement

$v_{Ed} < v_{Rd,c}$

The design value of the punching shear resistance $v_{Rd,c}$ without punching reinforcement per unit area must be greater or equal to the acting shear force v_{Ed} per unit area in the basic control perimeter u_1.

Check for slabs and foundations with punching shear reinforcement

1. $v_{Ed} < v_{Rd,max}$

The design value of the maximum punching shear resistance $v_{Rd,max}$ per unit area must be equal to or greater than the acting shear force v_{Ed} per unit area.

2. $v_{Ed} < v_{Rd,cs}$

The design value of the punching shear resistance $v_{Rd,cs}$ of the punching reinforcement per unit area must be greater than or equal to the acting shear force v_{Ed} per unit area.

3. $v_{Rd,c} \geq v_{Ed.out}$

The design value of the punching shear resistance $v_{Rd,c}$ without punching shear reinforcement per unit area must be greater than or equal to the acting shear force $v_{Ed.out}$ per unit area outside the punching reinforced area in the outer control perimeter u_{out} (also called outermost control perimeter).

2.2.2 Load Transfer and Design Sections

The basic control perimeter u_1 may generally be taken to be at a distance of 2.0 d from the loaded area and must be constructed so as to minimize its length.

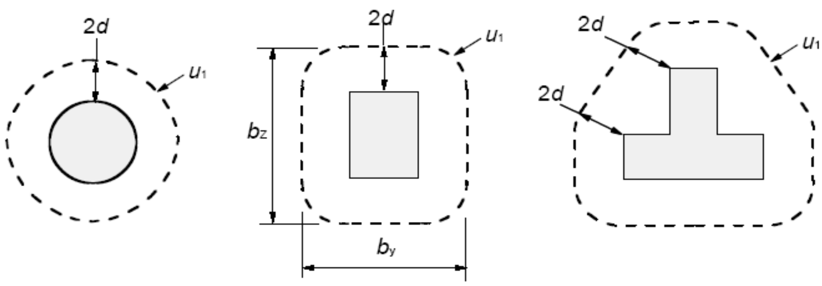


Figure 6.13: Typical basic control perimeters around loaded areas

Figure 2.20: Typical control perimeters

Control perimeters at a distance less than 2.0 d should be considered where the concentrated force is opposed by a high pressure (for example, soil pressure on a base), or by the effects of a load or reaction within a distance 2 d of the periphery of area of application of the force.

The effective depth of the slab is assumed as constant and may normally be determined as:

$$d_{eff} = \frac{d_y + d_z}{2} \qquad (6.32)$$

For loaded areas situated near openings, if the shortest distance between the perimeter of the loaded area and the edge of the opening does not exceed 6 d, that part of the control perimeter contained between two tangents drawn to the outline of the opening from the center of the loaded area is considered to be ineffective. This perimeter section is determined by the distance of the intersection points of the connecting lines with the considered control perimeter according to the following figure.

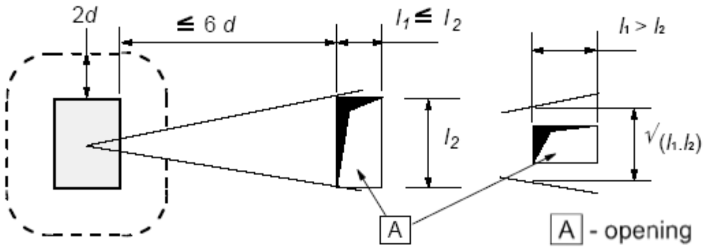


Figure 6.14: Control perimeter near an opening

Figure 2.21: Control perimeter situated near openings

For a loaded area situated near an edge or a corner, the control perimeter should be taken as follows.

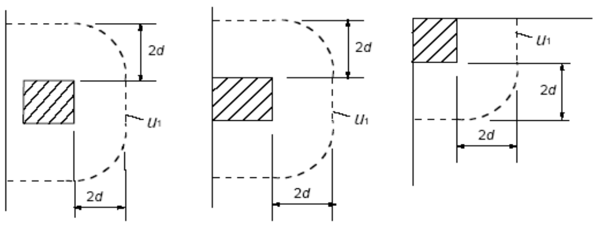


Figure 6.15: Basic control perimeters for loaded areas close to or at edge or corner

Figure 2.22: Basic control perimeters close to or at edge or corner

The design cross-section is obtained along the control perimeter with the effective depth d. For slabs of constant depth, the control section is perpendicular to the middle plane of the slab. For slabs or footings of variable depth other than step footings, the effective depth may be assumed to be the depth at the perimeter of the loaded area as shown in the following figure.

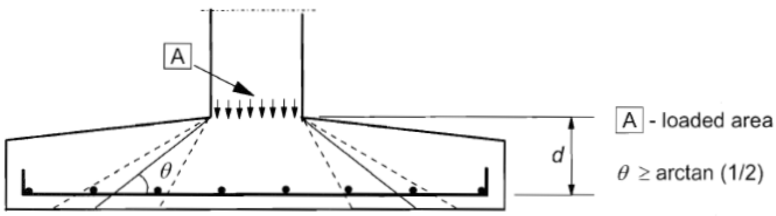


Figure 6.16: Depth of control section in a footing with variable depth

Figure 2.23: Depth of control section in a footing with variable depth

The punching shear resistance should be checked at the face of the column and at the basic control perimeter u_1. If shear reinforcement is required, a further perimeter $u_{out,ef}$ should be found where shear reinforcement is no longer required.

The outermost row of shear reinforcement should be placed at a distance not greater than k·d from $u_{out,ef}$. The recommended value for k is 1.5. The calculation of u_{out} is described in chapter 2.2.5.

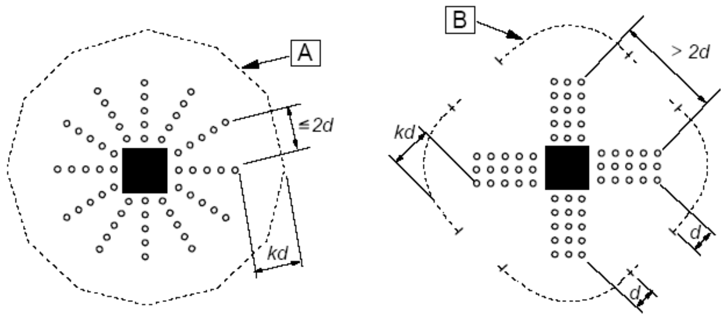


Figure 2.24: Outermost control perimeter

2.2.3 Determining the Action Effects

For the determination of the maximum acting shear force per unit area, the EN 1992-1-1:2004 distinguishes between the maximum acting shear force per unit area for a **slab** according to (6.38) and the maximum acting shear force for a **column base** according to (6.49) or (6.51).

Acting shear force for slabs

To determine the shear force, it is necessary to divide the design value of the applied shear force V_{Ed} by the product from the length u_1 of the control perimeter being considered and the mean effective depth d, and then to multiply it by the factor β to take into account the uneven shear force distribution. The design value of the acting shear force v_{Ed} per unit area according to EN 1992-1-1 clause 6.4.3 is therefore:

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d} \qquad (6.38)$$

where

V_{Ed} Design value of the applied shear force

u_1 Length of the basic control perimeter

d Mean effective depth of the slab, which may be taken as $(d_y + d_z) / 2$

d_y, d_z Effective depths in the y- and z-directions of the control section

β Factor for taking into account the uneven shear force distribution

The factor β can be determined based on a fully plastic shear stress distribution according to 6.4.3(3) or in a simplified way by means of approximate values according to Figure 6.21 (see the following pages).

Factor β under consideration of fully plastic distribution of shear stresses

$$\beta = 1 + k \frac{M_{Ed}}{V_{Ed}} \cdot \frac{u_1}{W_1} \qquad (6.39)$$

where

k Coefficient dependent on the column ratio of the column dimensions c_1 and c_2

c_1 Column dimension parallel to the eccentricity of the load

c_2 Column dimension perpendicular to the eccentricity of the load

Table 6.1: Values of *k* for rectangular loaded areas

c_1/c_2	≤ 0,5	1,0	2,0	≥ 3,0
k	0,45	0,60	0,70	0,80

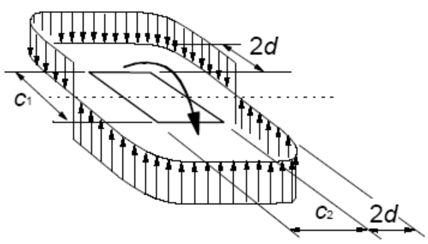


Figure 6.19: Shear distribution due to an unbalanced moment at a slab-internal column connection

Figure 2.25: Values for k

u_1 Length of basic control perimeter

W_1 $W_1 = c_1^2 / 2 + c_1 \cdot c_2 + 4 \cdot c_2 \cdot d + 16 \cdot d^2 + 2 \cdot \pi \cdot d \cdot c_1$

The Equation (6.39) according to EN (CEN) determines the factor β for uniaxial eccentricity of the punching load. The German National Annex provides a solution for a biaxial eccentricity that is also used for all National Annexes in the program:

$$\beta = 1 + \sqrt{\left(k_x \frac{M_{Ed,x}}{V_{Ed}} \cdot \frac{u_1}{W_{1,x}}\right)^2 + \left(k_y \frac{M_{Ed,y}}{V_{Ed}} \cdot \frac{u_1}{W_{1,y}}\right)^2} \qquad (NA.6.39.1)$$

Coefficient β by means of approximate values

EN 1992-1-1: 2004 clause 6.4.3 (6): For structures where the lateral stability does not depend on frame action between the slabs and the columns, and where the adjacent spans do not differ in length by more than 25%, approximate values for p may be used for β:

β = 1.0 (internal column)

β = 1.4 (edge column)

β = 1.5 (corner column)

Those are the recommended values. Values of β for use in a specific country may be found in its National Annex.

The user must decide for each punching node whether these approximate values can be used, because the program cannot check the preconditions described above. You decide this in the 1.5 *Node of Punching Shear* window (see the following figure).

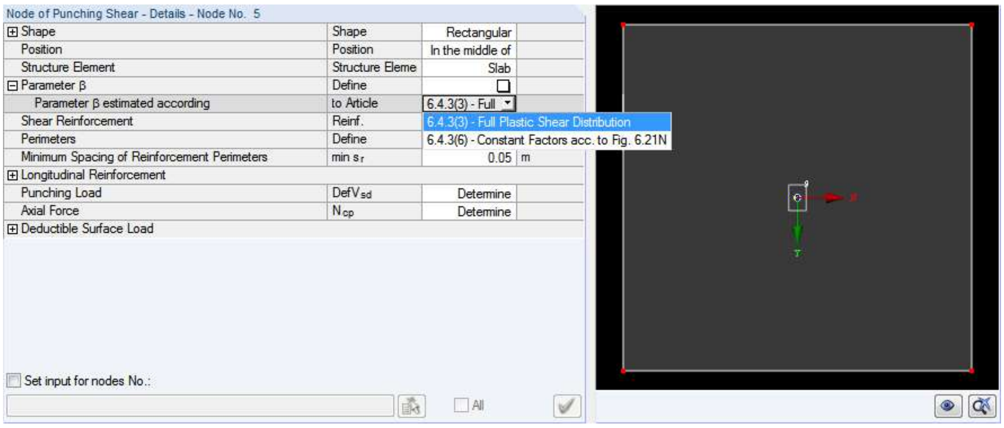


Figure 2.26: Selection of coefficient β in window 1.5 *Node of Punching Shear*

Applied shear force on column bases

The punching resistance of column bases should be verified at control perimeters within 2 d from the periphery of the column. The position of the control perimeter is to be determined iteratively.

The determination of the shear force according to clause 6.4.4 (2) depends on the type of loading.

Concentric loading

$$V_{Ed,red} = V_{Ed} - \Delta V_{Ed} \qquad (6.48)$$

where

V_{Ed} Applied shear force

$$V_{Ed} = V_{Ed,red} / (u \cdot d) \qquad (6.49)$$

ΔV_{Ed} Net upward force within the control perimeter considered, that is, the upward pressure from soil minus self-weight of base.

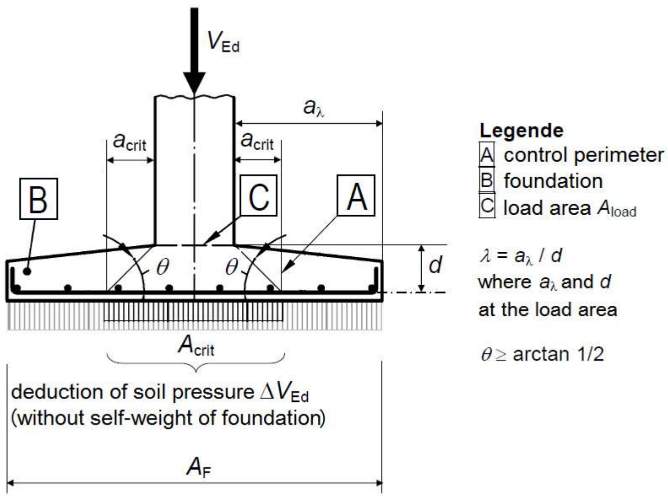


Figure 2.27: Control perimeter and subtracted soil pressure for foundations

Eccentric loading

$$V_{Ed} = \frac{V_{Ed,red}}{u \cdot d}\left(1 + k \frac{M_{Ed}}{V_{Ed,red}} \cdot \frac{u}{W}\right) \qquad (6.51)$$

The part in brackets represents the load increase factor β.

2.2.4 Punching Resistance Without Punching Reinforcement

The punching shear resistance of a **slab** should be assessed for the basic control section according to EN 1992-1-1 clause 6.4.4(1) as follows:

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp} \geq (v_{min} + k_1 \cdot \sigma_{cp}) \quad (6.47)$$

where

$C_{Rd,c} = 0.18 / \gamma_c$

$k = 1 + \sqrt{(200 / d)} \leq 2.0$ where d in [mm]

$\rho_l = \sqrt{(\rho_{lz} \cdot \rho_{ly})} \leq 0.02$

ρ_{lz}, ρ_{ly} Related to the bonded tension steel in y- and z-directions, respectively.

f_{ck} Characteristic concrete compressive strength in [N/mm²]

$k_1 = 0.1$

$\sigma_{cp} = (\sigma_{cy} + \sigma_{cz}) / 2$

Normal concrete stresses in the control perimeter in y- and z-direction [N/mm²], positive if compression): $\sigma_{cy} = N_{Ed,y} / A_{cy}$ and $\sigma_{cz} = N_{Ed,z} / A_{cz}$

$$v_{min} = 0.035\ k^{3/2} \cdot f_{ck}^{1/2} \quad (6.3)$$

The shear force resistance of a **column base** without punching resistance is to be determined according to clause 6.4.4 (2).

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp} \cdot 2 \cdot d / a \geq (v_{min} + k_1 \cdot \sigma_{cp}) \cdot 2 \cdot d / a \quad (6.50)$$

where

a Distance from the periphery of the column to the control perimeter considered

d Mean effective depth of the slab may be taken as $(d_y + d_z) / 2$

Whether a punching reinforcement is required depends on whether the punching reinforcement $v_{Rd,c}$ is greater than the maximum applied shear force v_{Ed} per unit area. If $v_{Rd,c}$ is greater, the check is OK and the program successfully terminates the design. If, however, $v_{Rd,c}$ is less than v_{Ed}, a punching reinforcement is required.

If the user specified that the longitudinal reinforcement can be used for the punching design, the program increases the longitudinal reinforcement ratio by increasing the longitudinal reinforcement. If even with a maximum allowable longitudinal reinforcement ratio the punching resistance $v_{Rd,c}$ without punching reinforcement is smaller than the maximum applied shear force v_{Ed} per unit area, a punching reinforcement becomes inevitable.

The check without punching reinforcement is shown in the following flowchart.

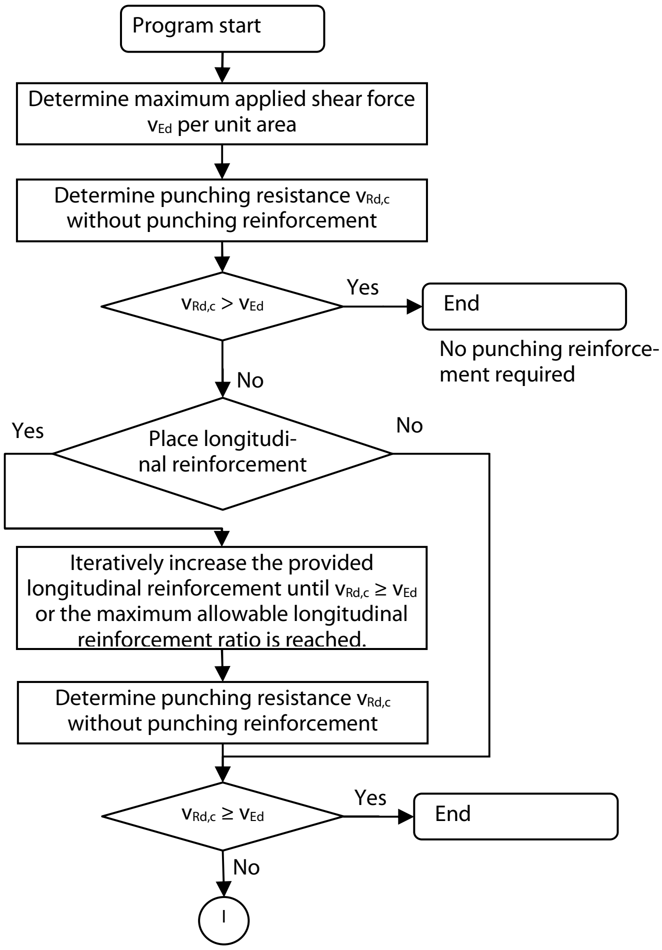


Figure 2.28: Program flowchart without punching reinforcement

2.2.5 Punching Resistance with Punching Reinforcement

If a punching reinforcement is allowed by the user, the following two checks are to be run for the slab:

- Check of maximum punching shear resistance ($v_{Rd,max} > v_{Ed}$)
- Check of the punching resistance with punching reinforcement ($v_{Rd,cs} > v_{Ed}$)

The check of the maximum punching resistance $v_{Rd,max}$ is not performed at the control perimeter but, according to 6.4.5 (3), at the column edge.

The maximum applied shear force per unit area v_{Ed} at the loaded area is determined as follows:

$$v_{Ed} = \beta \cdot \frac{V_{Ed}}{u_0 \cdot d} \leq v_{Rd,max} \tag{6.53}$$

where

β	Factor as for maximum shear force of the control perimeter	
u_0	for an interior column	u_0 = enclosing minimum periphery
	for an edge column	$u_0 = c_2 + 3d \leq c_2 + 2c_1$
	for a corner column	$u_0 = 3d \leq c_1 + c_2$
	c_1, c_2	Column dimensions as shown in EN 1992-1-1 Figure 6.20

The maximum punching resistance $v_{Rd,max}$ is to be taken from the National Annex. The recommended value is:

$$v_{Rd,max} = 0.4 \cdot \nu \cdot f_{cd}$$

where

$\nu = 0.6 \cdot (1 - f_{ck} / 250)$ where f_{ck} in [N/mm²] (6.6)

f_{cd} Design value of concrete compressive strength in [N/mm²]

According to CEN EN 1992-1-1, it is not possible to influence the maximum punching resistance $v_{Rd,max}$ by increasing the longitudinal reinforcement. Some National Annexes, however, do include such a possibility.

The flowchart for CEN EN 1992-1-1 for verifying the maximum punching resistance $v_{Rd,max}$ is as follows:

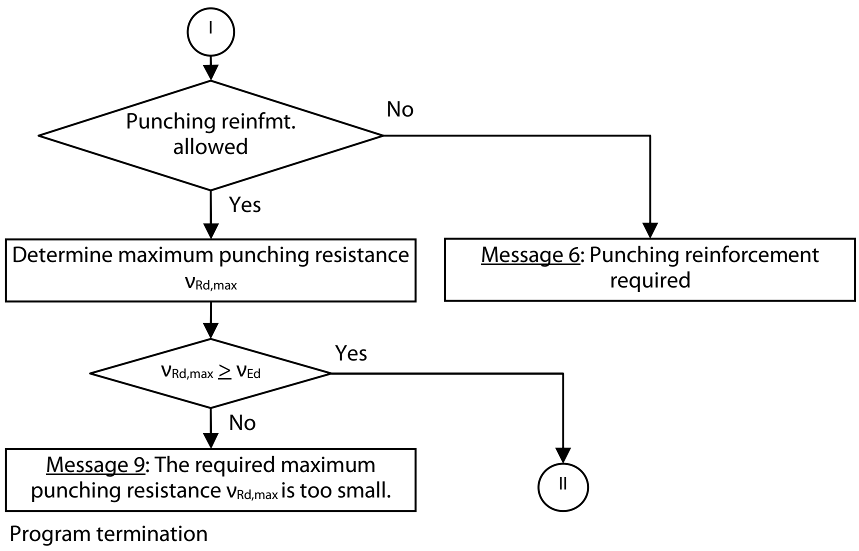


Figure 2.29: Program flowchart with punching reinforcement

As the flowchart shows, the program first analyzes whether the user has allowed a punching reinforcement or not. Then, the program determines the maximum punching resistance $v_{Rd,max}$. If it is smaller than the maximum applied shear force v_{Ed} per unit area, the design is terminated.

If $v_{Rd,max}$ is greater than v_{Ed}, the required punching reinforcement A_{sw} can be determined in a control perimeter around the column from EN 1992-1-1 Equation (6.52).

$$\text{req } A_{sw} = \frac{(v_{Ed} - 0.75 \cdot v_{Rd,c}) \cdot u_1 \cdot d}{1.5 \cdot \left(\frac{d}{s_r}\right) \cdot f_{ywd,ef} \cdot \sin\alpha} \quad \text{in [mm}^2\text{]}$$

where

v_{Ed} Maximum applied shear force per unit area in control perimeter

s_r Spacing of shear links in the radial direction in [mm]

$f_{ywd,ef}$ Design yield of shear reinforcement

$f_{ywd,ef} = 250 + 0.25d \leq f_{ywd}$ in [N/mm²]

u_1 Length of basic control perimeter in [mm]

α Angle between the punching reinforcement and the plane of the slab

Minimum punching reinforcement

The EN 1992-1-1 specifies a minimum punching reinforcement: According to 9.4.3 (2), the required punching reinforcement may not be smaller than the following value:

$$A_{sw,min} \geq \frac{0.08 \cdot \sqrt{\frac{f_{ck}}{f_{yk}}}}{\frac{1.5 \cdot \sin\alpha + \cos\alpha}{s_r \cdot s_t}} \qquad (9.11)$$

where

α	Angle between punching reinforcement and main reinforcement (for vertical links: $\alpha = 90°$ and $\sin \alpha = 1$)
s_r	Spacing of shear links in the radial direction
s_t	Spacing of shear links in the tangential direction
f_{ck}	Concrete compression strength in [N/mm²]

The design value of the punching resistance per unit area for a slab with punching reinforcement is determined as follows:

$$v_{Rd,cs} = 0.75 \cdot v_{Rd,c} + 1.5 \frac{d}{s_r} \cdot A_{sw} \cdot f_{ywd,ef} \cdot \frac{1}{u_1 \cdot d} \cdot \sin\alpha \qquad (6.52)$$

where

d	Mean value of effective depth in the orthogonal direction in [mm]
u_1	Length of control perimeter
s_r	Spacing of shear links in the radial direction in [mm]
A_{sw}	Punching reinforcement in a reinforcement row about the column in [mm²]
$f_{ywd,ef}$	Effective design strength of the punching shear reinforcement $f_{ywd,ef} = 250 + 0.25d \leq f_{ywd}$ in [N/mm²]
α	Angle between the punching shear reinforcement and the plane of the slab

The following flowchart shows the computation of the required punching reinforcement.

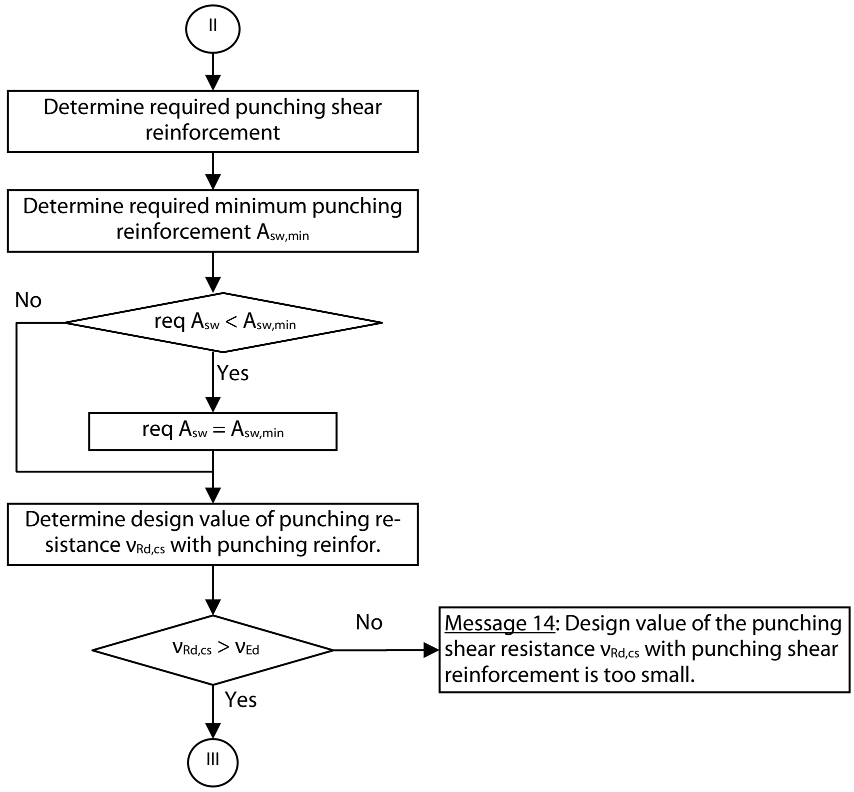


Figure 2.30: Flowchart for computation of punching shear reinforcement

Since according to EN 1992-1-1 the required punching reinforcement is always determined in the basic control perimeter, the flowchart for the vertical and inclined punching reinforcement is identical.

According to EN 1992-1-1, the first inner control perimeter can be taken at a distance of 0.5 d. The area reinforced against punching shear ends at a distance of 1.5 d from the outer control perimeter. It is to be determined according to the rules of clause 6.4.5 (4). The length $u_{out,ef}$ of the outer control perimeter is determined as follows:

$$u_{out,ef} = \beta \cdot \frac{V_{Ed}}{v_{Rd,c} \cdot d} \qquad (6.54)$$

Within the area reinforced against punching, the distances between the rows of punching reinforcement can be arranged in any way up to a maximum value. There are two options to determine the position of the outer control perimeter:

- The user specifies the outer control perimeter by means of the distance l_{wa}.
- The outer control perimeter is determined iteratively.

User-defined outer control perimeter

Clause 9.4.3 (4) and Figure 9.10 prescribed that the first inner control perimeter is to be placed at a distance of 0.3 d to 0.5 d and the outer control perimeter at a distance of 1.5 d from the last inner control perimeter. Therefore, if a distance l_{wa} of the outer control perimeter is given, it is possible to calculate the remaining distance **x**. The distance of the first reinforced control perimeter is taken as 0.5 d.

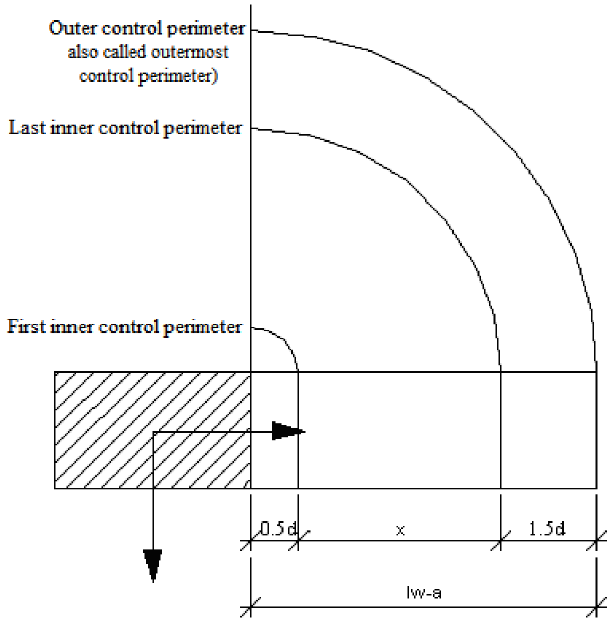


Figure 2.31: Control perimeters

The distance x is computed as follows:

$$x = l_{wa} - 2 \cdot d$$

If x is less than zero, the user-defined distance of the outer control perimeter is too small. This is checked before the calculation. No calculation is run in this case. If x is equal zero, the first and last inner control perimeter coincides; no further inner control perimeters are possible.

If x is greater than zero, you must determine how many inner control perimeters can be inserted. There are three possibilities:

- Possibility 1: The user specified the number n_i and the position of each inner control perimeter by means of the distance l_{wi} to the loaded area.
- Possibility 2: The user specified the number $n_{i,}$ of the control perimeters but not their position.
- Possibility 3: The user has defined neither the number nor the position of the control perimeters.

Possibility 1: Number and position defined

The position of the inner control perimeters is clearly defined. What is left to do for the program is to check whether the following regulations of EN 1992-1-1 are kept:

- The distance of the first inner control perimeter is, according to clause 9.4.3 (4) and Figure 9.10, between 0.3 d and 0.5 d.
- The distance between the inner control perimeters does not exceed, according to clause 9.4.3 (1), the allowable maximum distance of 0.75 d.
- Because the distance l_{wa} of the outer control perimeter is also given, the program checks whether there is a distance of 1.5 d between the last inner control perimeter and the outer control perimeter.

Possibility 2: Number given, position unknown

For the given number of inner control perimeters and the given distance of the outer control perimeter, you need to determine the distance between the inner control perimeters. This distance is constant for all control perimeters.

$$s_{r,i} = \frac{x}{n_i - 1}$$

Possibility 3: Number and position unknown

To obtain the number of inner control perimeters n_i, the remaining distance x is divided by the maximum distance $s_{r,max} = 0.75\,d$.

$$n_i = \frac{x}{s_{r,max}}$$

The number of the inner control perimeters determined in this way is an integer by chance only. Therefore, the obtained number n_i is rounded. According to clause 9.4.3 (1), n_i must have at least the value 2. With this rounded number n_i, we obtain the following constant distance s_r of the inner control perimeters:

$$s_r = \frac{x}{n_i}$$

Iterative determination of the outer control perimeter

If the position of the outer control perimeter is not specified by the user, RF-PUNCH iteratively determines the optimal position of the outer control perimeter. This position is obtained when the shear resistance $V_{Rd,ct,a}$ is for the first time greater than the design shear force V_{Ed}. The position of the inner control perimeters is determined as described above for the possibilities of user-defined specification of the outer control perimeter.

For the sake of completeness, it must be noted that for a user-defined position of the inner control perimeters (possibility 1), no optimal position of the outer control perimeter is determined. In this case, it is placed at a distance of 1.5 d from the last inner control perimeter.

The following flowchart shows the three possibilities described above.

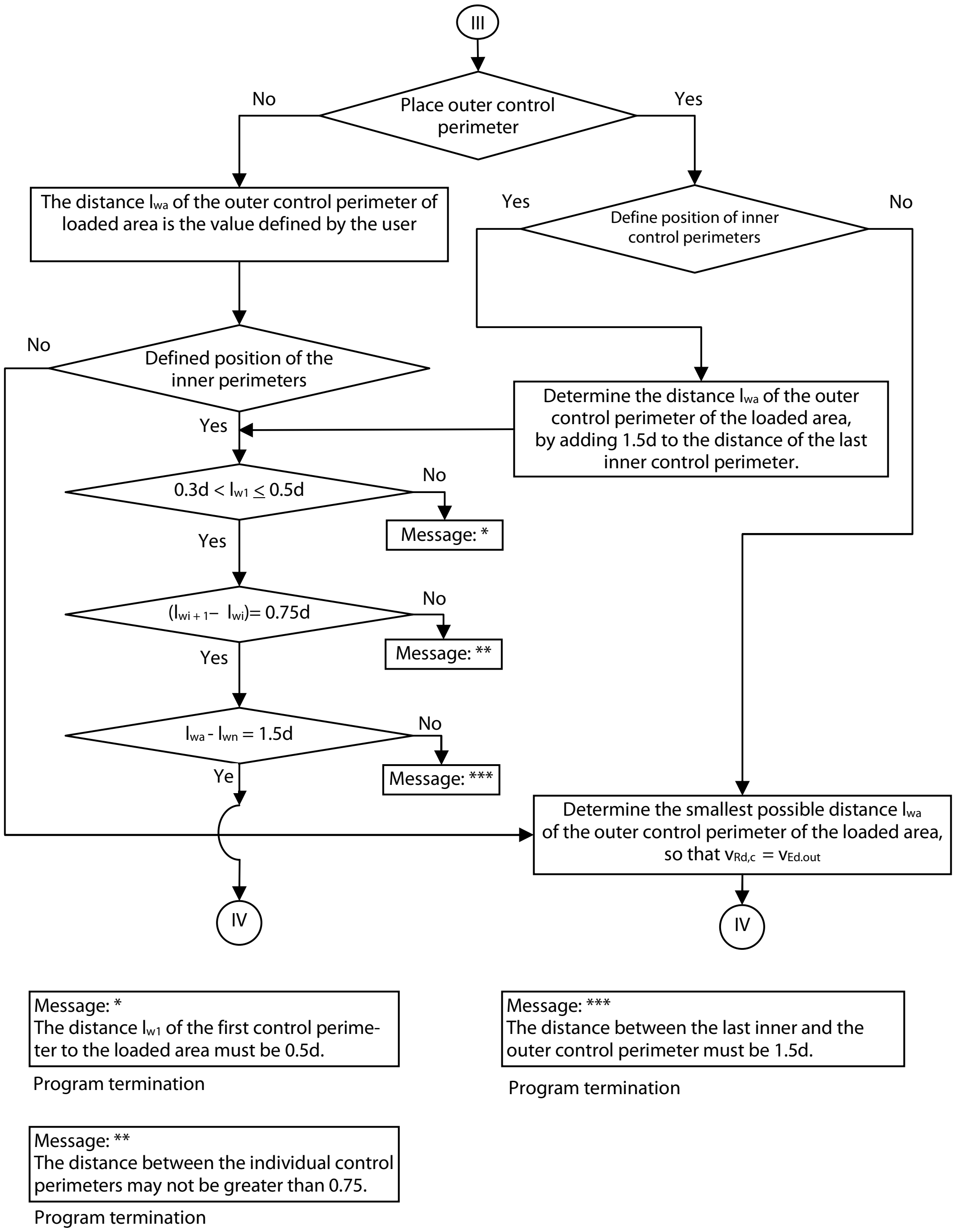


Figure 2.32: Program flowchart for determining control perimeters

In the left part of the flowchart, the program checks the user-defined distances between the inner control perimeters or the distance to the loaded area or to the outer control perimeter. In the right part, the most economical position of the outer control perimeter is determined.

If the position of the outer control perimeters was not defined, RF-PUNCH proceeds according to the following flowchart.

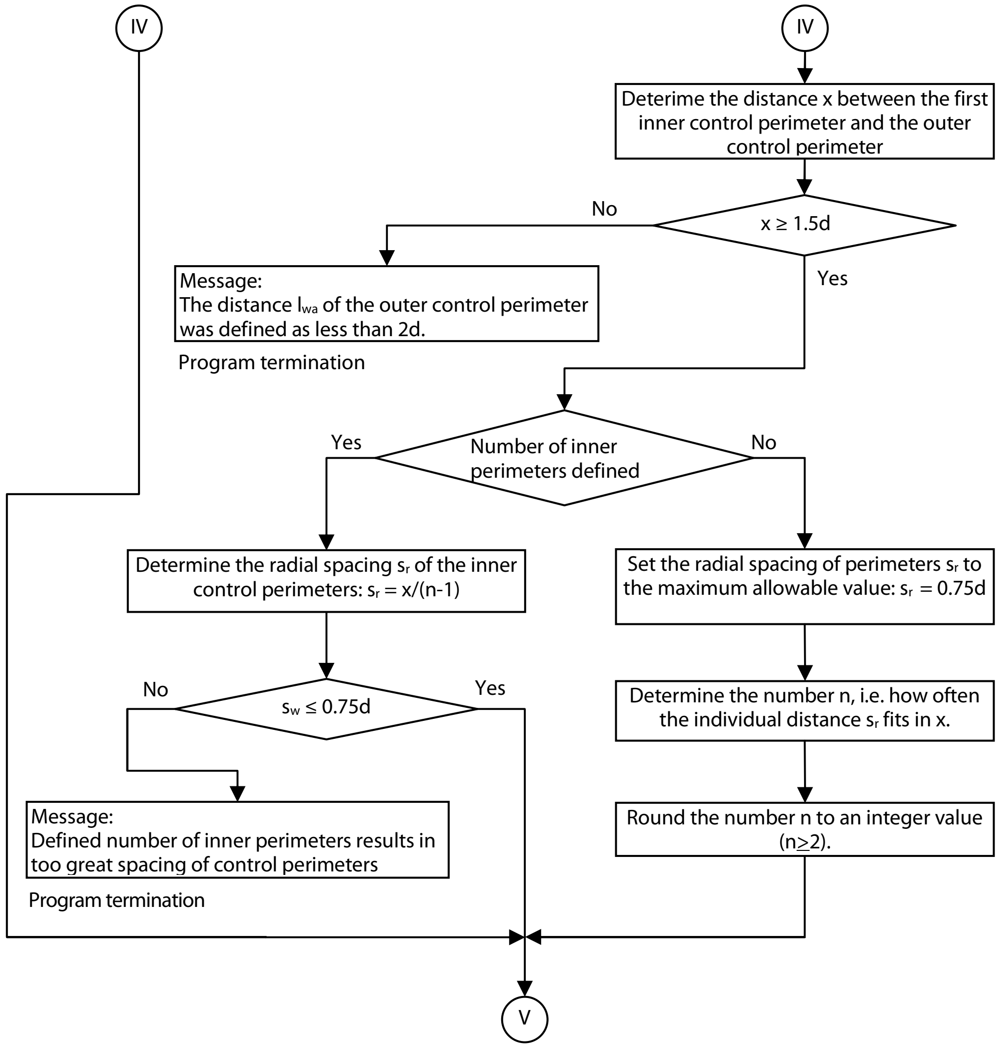
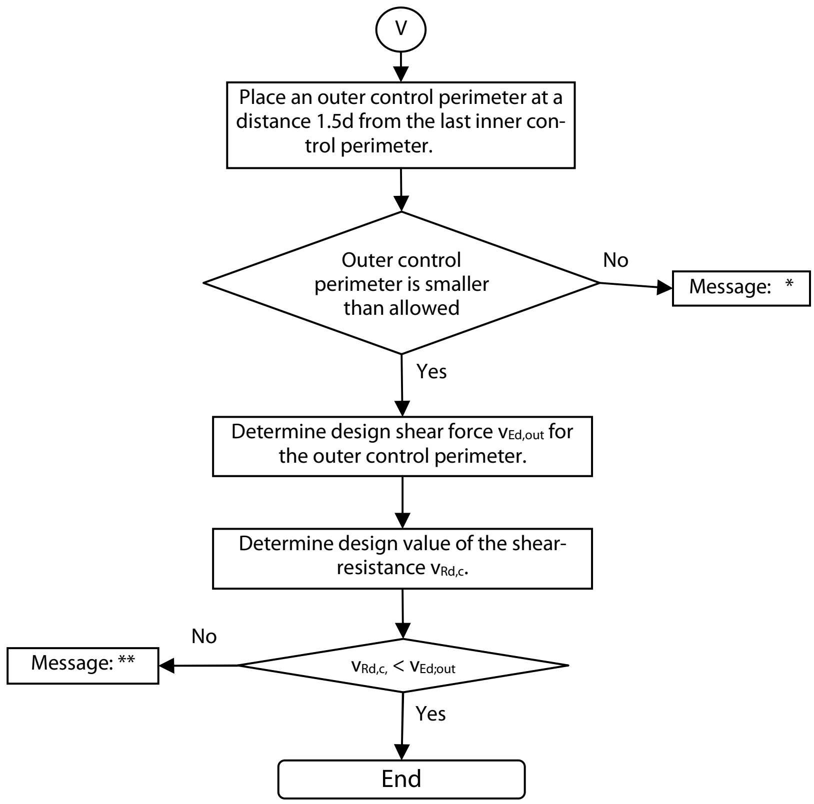


Figure 2.33: Program flowchart for inner control perimeters

From the number and the distances of inner control perimeters, the required punching shear reinforcement can be determined in the individual control perimeters. Finally, an outer control perimeter is placed and the design of the shear force resistance $v_{Ed,out}$ is run outside the area reinforced against punching.

The last part of the program runs as shown in the following figure.



Message: *
Maximum possible length of the outer control perimeter reached.

Program termination

Message: **
The design shear resistance $v_{Rd,c}$ for outer control perimeter is too small.

Program termination

Figure 2.34: Flowchart for determination of shear reinforcement

2.2.6 Punching Design for Slabs Loaded on Both Sides

If there are punching loads on one node, from which one receives the punching effect on the top surface of the slab and the other on the bottom surface, then both surfaces have to be analyzed separately. For the design of the minimum moments, the encompassing longitudinal reinforcement can be determined as the greatest reinforcement cross-section per slab surface. In the case of the punching reinforcement, this is possible only in a limited way.

The following figure shows the effect of the "compression vault" for a load application on the top or bottom surface of the slab.

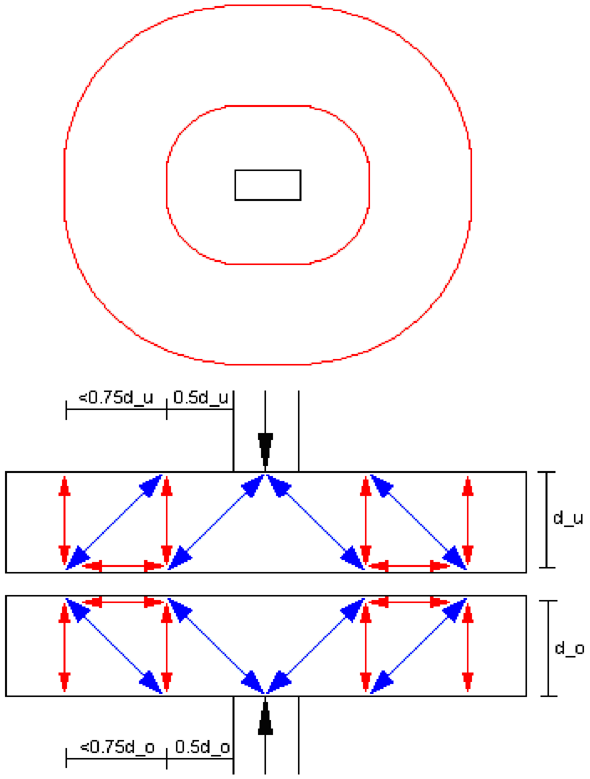


Figure 2.35: "Compression vault" if load effect from both sides

For the compression struts due to the loading on the top surface of the slab, a vertical punching reinforcement is determined for every inner control perimeter. The same is done for the inner control perimeters from the loading on the bottom surface of the slab.

Provided that the inner control perimeters for the loading on the top and bottom surface are located at the same distance from the loaded area, the punching shear reinforcement to be placed there could be compared and only the greatest reinforcement be determined as enveloping solution. The inner control perimeters, however, are located at the same distance from the loaded area only if the effective depths for the top and bottom surface are identical. For inclined punching shear reinforcement, it is not possible to determine a governing cross-section of the punching shear reinforcement, because for both loadings these run perpendicular to each other.

Due to this issue, the program proceeds as follows: From the punching loads determined as governing, the greater one is determined as the load for which a punching shear reinforcement is to be determined. It is referred to as "primary load." For the smaller one of the two loads, the program runs a punching shear design without punching shear reinforcement.

3. Working with RF-PUNCH

3.1 Opening the Add-on Module RF-PUNCH

You can open the add-on module RF-PUNCH by using the command from the RFEM menu

Add-on Modules → RF-PUNCH

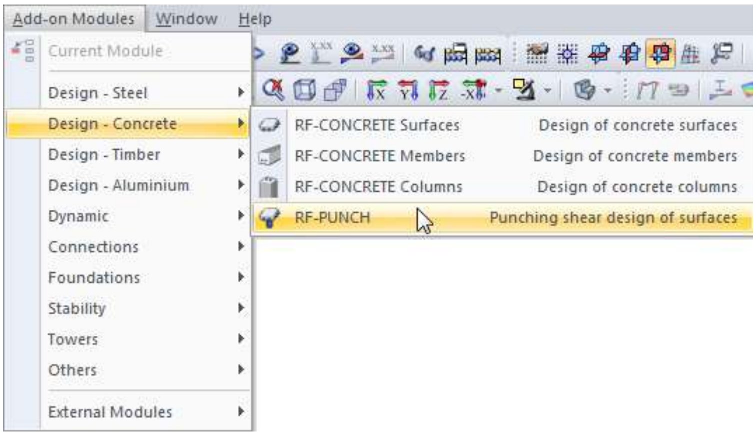


Figure 3.1: Opening RF-PUNCH by using the *Add-on Modules* menu

Alternatively, you can open RF-PUNCH by using the Project Navigator.

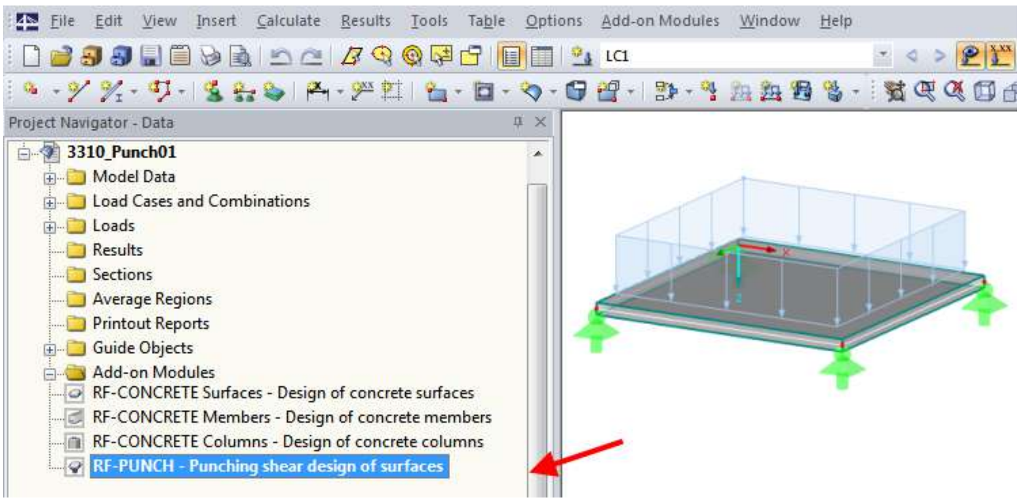


Figure 3.2: Starting RF-PUNCH from the *Project Navigator*

3.2 Module Windows

The input for the definition of the RF-PUNCH cases as well as the numerical results output are shown in so-called module windows.

To open the individual windows, click the corresponding entry in the RF-PUNCH navigator on the left. Alternatively, press the keys **F2** and **F3** or use the two following buttons.

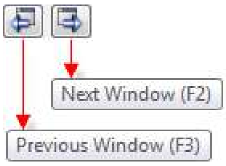


Figure 3.3: Buttons [Browse]

Above the RF-PUNCH navigator, you find a drop-down list with the design cases. By clicking [▼], you open the list from which you can choose the desired design case.

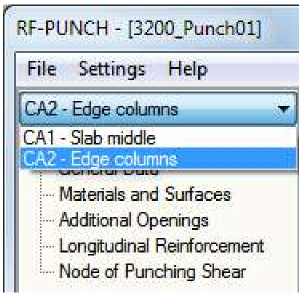
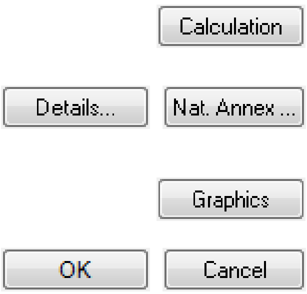


Figure 3.4: Selecting the design case



Having entered all relevant data, you can click [Calculation] to run the analysis. After the calculation, the results are shown in the output windows and in the RFEM work window.

To open the *Design Details* dialog box with the coefficients from the standard, click [Details] (see Figure 3.47, page 51). To control the parameters of the National Annex, click [Nat. Annex] (see Figure 3.8, Figure 36).

To show the results in the RFEM work window, click [Graphics].

To save all input and results before exiting the module RF-PUNCH, click [OK]. To exit the module without saving the input data, click [Cancel].

To open the online help, click [?] or press [F1].

3.3 Input

You define the data in five input windows. Some dialog boxes provide additional options for specification.

3.3.1 General Data

In the 1.1 *General Data* window, you specify the design standard as well as the load cases, load combinations, and result combinations that are relevant for the punching design.

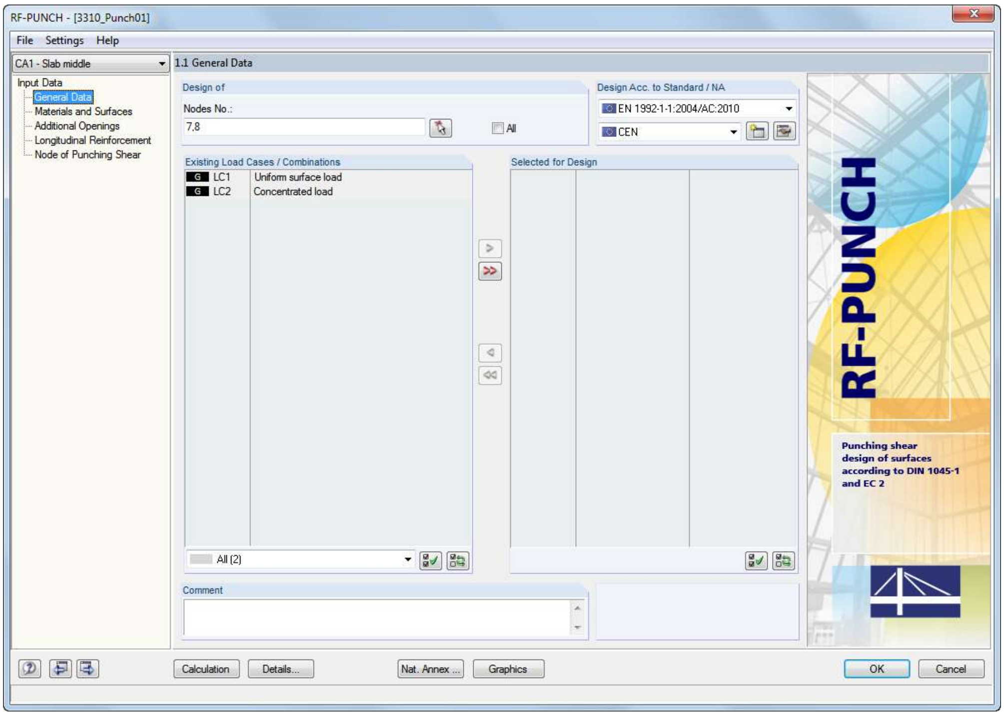


Figure 3.5: Window 1.1 *General Data*

Design of

In the input field of this section, you must specify the *Nodes* that you want to analyze. If you want to analyze only certain nodes, clear the *All* check box. Thus, the input field becomes available where you can specify the numbers of the relevant nodes. You can also select the list of the preselected numbers by double-clicking them, and then rewrite them manually. Furthermore, you can click [↖] to graphically select the objects in the RFEM work window.

Design Acc. to Standard / NA

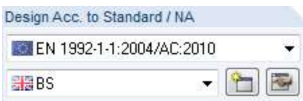
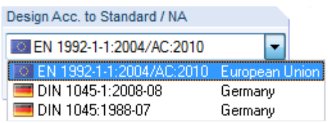


Figure 3.6: Standard and National Annex for reinforced concrete design

Standard



You must specify according to which standard you want to analyze the punching design. In the list, you can select from the following concrete standards:

- EN 1992-1-1:2004/AC:2010 European Union
- DIN 1045-1:2008-08 Germany
- DIN 1045:1988-07 Germany

National Annex

If you want to design according to the Eurocode (EN 1992-1-1:2004/AC:2010), you must specify a National Annex whose parameters should apply for the designs.

Figure 3.7: National Annexes for EN 1992-1-1

To view the preset values, click [Edit].

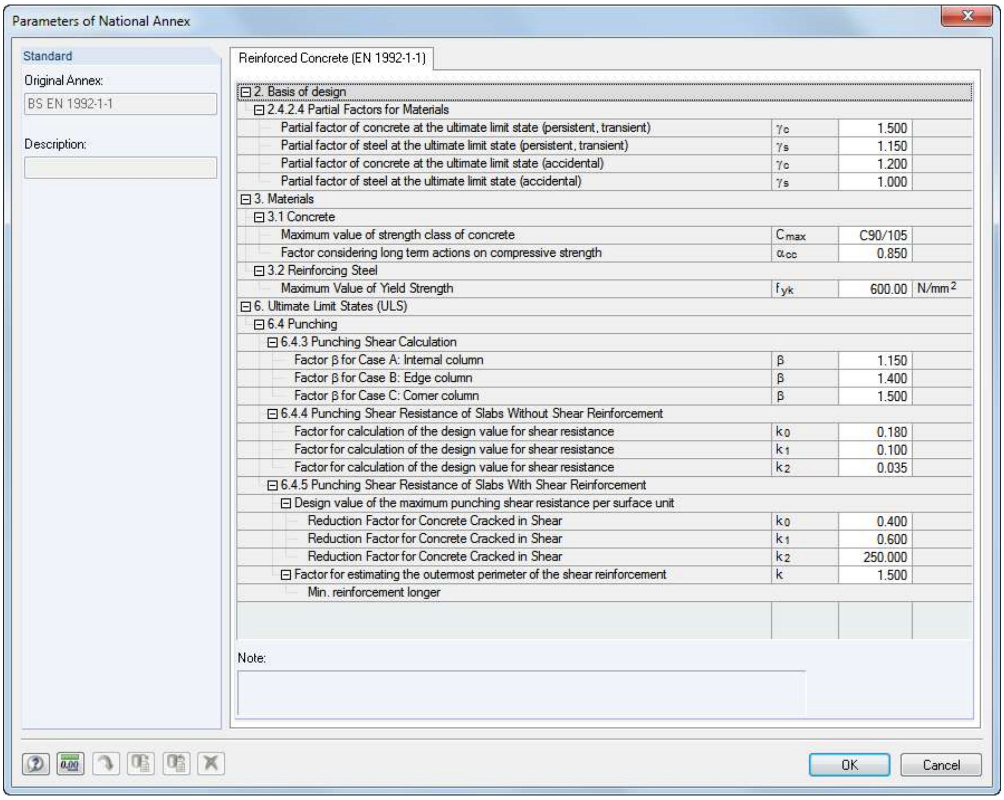


Figure 3.8: Dialog box *Parameters of National Annex*

Here, you find all design-relevant coefficients that are regulated in the National Annexes. They are listed by the clause number from the Eurocode.

If there are other application requirements for the partial safety factors, reduction factors, etc., you can adjust the parameters accordingly. To do this, first click [New] to create a copy of the current National Annex. In this copied user-defined Annex, you can change the parameters.

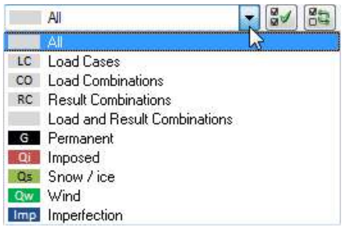
Existing Load Cases / Combinations

This column lists all load cases, load combinations, and result combinations defined in RFEM.

To transfer the selected entries to the *Selected for Design* section on the right, click [▶]. Alternatively, you can double-click the items. To transfer the entire list to the right, click [▶▶].

To use a multiple selection, click the relevant load cases while pressing the [Ctrl] key. This allows you to transfer several load cases to the right in one go.

If a load case is marked by an asterisk (*), this means that it can't be designed: This can be either a load case without load data or an imperfection load case. If you try to select this case for design, a corresponding warning appears.



Several filter options are available below the list. These options make it easier to assign loadings sorted by load cases, load combinations, or action categories. The buttons have the following functions:

	Selects all load cases in the list
	Inverts the selection of load cases

Table 3.1: Buttons in the tab *Load Combinations*

Selected for Design

The right column lists the load cases, load combinations, and result combinations selected for design. To remove the selected entries from the list, click [◀] or just double-click them.

To empty the entire list, click [◀◀].

You can assign the load cases, load combinations, and result combinations to the following design situations:

- *Permanent and transient*
- *Accidental*

This classification controls the partial safety factors γ_c and γ_s according to EN 1992-1-1, Table 2.1 (see Figure 3.8, page 36 and Figure 3.47, page 51).

You can change the design situation by clicking [▼] at the end of the input field.

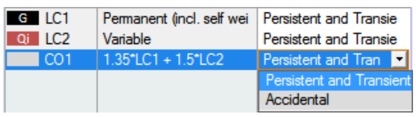


Figure 3.9: Assigning the design situation

Here, you can also use a multiple selection by clicking the relevant entries while pressing the [Ctrl] key.

The design of an enveloping max/min result combination is faster than if you just select all load cases and load combinations for design. For the design of a result combination, consider the information in chapter 2.1.

Comment

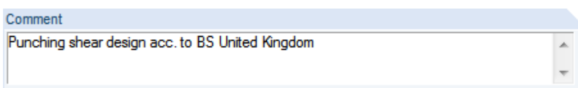


Figure 3.10: User-defined comment

In this input field, you can write your own comments.

3.3.2 Materials and Surfaces

The 1.2 *Materials and Surfaces* window consists of two parts. The section above lists the concrete classes and steel grades that are relevant for the design. For surfaces, all *Materials* of the category concrete used in RFEM are preset.

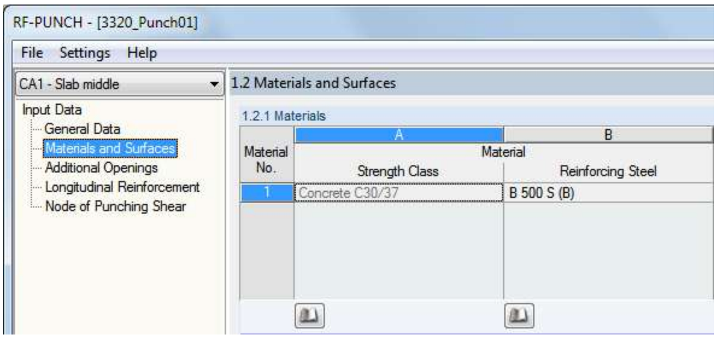


Figure 3.11: Window 1.2 *Materials and Surfaces*, Table 1.2.1 *Materials*

To open the list for the selection of a concrete strength class or steel grade for the chosen standard, click in a row of a concrete or steel grade, and then click the appearing [▼] button.

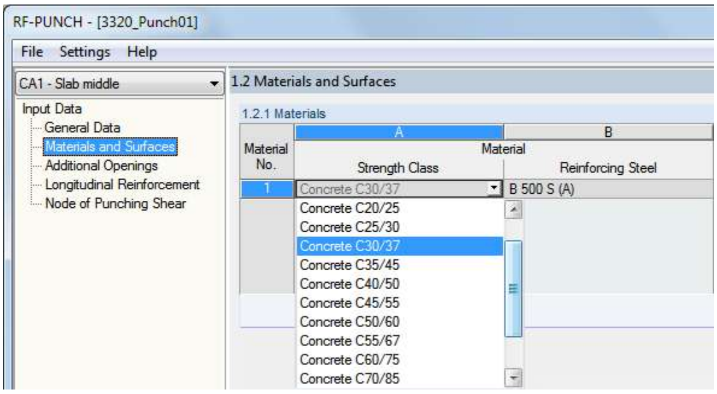
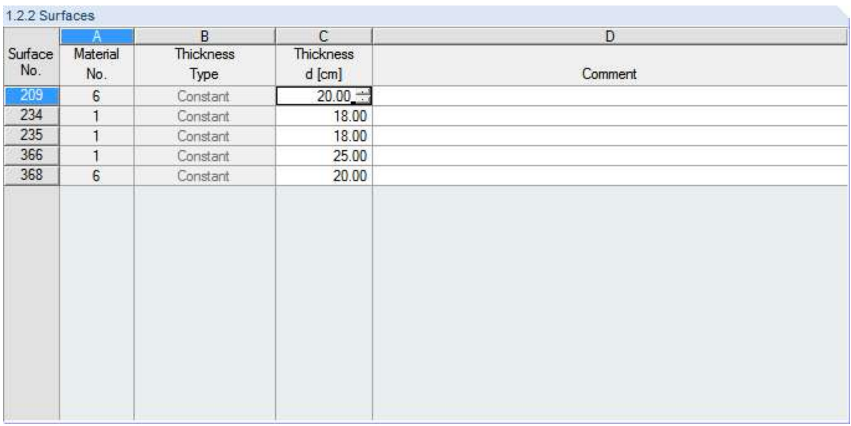


Figure 3.12: Changing the concrete strength class

The materials can also be selected in the libraries (see the following page).

The section below lists the surfaces that are relevant for the design.



1.2.2 Surfaces

Surface No.	A Material No.	B Thickness Type	C Thickness d [cm]	D Comment
209	6	Constant	20.00	
234	1	Constant	18.00	
235	1	Constant	18.00	
366	1	Constant	25.00	
368	6	Constant	20.00	

Figure 3.13: Window 1.2 *Materials and Surfaces*, Table 1.2.2 *Surfaces*

The material numbers defined above are assigned to the individual *Surfaces*.

Column C shows the preset surface thicknesses from RFEM. If necessary, you can change them for the design in RF-PUNCH.

Material Library

The library stores many materials. To access the libraries for concrete and reinforced steel, click [Library].

Figure 3.14: Button [Concrete Library]

The following dialog box appears:

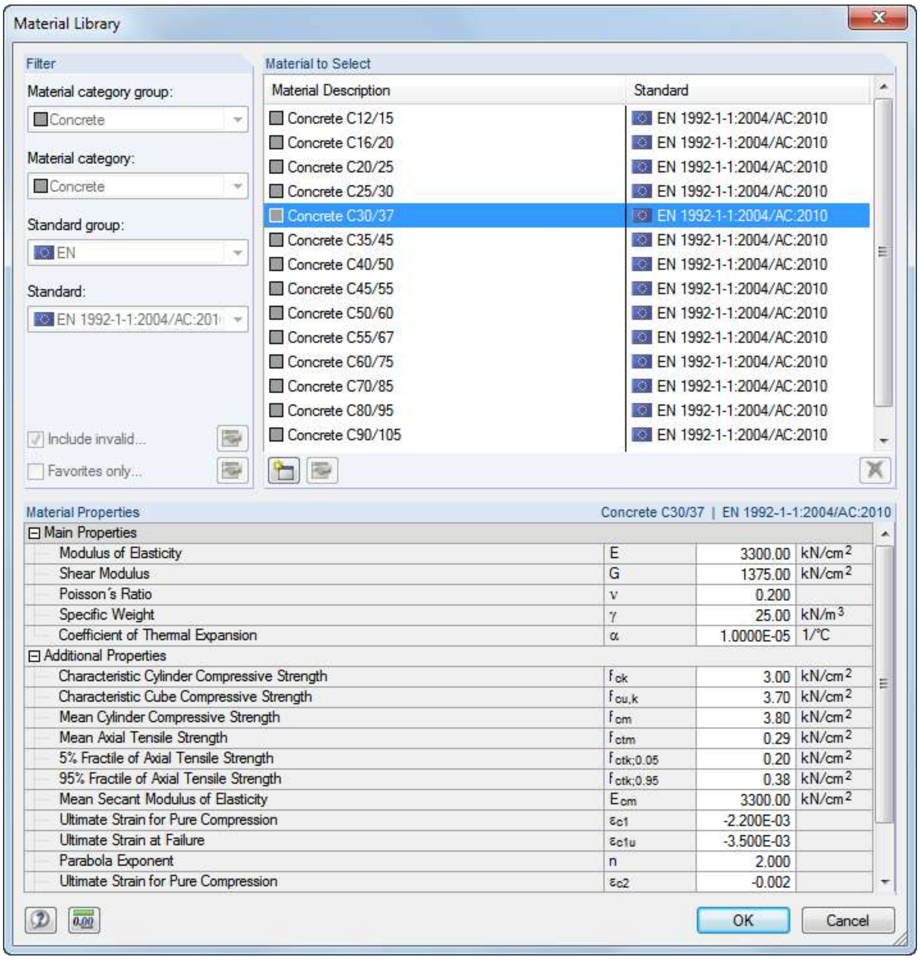


Figure 3.15: Dialog box *Material Library*

In the *Filter* section, the design relevant materials are preset in such a way that no other categories or standards are accessible. You can select the desired concrete strength class from the *Material to Select* list; the properties of the selected material are shown in the section below the list.

To transfer the selected concrete to module window 1.2, click [OK] or press [↵].

Chapter 4.3 of the RFEM manual describes how to filter, add, or reorganize the materials.

A reinforcing steel must be assigned to each concrete strength class. To open the steel library, click [Reinforcing Steel Library].

Figure 3.16: Button [Reinforcing Steel Library]

The following dialog box appears:

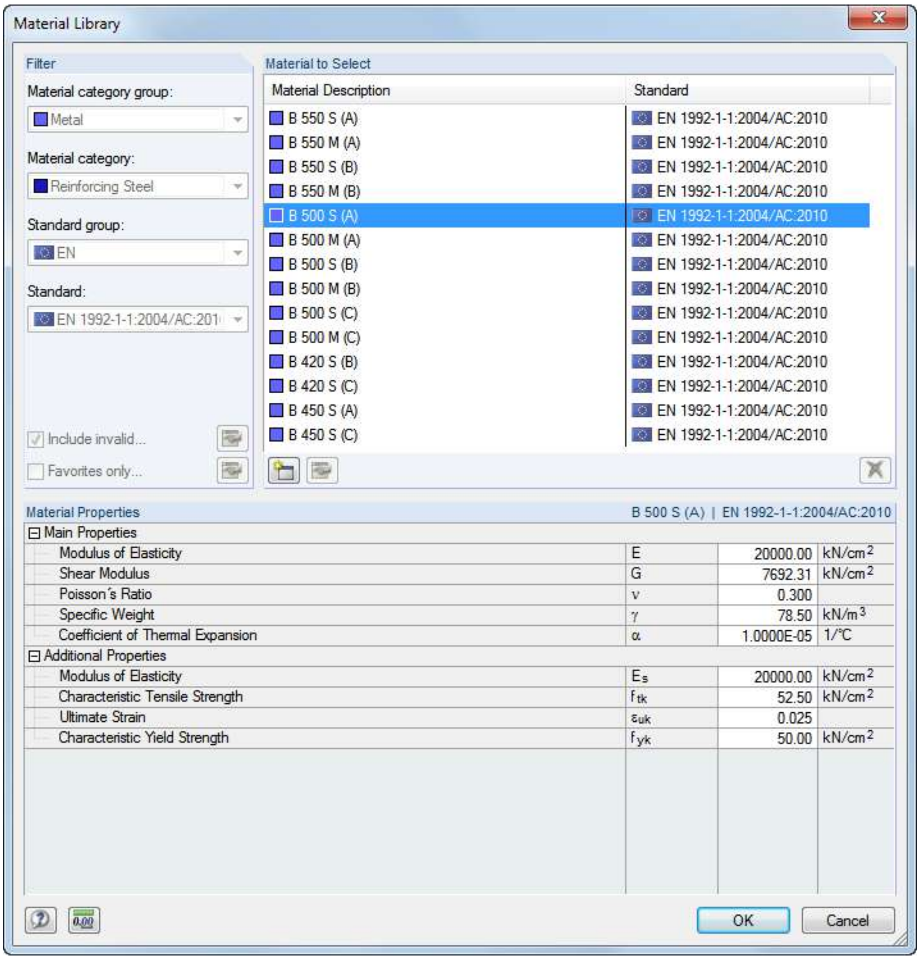


Figure 3.17: Dialog box *Material Library*

In the *Filter* section, the reinforcing steels allowed by the selected standard are preset.

3.3.3 Additional Openings

All openings from the RFEM model are automatically considered in the punching design. In the 1.3 *Additional Openings* window, you can define recesses that do not influence the stiffness of the RFEM model: These openings are considered only for the punching shear design.

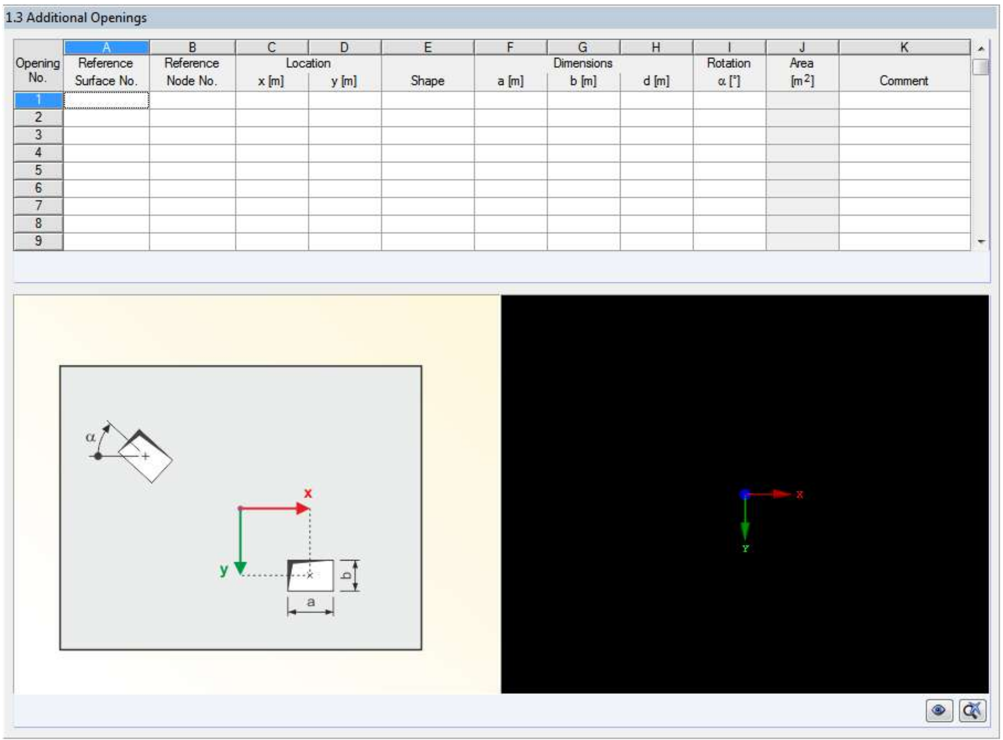
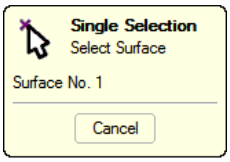


Figure 3.18: Window 1.3 *Additional Openings*

In the left part below the table, there is a graphic illustrating the parameters of the definition. The interactive graphic to the right represents the surface for which an additional opening is to be specified.

At first, window 1.3 looks as shown above. The graphic window on the right, however, does not show a surface, because no surface or opening was selected. To specify a surface containing an opening, enter the number of the surface in the *Reference Surface* column. Alternatively, you can click [...] to graphically select the surface in the RFEM work window.



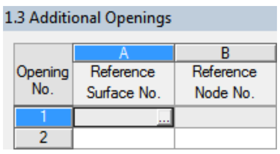


Figure 3.19: Button [...] for selecting the surface

If the number of the surface is given, this surface is also shown in the graphic window (see the following figure).

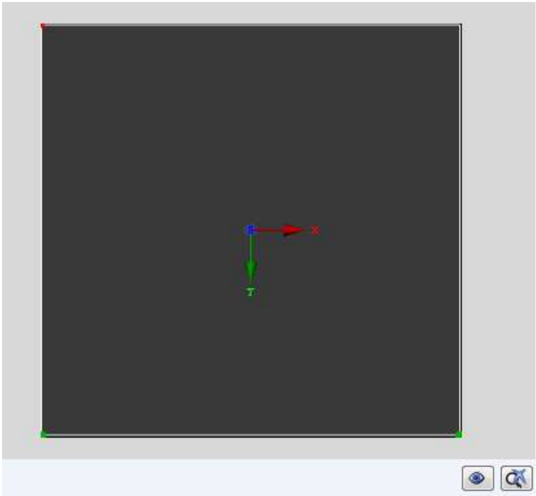


Figure 3.20: Representation of the surface

The graphic also shows the nodes, for which a punching shear design is to be performed (in this figure: node in the middle of the surface).

In the following table columns, you can now define the location of the opening in the surface. To this end, you can enter the *Reference Node No.* in column B, or click [...] to determine them in the RFEM work window. As reference node, you can select any node of the selected surface.

Next, specify the coordinates of the center of the opening relative to the reference node in both *Location* columns, or click [...] to determine them graphically.

Opening No.	A Reference Surface No.	B Reference Node No.	C Location x [m]	D y [m]
1	1	5	1.000	2.000

Figure 3.21: Reference node and location

If you leave the "0" as reference node, then the definition of the location refers to the distance in x- and y-direction of the local surface coordinate system as shown in the graphic on the lower right of the module window.

In column E, you then select the *Shape* of the opening from the drop-down list.

Opening No.	A Reference Surface No.	B Reference Node No.	C Location x [m]	D y [m]	E Shape
1	1	5	1.000	2.000	Rectangular
					Rectangular
					Circular

Figure 3.22: Shape of opening

Depending on the selection in the previous column, you can specify either the length and the width or the diameter of the opening in the *Dimensions* column.

For a rectangular opening, you can also define a rotation (positive if clockwise, relative to the positive x-axis of the coordinate system of the surface).

If all properties of the additional opening are defined, the opening is shown in the graphic.

Opening No.	A	B	C	D	E	F	G	H	I	J
	Reference Surface No.	Reference Node No.	Location x [m]	y [m]	Shape	Dimensions a [m]	b [m]	d [m]	Rotation α [°]	Area [m²]
1	1	5	1.000	2.000	Rectangular	0.50	0.80		30.00	0.40

Figure 3.23: Rectangular opening with rotation

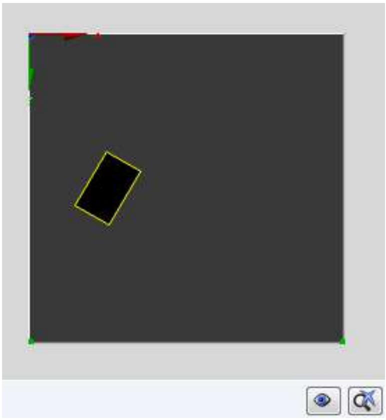


Figure 3.24: Graphic of the opening

Below the graphic, you find the [👁] button. By clicking it, you open a large window showing the surface.

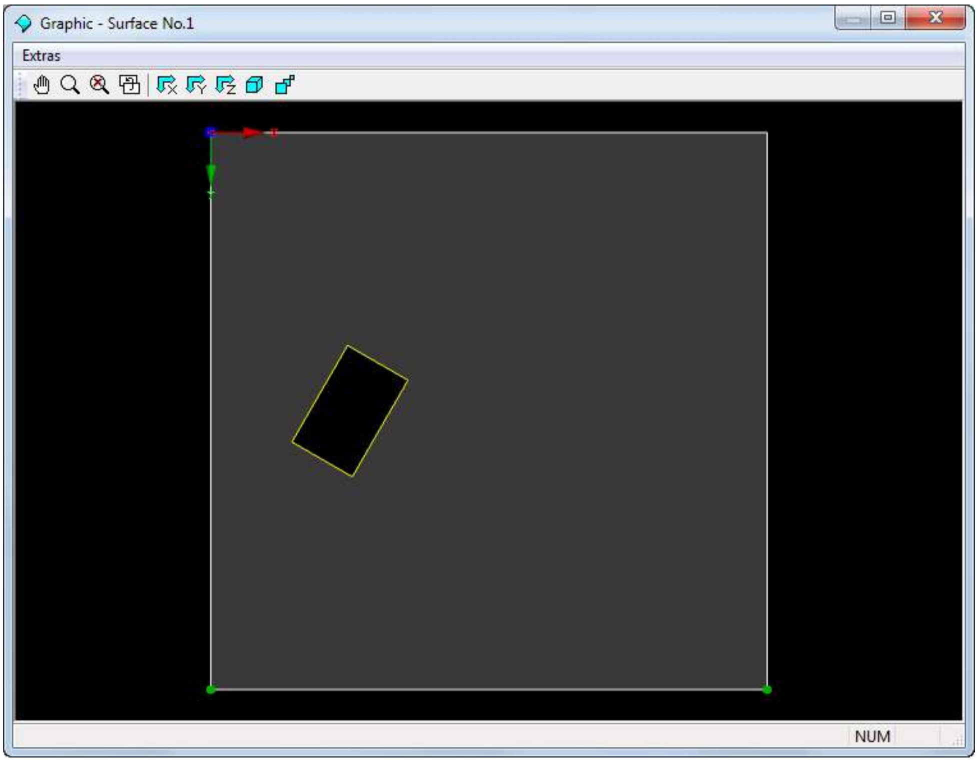


Figure 3.25: Graphic of the surface with additional opening

3.3.4 Longitudinal Reinforcement

In the 1.4 *Longitudinal Reinforcement* window, you can specify the number and direction of the reinforcement layers as well as the concrete covers for each surface . You can specify different parameters for the top and bottom surface of the slab.

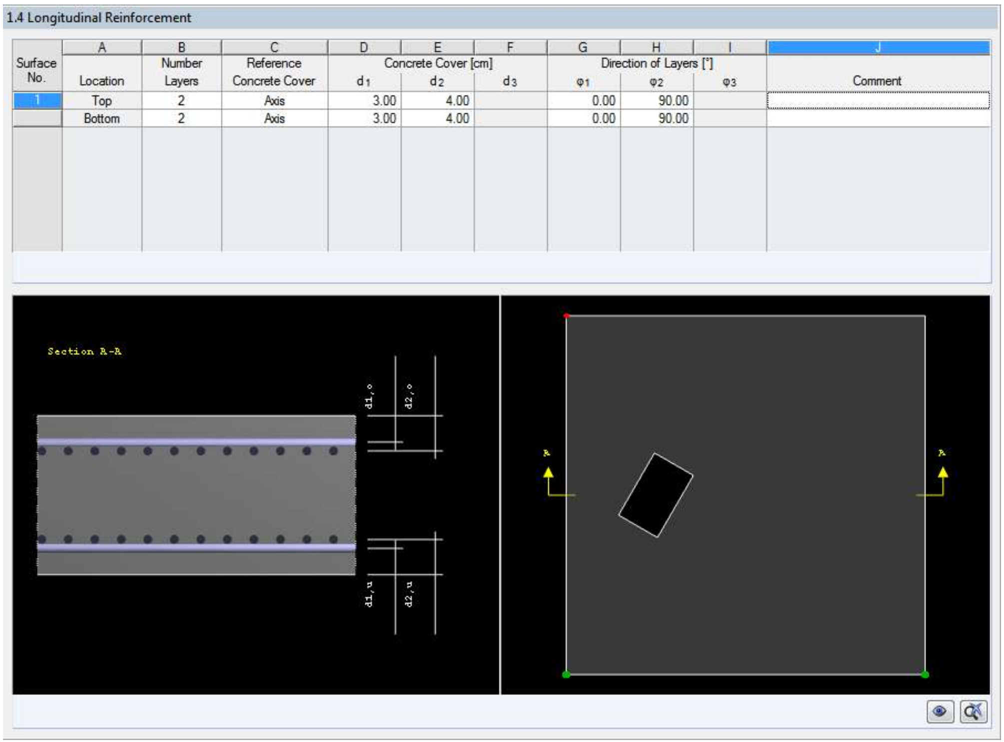


Figure 3.26: Window 1.4 *Longitudinal Reinforcement*

Below the table, two interactive graphics illustrate the meaning of the specifications. The left graphic shows a section through the slab. When you specify the concrete cover of a layer, the schematically represented rebars are selected in the graphic. The position of the section is shown in the graphic on the right.

3.3.5 Node of Punching Shear

The 1.5 *Node of Punching Shear* window consists of two tables and a graphic window showing the node selected in the table above. The nodes specified for the punching shear design appear green, the selected node yellow.

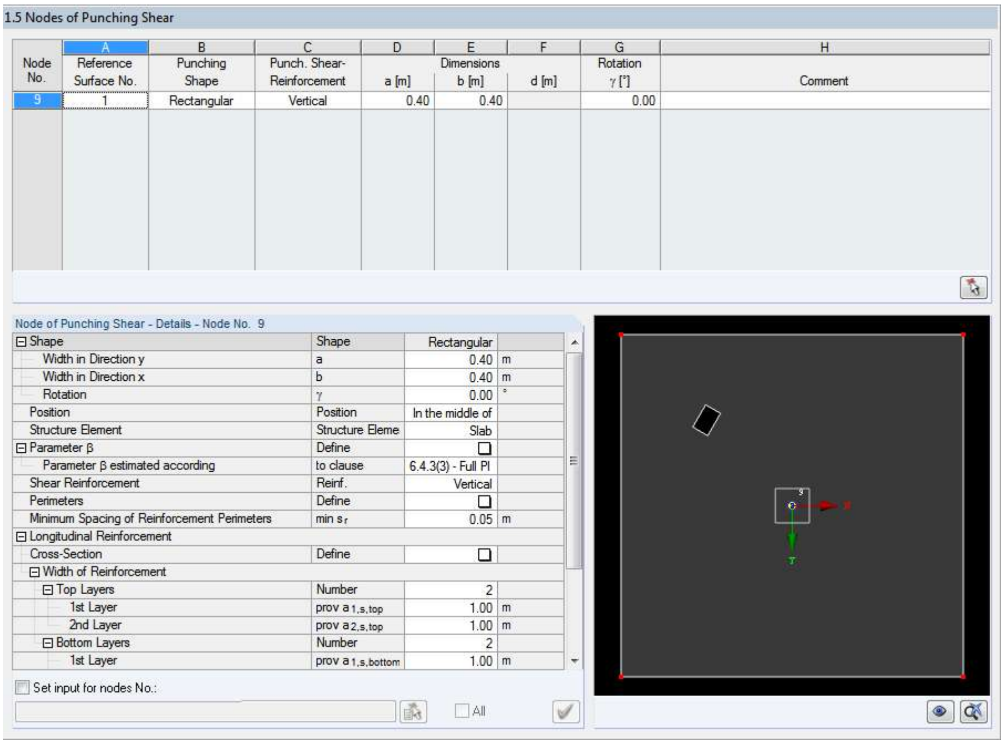


Figure 3.27: Window 1.5 *Node of Punching Shear*

The upper table shows an overview of all nodes selected for the punching shear design in the 1.1 *General Data* window. It also lists the most important characteristics (see Figure 3.28).

To define further characteristics of a node, click in the row of the relevant node in the table above. In the *Node of Punching Shear - Details* table, you can make further specifications for the selected node (see chapter 3.3.5.2).

1.5 Nodes of Punching Shear

	A	B	C	D	E	F	G
Node No.	Reference Surface No.	Punching Shape	Punch. Shear-Reinforcement	Dimensions a [m]	b [m]	d [m]	Rotation γ [°]
9	1	Rectangular	Vertical	0.40	0.40		0.00

Figure 3.28: Main table with the most important characteristics of the node of punching shear

Column A controls the reference surface of the node.

In column B, you can select the *Punching Shape* from the drop-down list upon clicking the [▼] button. You can choose between a rectangular and a circular shape of the loaded area.

Depending on the selection in the *Dimensions* columns, you can specify the length and width or the diameter of the column. For a rectangular shape of the loaded area, you can also define a rotation.

In column C, you define the type of the *Punching Shear Reinforcement*. There are various options that you can select from (see the following figure).

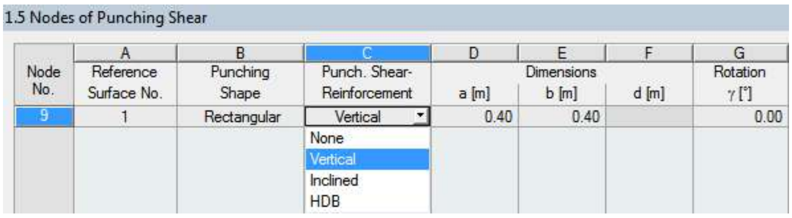


Figure 3.29: Selection of the punching shear reinforcement

If you select *None*, the program checks during the analysis only if the sole shear force resistance of the slab is sufficient. If you select *Vertical* or *Inclined* for the punching shear reinforcement, this has a decisive influence on the design process.

If you select *HDB*, the program designs with the design software by Halfen-Deha, a producer of shear rails (separate installation required). To start this program from RF-PUNCH, click [...].

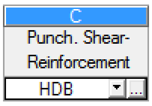


Figure 3.30: Starting the design software by Halfen-Deha

You can start the design program HDB from RF-PUNCH only for certain standards:

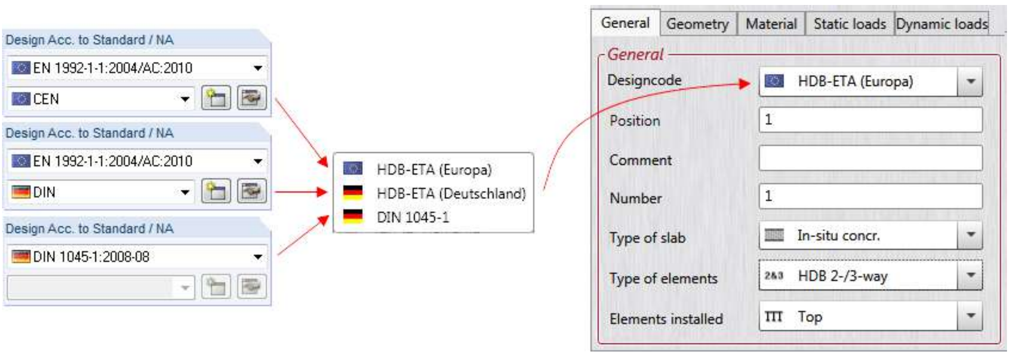


Figure 3.31: Standards for HDB

3.3.5.1 Shear Rails Software Halfen HDB

The following start window of HDB appears.

Figure 3.32: Start window of HDB

Click [Start]. The following dialog box appears.

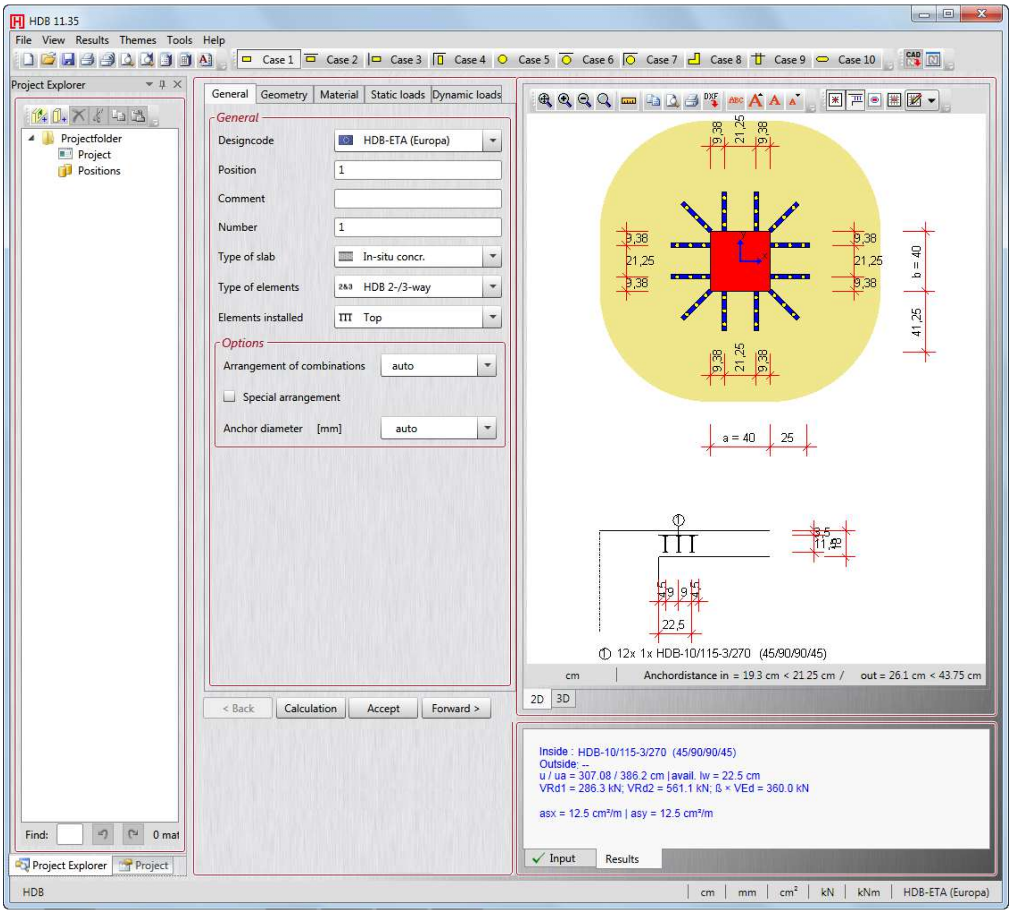


Figure 3.33: HDB dialog box for determining shear rails

Once you've completed the specifications in the tabs *General*, *Geometry*, *Material*, and *Static loads*, you can start the [Calculation].

After the calculation, the results are presented as 2D and 3D graphics.

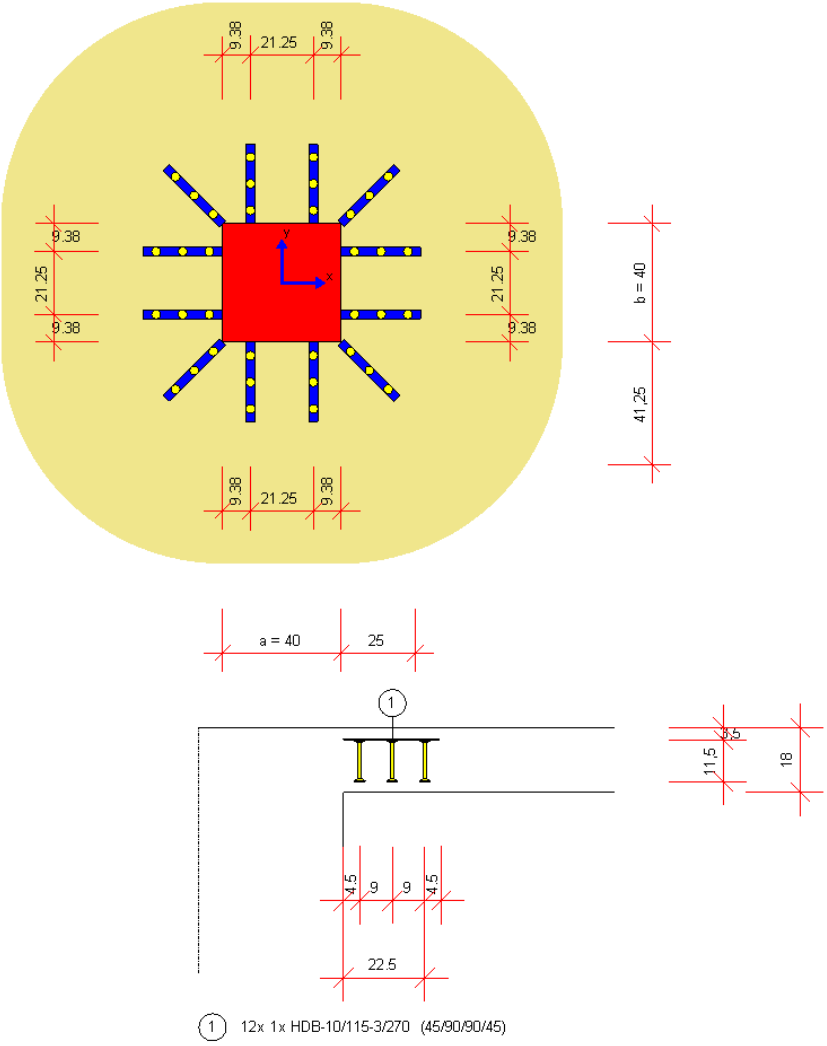


Figure 3.34: HDB results in 2D (plan view and section)

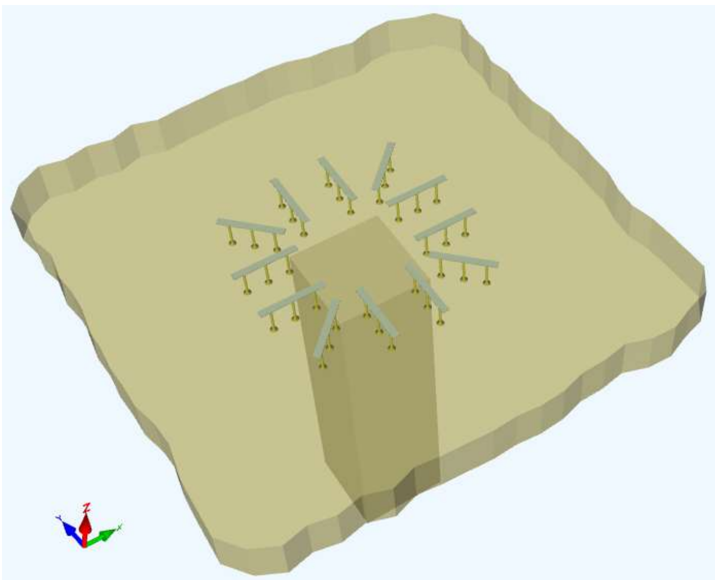


Figure 3.35: HDB results in 3D

3.3.5.2 Details Table for Design

In the *Node of Punching Shear - Details* table, the exact specifications for the design are prepared.

⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.40	m
Width in Direction x	b	0.40	m
Rotation	γ	0.00	°
Position	Position	In the middle of	
Structure Element	Structure Eleme	Slab	
⊟ Parameter β	Define	☐	
Parameter β estimated according	to clause	6.4.3(3) - Full Pl	
Shear Reinforcement	Reinf.	Vertical	
Perimeters	Define	☐	
Minimum Spacing of Reinforcement Perimeters	min s_r	0.05	m
⊟ Longitudinal Reinforcement			
Cross-Section	Define	☐	
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.00	m
2nd Layer	$b_{2,top}$	1.00	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.00	m
2nd Layer	$b_{2,bottom}$	1.00	m
Punching Load	DefV_{sd}	Determine	
Axial Force	N_{cp}	Determine	
⊟ Deductible Surface Load			
Value	q	0.00	N/mm^2
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	

Figure 3.36: Detail table

The shape of the loaded area can be *Rectangular* or *Circular*.

⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.40	m
Width in Direction x	b	0.40	m
Rotation	γ	0.00	°

⊟ Shape	Shape	Circular	
Width	D	0.40	m

Figure 3.37: Shape

The position of the column can be *In the middle of*, at the *Edge*, or in the *Corner* of the surface.

Position	Position	In the middle of

Position	Position	Edge	
⊟ Next Edge	Line No.	1	
Distance to Edge	d_R	0.200	m

Position	Position	Corner	
⊟ Next Edge	Line No.	1	
Distance to Edge	d_R	0.000	m
⊟ Next Edge	Line No.	2	
Distance to Edge	d_R	0.000	m

Figure 3.38: Position

The structural element can be a *Slab* or a *Foundation*.

Structure Element	Structure Eleme	Slab
		Foundation

Figure 3.39: Structural element: slab or foundation

The parameter (factor) β can be *estimated* or manually *defined*.

⊟ Parameter β	Define	☐
Parameter β estimated according	to Article	6.4.3(3) - Full Plastic Shear Distribution
		6.4.3(6) - Constant Factors acc. to Fig. 6.21N

⊟ Parameter β	Define	☑
Parameter β estimated according	to clause	1.500

Figure 3.40: Factor β

The punching shear reinforcement can be *None*, *Vertical*, *Inclined*, or computed by the program *HDB*. HDB is possible only for the standards EN (CEN), DIN EN, and DIN 1045-1:2008-08.

Shear Reinforcement	Reinf.	Vertical
		Inclined
		HDB

⊟ Shear Reinforcement	Reinf.	Inclined	
Inclination	α	45.00	°

Figure 3.41: Punching reinforcement

The control perimeters are calculated automatically; you can also *Define* them manually.

Perimeters	Define	☐

⊟ Perimeters	Define	☑	
⊟ Basic Control Perimeter			
Distance	$l_{w,crit}$	0.29	m
Perimeter	u_{crit}	0.86	m
⊟ Iterative Critical Section for Foundation	Define	☑	
Distance to Load Area	$l_{w,it}$	0.29	m
⊟ Sections for Analysis of Punching Shear Reinforcei	Define	☑	
Number	n_i	3	
Distance to Load Area	Define	☑	
1. Distance	$l_{w,1}$	0.30	m
Radial Spacing	s_r	0.20	m
⊟ Outer Section	Define	☑	
Distance to Load Area	$l_{w,a}$	2.00	m

Figure 3.42: Control perimeters

The longitudinal reinforcement for the shear force resistance is calculated by the program for both surfaces. Alternatively, you can *Define* it manually.

⊟ Longitudinal Reinforcement			
Cross-Section	Define	☐	

⊟ Longitudinal Reinforcement			
⊟ Cross-Section	Define	☑	
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	0.00	cm^2/m
2nd Layer	$b_{2,top}$	0.00	cm^2/m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	0.00	cm^2/m
2nd Layer	$b_{2,bottom}$	0.00	cm^2/m
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.00	m
2nd Layer	$b_{2,top}$	1.00	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.00	m
2nd Layer	$b_{2,bottom}$	1.00	m

Figure 3.43: Longitudinal Reinforcement

The punching load is usually calculated by the program. You can also *Determine* it manually.

Punching Load	Def V_{sd}	Determine

⊟ Punching Load	Def V_{sd}	Enter	
Value	V_{sd}	100.00	kN
Direction	V_{sd}-Direction	In +Z	

Figure 3.44: Punching load

The same is true for the axial force in the slab.

Axial Force	N_{cp}	Determine

⊟ Axial Force	N_{cp}	Enter	
Magnitude	N_{cp}	0.00	kN/m

Figure 3.45: Axial force

The deductible surface load can be specified at a distance up to 1.0 d for the slab or the foundation or up to a_{crit} only for the foundation.

⊟ Deductible Surface Load			
Value	q	0.00	N/mm²
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	
		a_crit	

Figure 3.46: Deductible surface load

3.3.6 Design Details

Details...

To check specific factors and, if necessary, adjust them, click the [Details] button, which is available in all input windows. The factors depend on the standard and the National Annex.

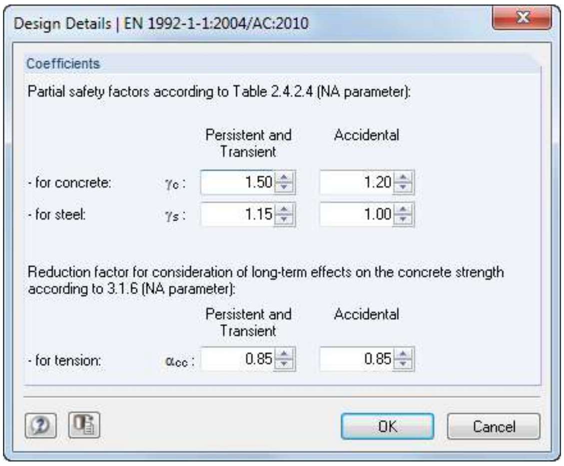


Figure 3.47: Dialog box *Design Details* for EN 1992-1-1:2004/AC:2010

In the *Details* dialog box, you can check the material partial safety factors for the various design situations and adjust them, if necessary. Table 2.1N of EN 1992-1-1 contains the recommended values for γ_c and γ_s. The country-specific values are given in the National Annexes.

This dialog box also controls the factor α_{cc} used for taking into account long-term effects (influence of creep and shrinkage) for the various design situations according to EN 1992-1-1 clause 3.1.6 (1).

3.4 Results Windows

3.4.1 Punching Shear Designs

Immediately after the [Calculation] is completed, the 2.1 *Punching Shear Design* window is shown. It consists of two tables and an interactive graphic window.

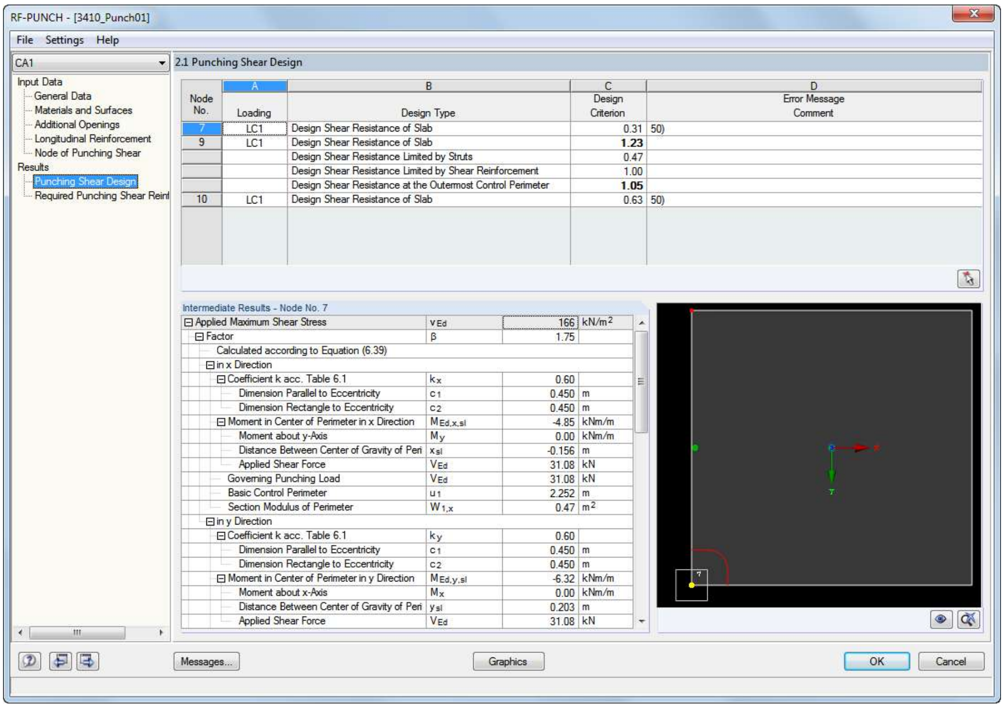


Figure 3.48: Window 2.1 *Punching Shear Design*

Summary Table

The first column of the upper table lists all *Nodes* selected for the punching shear design. The *Loading* column shows the load case, load combination, or result combination with the governing punching load. The *Design Type* column shows the descriptions of the individual checks included in the total design of the node.

The *Check Criterion* column provides quantitative and qualitative information about whether the design is or is not successful. The last column shows message numbers for some rows. The corresponding message is shown at the bottom of the module window, providing comments on the result of the design.

The result table is connected with the interactive graphic: If you click in the row of a node, the lower-right graphic shows the node together with the surface in the lower-right graphic.

Intermediate results

The lower table shows all intermediate steps of the design selected in the summary table above. It starts with the determination of the governing stress. Next comes the determination of the resistance. In the design, the two magnitudes are set in relation to each other and the check criterion is determined from them.

The table has a hierarchical structure, thus allowing for a clear and concise representation of the information. The final results of a calculation are on a higher level of representation than the respective intermediate results. To see the lower levels, click [+].

Graphical Selection

From the tables, you can graphically select an object upon clicking [↖]. It is located below the summary table on the right.

2.1 Punching Shear Design

Node No.	A Loading	B Design Type	C Design Criterion	D Error Message Comment
7	LC1	Design Shear Resistance of Slab	0.31	50)
9	LC1	Design Shear Resistance of Slab	**1.23**	
		Design Shear Resistance Limited by Struts	0.47	
		Design Shear Resistance Limited by Shear Reinforcement	1.00	
		Design Shear Resistance at the Outermost Control Perimeter	**1.05**	
10	LC1	Design Shear Resistance of Slab	0.63	50)

Figure 3.49: Button [↖]

If you click the button, the RFEM work window appears. In the model, you can now select one of the punching nodes that were chosen for design. Then, you return to the module RF-PUNCH. In the table, you can now see the results of this node.

Intermediate results

The intermediate results of the punching shear designs are arranged by different levels of representation. The highest levels are:

Intermediate Results - Node No. 7

⊞ Applied Maximum Shear Stress	v_{Ed}	738	kN/m²
⊞ Punching Shear Resistance without Punching Reinforcement			
⊞ Design			

Figure 3.50: Intermediate results - main entries

The lower levels are shown in the following figures.

⊟ Applied Maximum Shear Stress	v_{Ed}	738	kN/m²
⊟ Factor	β	3.12	
Calculated according to Equation (6.39)			
⊟ in x Direction			
⊞ Coefficient k acc. Table 6.1	k_x	0.60	
⊞ Moment in Center of Perimeter in x Direction	$M_{Ed,x,sl}$	11.25	kNm/m
Governing Punching Load	V_{Ed}	31.08	kN
Basic Control Perimeter	u_1	0.906	m
Section Modulus of Perimeter	$W_{1,x}$	0.13	m²
⊟ in y Direction			
⊞ Coefficient k acc. Table 6.1	k_y	0.60	
⊞ Moment in Center of Perimeter in y Direction	$M_{Ed,y,sl}$	11.25	kNm/m
Governing Punching Load	V_{Ed}	31.08	kN
Basic Control Perimeter	u_1	0.906	m
Section Modulus of Perimeter	$W_{1,y}$	0.13	m²
⊟ Applied Shear Force	V_{Ed}	31.08	kN
Load Case	LF	LF1	
Unloaded Surface	Side	Upper Surface	
⊟ Basic Control Perimeter	u_1	0.906	m
Distance of Load Area	$l_{w,1}$	0.290	m
⊟ Mean Static Depth	d	14.50	cm
Effective Depth 1st Layer	d_1	14.00	cm
Effective Depth 2nd Layer	d_2	15.00	cm
⊞ Punching Shear Resistance without Punching Reinforcement			
⊞ Design			

Figure 3.51: Subentries of *Applied Maximum Shear Stress*

⊞ Applied Maximum Shear Stress	v_{Ed}	166	kN/m²
⊟ Punching Shear Resistance without Punching Reinforcement			
⊟ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	0	kN/m²
Value of National Annex	$C_{Rd,c}$	0.12	
Factor (Influenced by Thickness)	k	2.00	
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	15.00	cm
Effective Depth 2nd Layer	d_2	14.00	cm
Mean Static Depth	d	14.50	cm
⊟ Mean Longitudinal Reinforcement Ratio			
⊞ Reinf. Ratio of 1st Layer	ρ_1	0.000	
⊞ Reinf. Ratio of 2nd Layer	ρ_2	0.000	
Mean Longitudinal Reinforcement Ratio	ρ	0.000	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Characteristic Concrete Comprehensive Strength	f_{ck}	30.00	N/mm²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membrane Force	N_{cp}	0.00	kN/m
⊟ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	542	kN/m²
Value of National Annex	v_{min}	542	kN/m²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membrane Force	N_{cp}	0.00	kN/m
Governing Shear Resistance	$v_{Rd,c}$	542	kN/m²
⊞ Design			

Figure 3.52: Subentries of *Punching Shear Resistance*

⊞ Applied Maximum Shear Stress	v_{Ed}	166	kN/m²
⊞ Punching Shear Resistance without Punching Reinforcement			
⊟ Design			
Applied Maximum Shear Stress	v_{Ed}	166	kN/m²
Governing Shear Resistance	$v_{Rd,c}$	542	kN/m²
Check Criterion	Criterion	0.31	

Figure 3.53: Subentries of *Design*

3.4.2 Required Punching Shear Reinforcement

The makeup of the second output window also depends on the type of reinforcement.

2.2 Required Punching Shear Reinforcement

Node No.	A Loading	B Reinforcement Type	C Reinforcement Area	D Unit	E Error Message Comment
7	LC1	Top Surface in Direction of φ_1	0.00	cm²/m	
		Top Surface in Direction of φ_2	0.00	cm²/m	
		Bottom Surface in Direction of φ_1	0.00	cm²/m	
		Bottom Surface in Direction of φ_2	0.00	cm²/m	
		1. Perimeter	0.73	cm²	
		2. Perimeter	0.73	cm²	
		3. Perimeter	0.73	cm²	
9	LC1	Top Surface in Direction of φ_1	0.00	cm²/m	
		Top Surface in Direction of φ_2	0.00	cm²/m	
		Bottom Surface in Direction of φ_1	0.00	cm²/m	

Intermediate Results - Node No. 7

⊟ For Design Shear Resistance			
⊟ Required Ratio of Longitudinal Reinforcement	ρ	0.000	
⊞ Reinf. Ratio of 1st Layer	ρ_1	0.000	
⊞ Reinf. Ratio of 2nd Layer	ρ_2	0.000	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Req. Reinforcement	req a_s	0.00	cm²/m
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{1,t}$	1.00	m
Defined Longitudinal Reinforcement	prov $a_{s,1,t}$	0.00	cm²/m

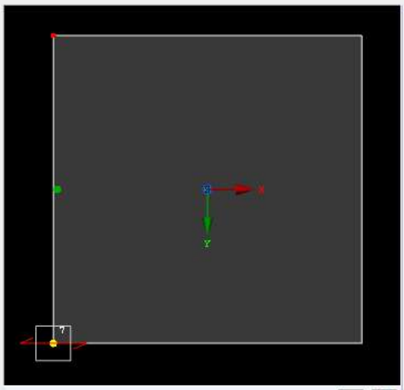


Figure 3.54: Window 2.2 *Required Punching Shear Reinforcement*

This window consists of a summary table, a details table, and an interactive graphic window.

Summary Table

The first column lists all *Nodes*, for which the punching shear design was performed. You can also select a node graphically in the RFEM model upon clicking [↖]. The *Loading* column shows the load case, load combination, or result combination with the governing punching load.

The *Reinforcement Type* column lists the descriptions of the individual reinforcements. The number of reinforcement layers is specified in the 1.4 *Longitudinal Reinforcement* module window. If two reinforcement layers were specified at the top of the slab, then the first two cells show the data for the longitudinal reinforcement at the top of the slab for the reinforcement directions φ_1 and φ_2 according to window 1.4. If there are three layers of reinforcement, a third column for the reinforcement direction φ_3 follows. The next columns show the respective definitions for the longitudinal reinforcement at the bottom of the slab. For each node, the output ends with information on the punching shear reinforcement for the individual control perimeters.

The *Reinforcement Area* column shows the cross-sections of the reinforcements to be placed. Column D shows the *Unit*. The required longitudinal reinforcement is always shown relative to one meter of the slab width, whereas the punching shear reinforcement represents an absolute value.

The last column shows numbers of messages, which are explained at the bottom of the module window.

Intermediate results

The details table shows all intermediate steps for the determination of the reinforcement that apply to the node selected above.

The following figures show different levels of the intermediate results.

Intermediate Results - Node No. 7			
⊟ For Design Shear Resistance			
⊟ Required Ratio of Longitudinal Reinforcement	ρ	0.000	
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.000	
Required Longitudinal Reinforcement	req $a_{s,1}$	0.00	cm²/m
Effective Depth 1st Layer	d_1	15.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.000	
Required Longitudinal Reinforcement	req $a_{s,2}$	0.00	cm²/m
Effective Depth 2nd Layer	d_2	14.00	cm
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Req. Reinforcement	req a_s	0.00	cm²/m
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{1,t}$	1.00	m
Defined Longitudinal Reinforcement	prov $a_{s,1,t}$	0.00	cm²/m

Figure 3.55: Subentries *For Design Shear Resistance* and *Defined Longitudinal Reinforcement*

Intermediate Results - Node No. 7			
⊟ Calculation of Number of Inner Perimeters			
Distance Between Second and Last Inner Perimete	x_{in}	0.21	m
Max. Allowed Radial Spacing of Inner Perimeters	max s_r	0.11	m
Calc. Req. Number of Spacings	$n_{dis,calc}$	1.91	
Designed Number of Spacings	n_{dis}	2	
Designed Number of Perimeters	n_{in}	3	
⊟ Position of 1. Section			
Perimeter of Section	u	0.56	m
Distance to Load Area	l_w	0.07	m
⊟ Applied Maximum Shear Stress	v_{Ed}	738	kN/m^2
⊞ Factor	β	3.12	
⊞ Applied Shear Force	V_{Ed}	31.08	kN
⊞ Basic Control Perimeter	u_1	0.906	m
⊞ Mean Static Depth	d	14.50	cm
⊟ Punching Shear Resistance without Punching Reinforcement			
⊞ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	0	kN/m^2
⊞ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	542	kN/m^2
Governing Shear Resistance	$v_{Rd,c}$	542	kN/m^2
⊟ Statically Required Shear Reinforcement			
Mean Static Depth	d	14.50	cm
Radial Spacing of Reinforcement Perimeters	s_r	0.10	m
Effective Strength of Reinforcement	$f_{ywd,ef}$	286.25	N/mm^2
⊞ Basic Control Perimeter	u_1	0.906	m
Statically Required Punching Reinforcement	$A_{sw,stat}$	0.73	cm^2
⊞ Minimum Cross-Sectional Area of One Shear Stud	$A_{sw,min,stirrup}$	0.11	cm^2
⊞ Minimum Number of Shear Studs			
⊞ Minimum Shear Reinforcement	$A_{sw,min}$	0.34	cm^2
⊟ Governing Punching Reinforcement A_{sw}			
Statically Required Punching Reinforcement	$A_{sw,stat}$	0.73	cm^2
Minimum Shear Reinforcement	$A_{sw,min}$	0.34	cm^2
Governing Punching Reinforcement	A_{sw}	0.73	cm^2

Figure 3.56: Subentries of *Perimeters*

Graphic window

The graphic window illustrates the results of the row selected in the table.

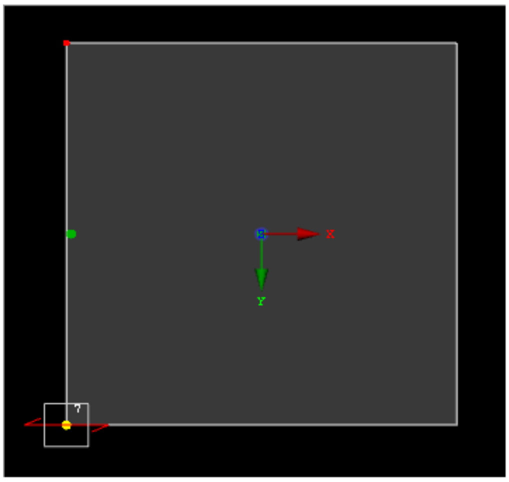


Figure 3.57: Graphic window for required punching shear reinforcement

The representation of the surface and the current node of punching shear helps you find the results of a node in the table. Furthermore, you can check the current reinforcement, which is schematically shown with its direction of reinforcement.

To open a large window representing the surface, click [👁] below this graphic.

3.5 Drop-Down Menus

The drop-down menus contain important functions for managing the RF-PUNCH cases.

3.5.1 File

To manage the RF-PUNCH cases, use the "File" menu.

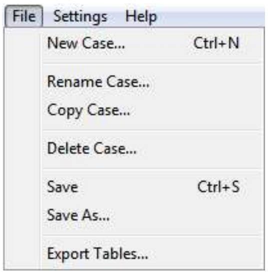


Figure 3.58: Drop-down menu *File*

New Case

This command allows you to create a new design case.

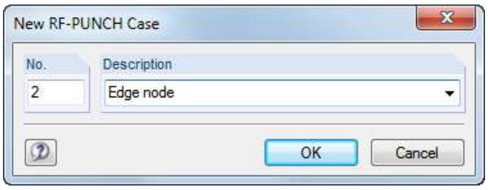


Figure 3.59: Dialog box *New RF-PUNCH Case*

In this dialog box, you enter a *number* (one that is still free) for the new design case. The *Description* will later help you select the right case from the load case list.

Clicking [OK] opens the 1.1 *General Data* module window, where you can specify the design data for this case.

Rename Case

You can also change the description of the current RF-PUNCH case.

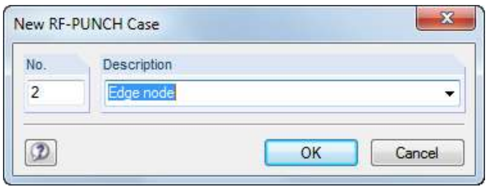


Figure 3.60: Dialog box *Rename RF-PUNCH Case*

In this dialog box, you can specify a different *Description* as well as a different *No.* for the design case.

Copy Case

You can also copy the input data of the current design case.

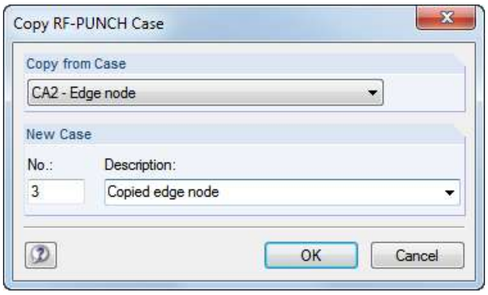


Figure 3.61: Dialog box *Copy RF-PUNCH Case*

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

Delete Case

You can also delete design cases.

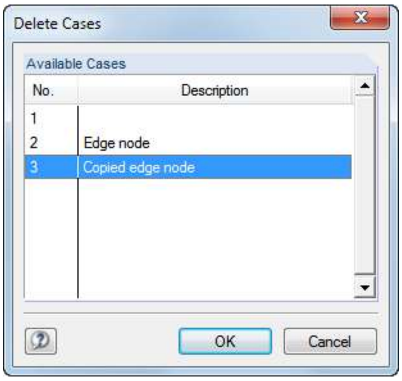


Figure 3.62: Delete RF-PUNCH Cases

To delete a design case, you first select it in the *Available Cases* list, and then delete it by clicking [OK].

3.5.2 Settings

To open the settings of the units and decimal places, use the "Settings" menu.

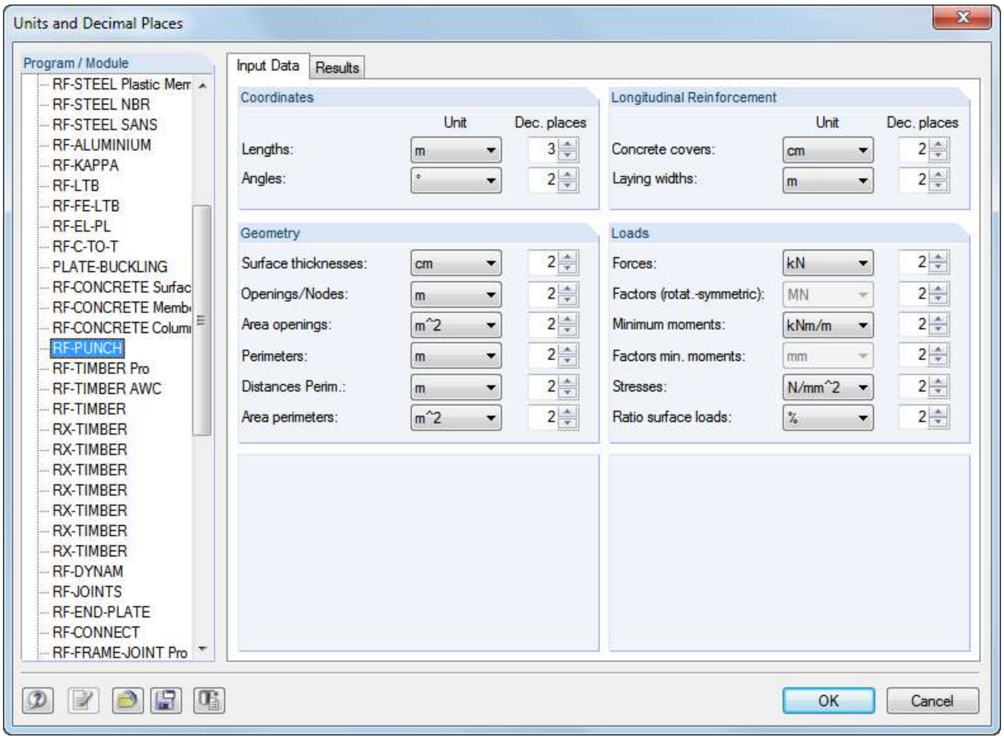


Figure 3.63: Dialog box *Units and Decimal Places*, tab *Input Data*

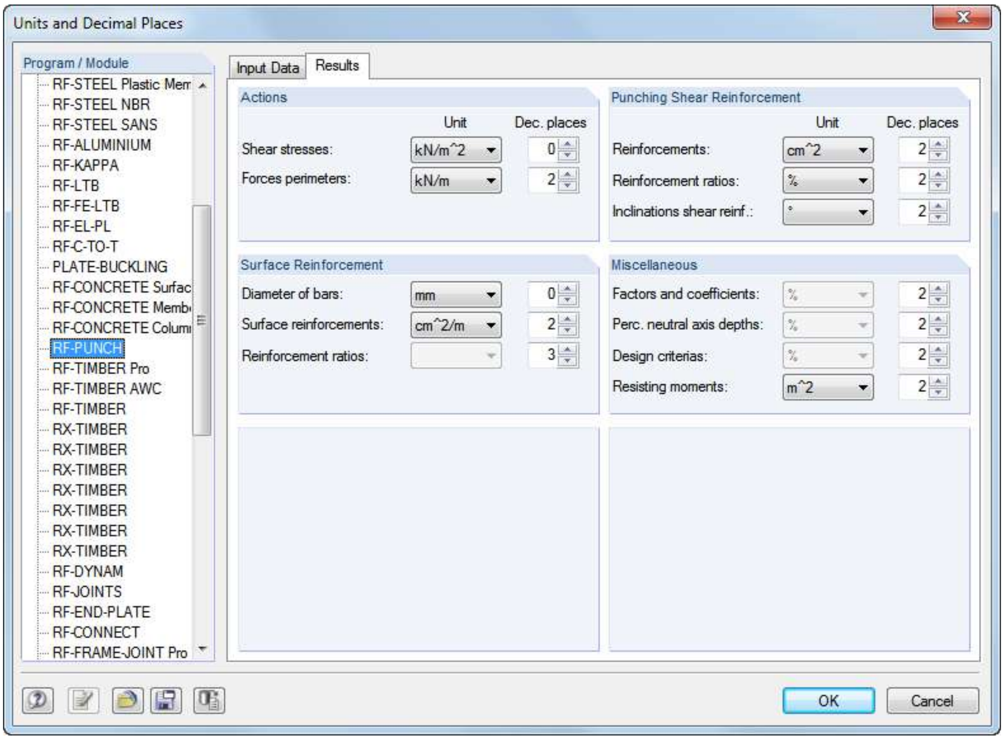


Figure 3.64: Dialog box *Units and Decimal Places*, tab *Results*

3.5.3 Help

To access the help function, use the "Help" menu.

4. Results Evaluation

4.1 Representation of Results

For the results evaluation, you can also use the RFEM work window: To go to the RFEM work window, click [Graphics]. The RFEM work window now shows the reinforcements and design internal forces. The RF-PUNCH case appears in the list of load cases.

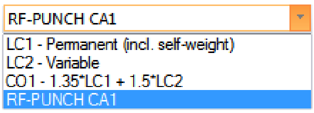


Figure 4.1: RF-PUNCH case in list of load cases

The available options of the *Results* navigator are dependent on the output options of RF-PUNCH.

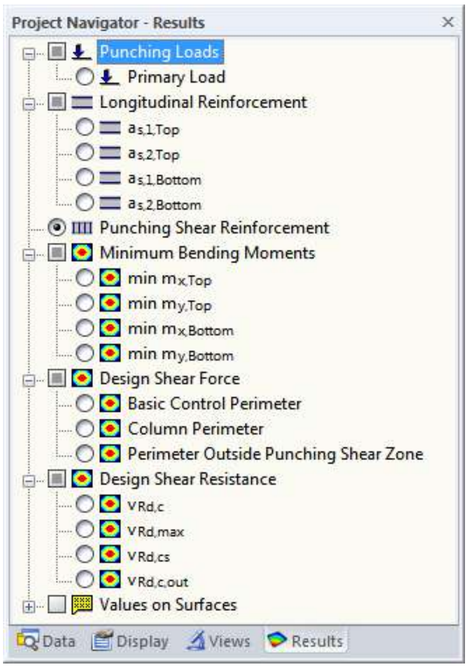


Figure 4.2: *Results* navigator for RF-PUNCH

Thus, you can visualize the different types of results on the RFEM model (see the following figure).

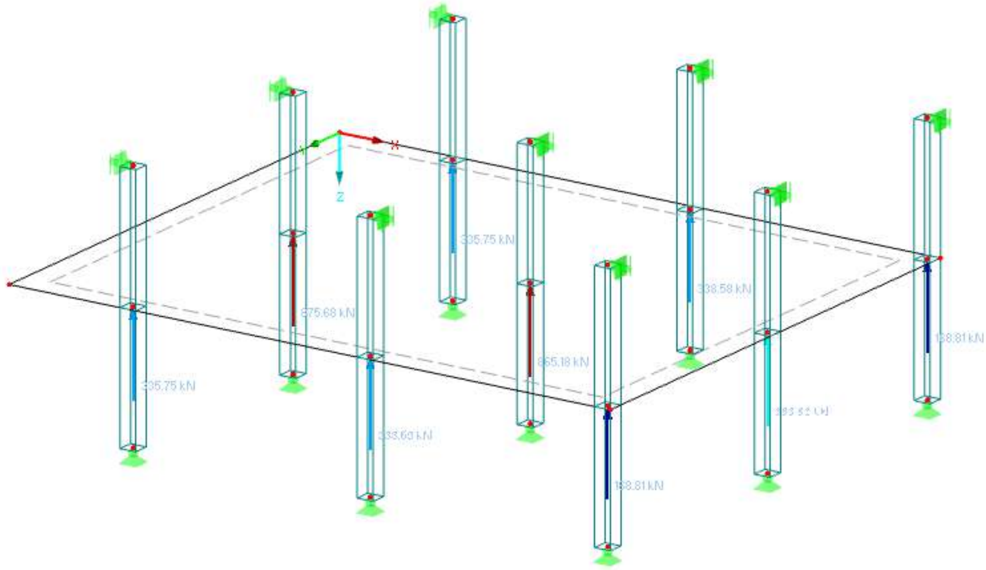


Figure 4.3: Punching loads

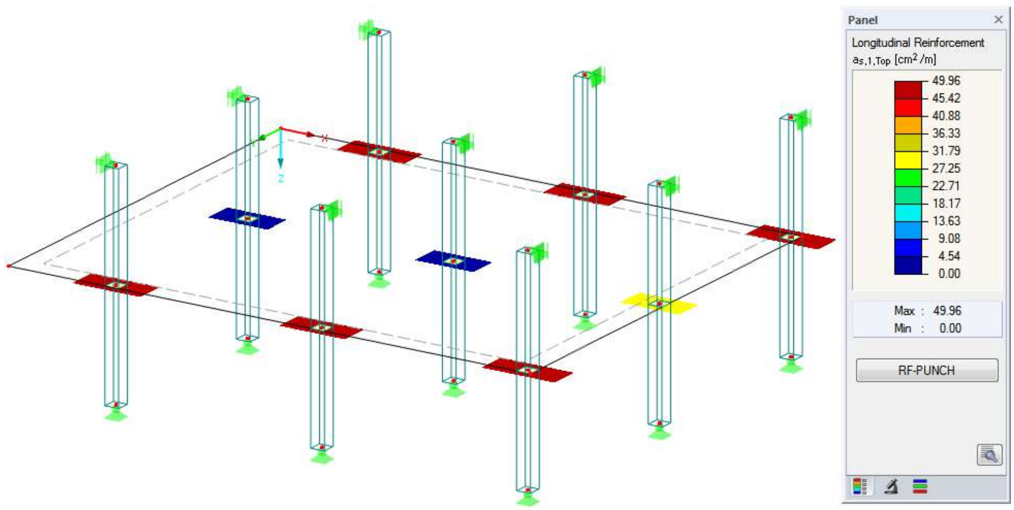


Figure 4.4: $A_{s,1\text{-top}}$ (Longitudinal reinforcement for the top surface in direction 1)

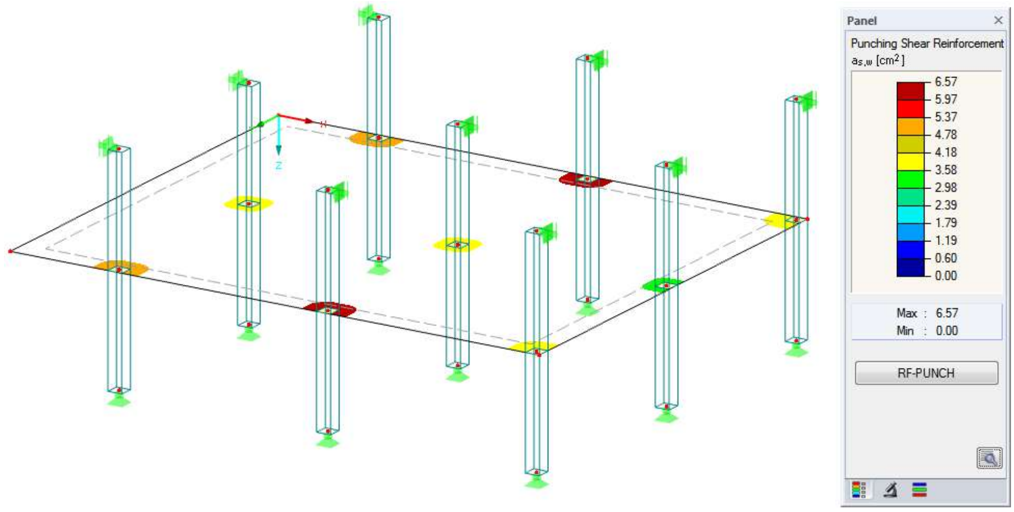


Figure 4.5: Punching reinforcement

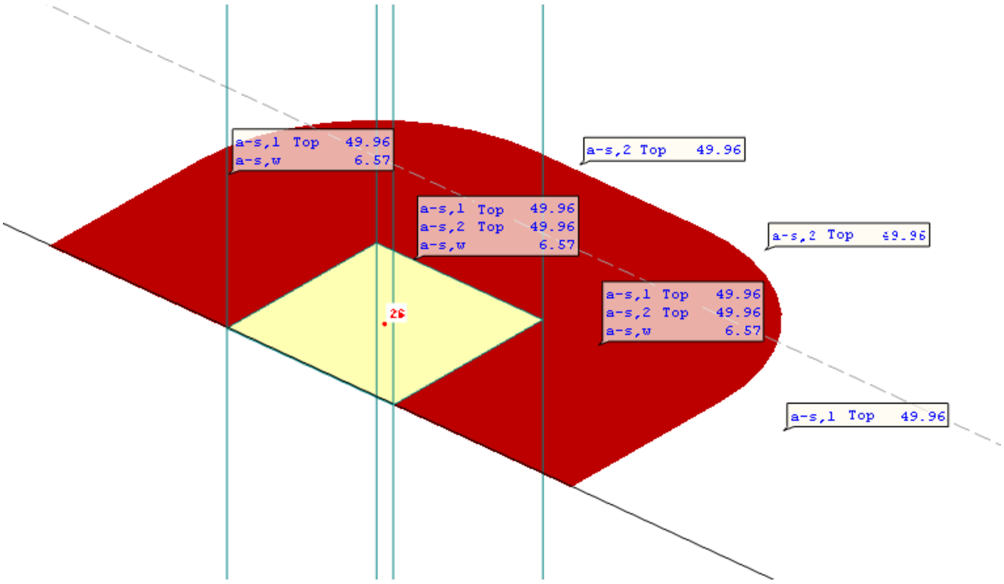


Figure 4.6: Details with values

The color panel provides the usual control options. They are described in chapter 3.4.6 of the RFEM manual.

For RF-PUNCH, you can also use the options of the *Visibilities* (see RFEM manual, chapter 9.9.1) to filter surfaces for the evaluation.

4.2 Printout

4.2.1 Printout Report

For the printout of the numeric results, you must first close RF-PUNCH by clicking [OK]. In RFEM, you can now open the printout report.

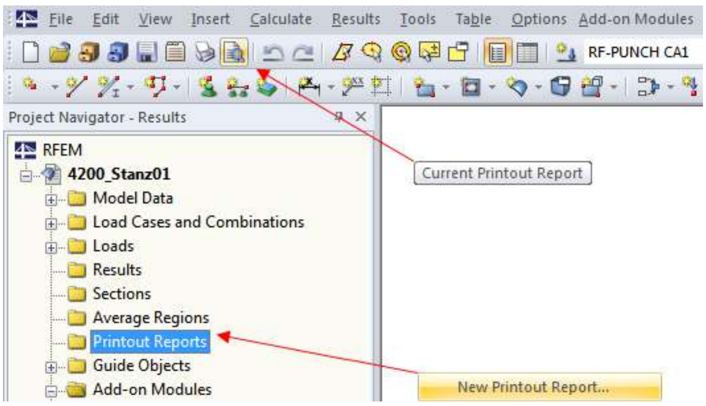


Figure 4.7: Printout report in RFEM

Like in RFEM, a printout report is thus generated for the data of the module RF-PUNCH. You can add graphics and explanations to the printout report. The selection in the printout report controls which data of the design module will finally appear in the printout.

The printout report is described in the RFEM manual: chapter 10.1.3.4 *Selecting Data of Add-on Modules* explains how to prepare the input and output data of add-on modules for the printout.

For complex structural systems with a high number of design cases, it is recommended to split data into several printout reports, thus allowing for a clear representation.

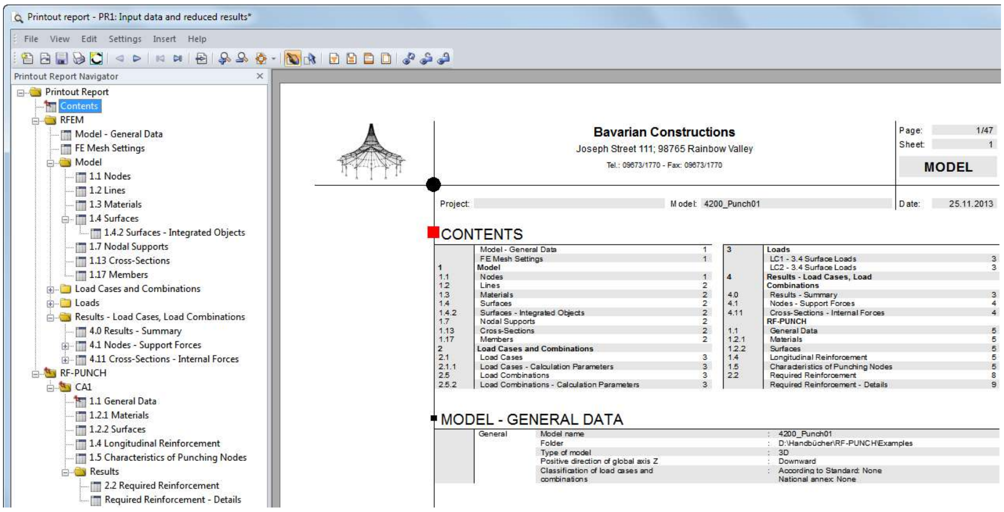


Figure 4.8: Printout report with RF-PUNCH data

4.2.2 Graphic Printout

In RFEM, you can transfer every graphic shown in the work window to the printout report or send it directly to the printer. Thus, you can also prepare the reinforcements and design internal forces shown in the RFEM model for the printout report.

To print the graphic of the design ratios, use the command on the menu

File → Print

or click the toolbar button shown on the left.

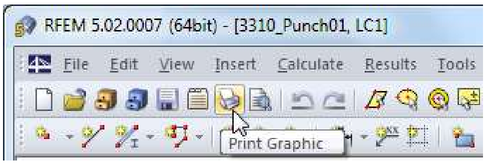


Figure 4.9: Button *Print* in RFEM toolbar

The printing of graphics is described in chapter 10.2 of the RFEM manual.

To move a graphic to a different place within the printout report, use the drag-and-drop function.

5. Worked Example: Slab Supported on Column

In this chapter, we analyze a slab according to example 4: *Slab supported on column* from [3] step by step. As described in the book of the German Concrete Association, we look at the calculation according to EC CEN and EN DIN.

Model

Concrete C35/45 is generally used for the model. The slab is 240 mm thick; the cross-section of all columns is squared and has a side length of 450 mm.

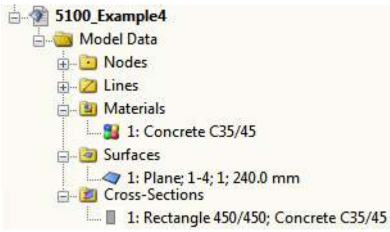


Figure 5.1: Properties for material, surface, and column cross-section

The model is created in RFEM.

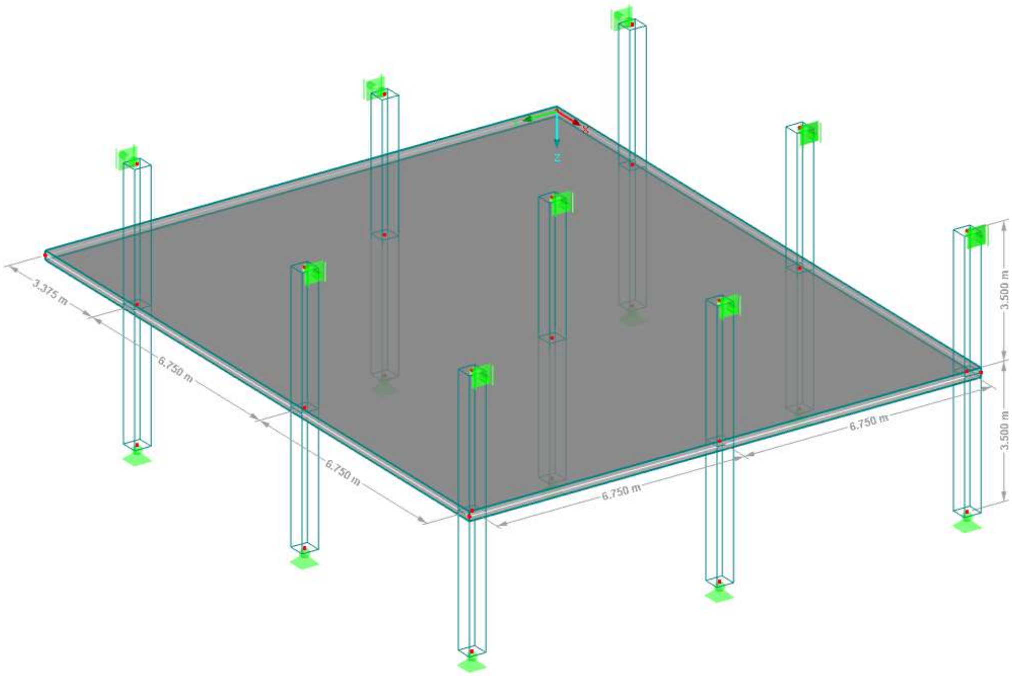


Figure 5.2: Model geometry in RFEM

Load Cases and Combinations

We create the two load cases and the load combination, and then define the loads.

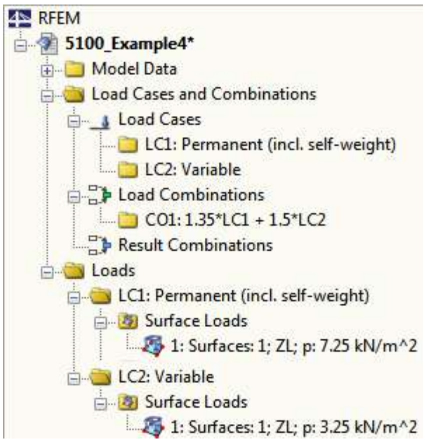


Figure 5.3: Load cases, load combination, loads

Next, we check the load combination CO1 graphically.

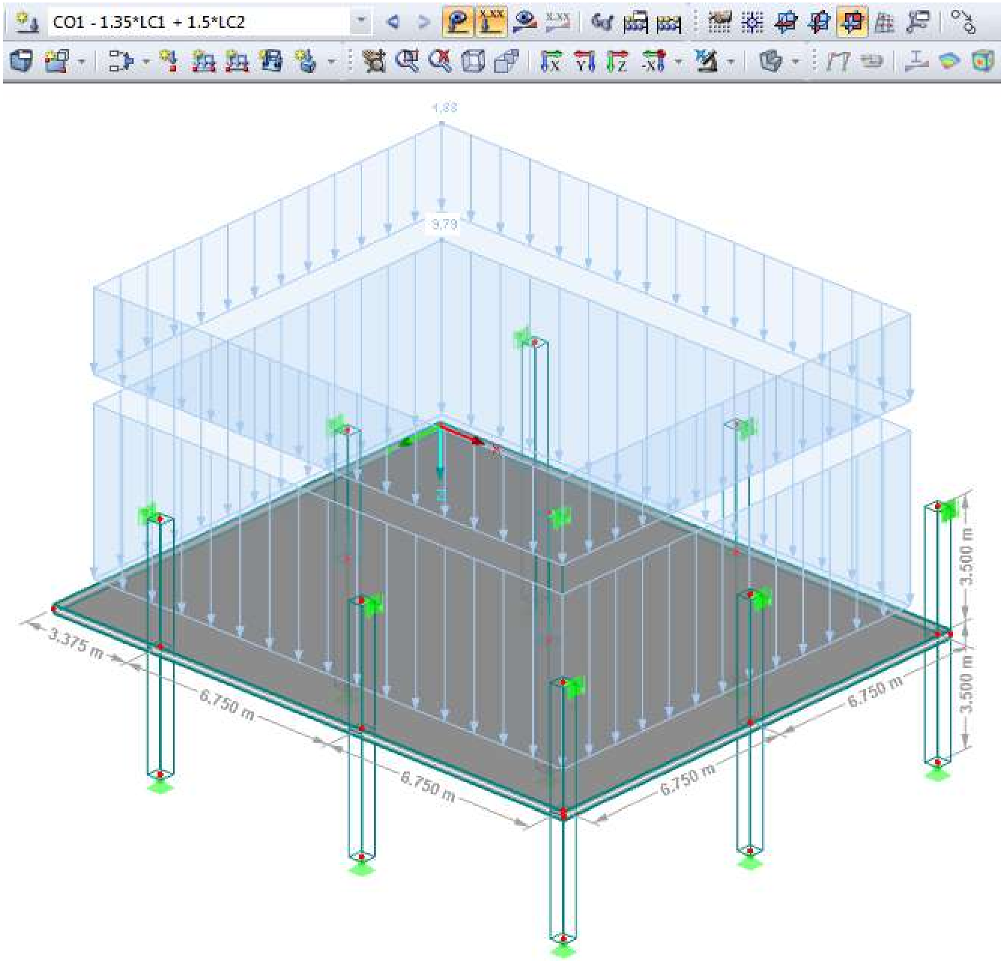


Figure 5.4: Loads in LC1

Once the model is completely defined, we start the add-on module RF-PUNCH from the family of concrete modules.

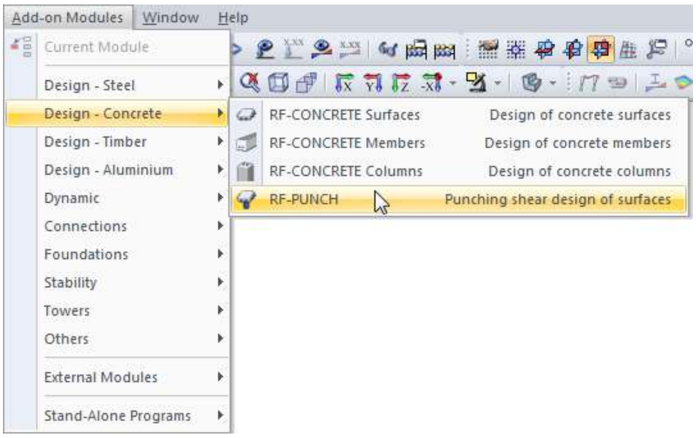


Figure 5.5: Starting RF-PUNCH

In RF-PUNCH, we first define the design data for CEN. (When we have specified all parameters, we can later copy a new design case for EN DIN.)

For the punching shear design, we graphically select the node **17** (center column) and node **26** (edge column).

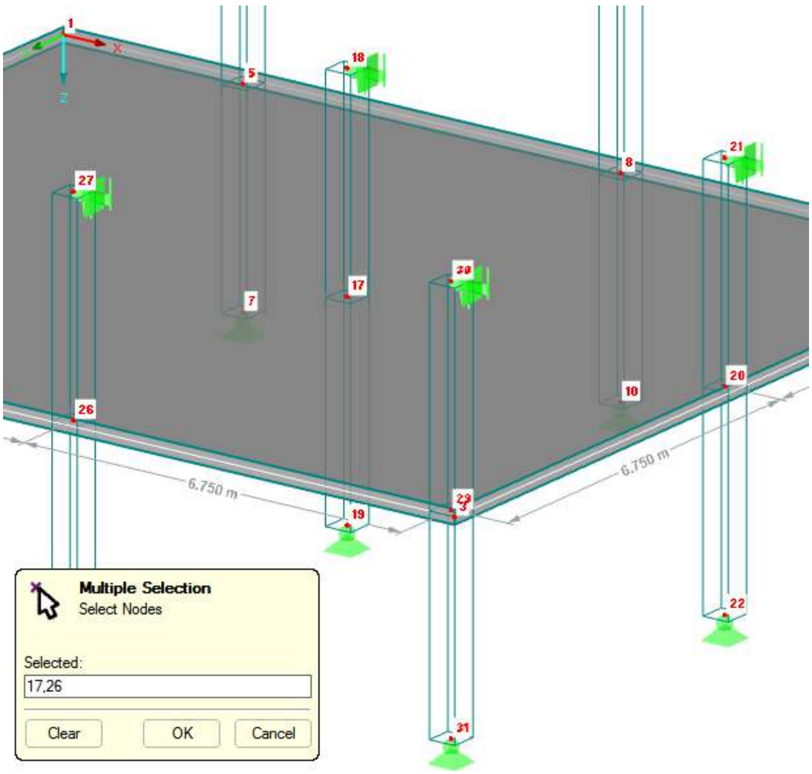


Figure 5.6: Selecting the node of punching shear

In the 1.1 *General Data* window, we first select the standard **EN 1992-1-1** with the Annex **CEN**. As loading, we take **LC1**.

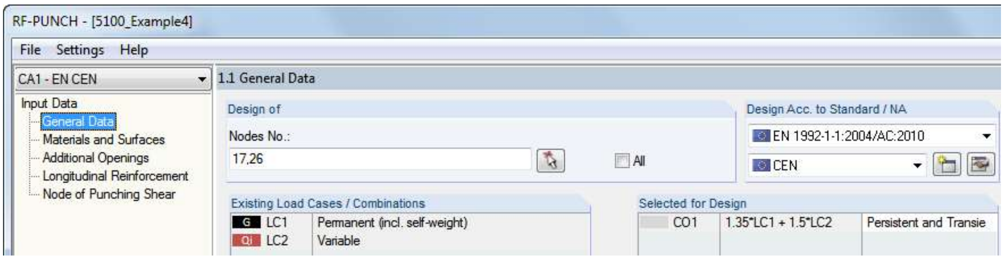


Figure 5.7: Window 1.1 *General Data*

In the 1.2 *Materials and Surfaces* window, you can control the material properties of concrete and reinforcing steel as well as the thickness of the slab. We keep the presettings unchanged.

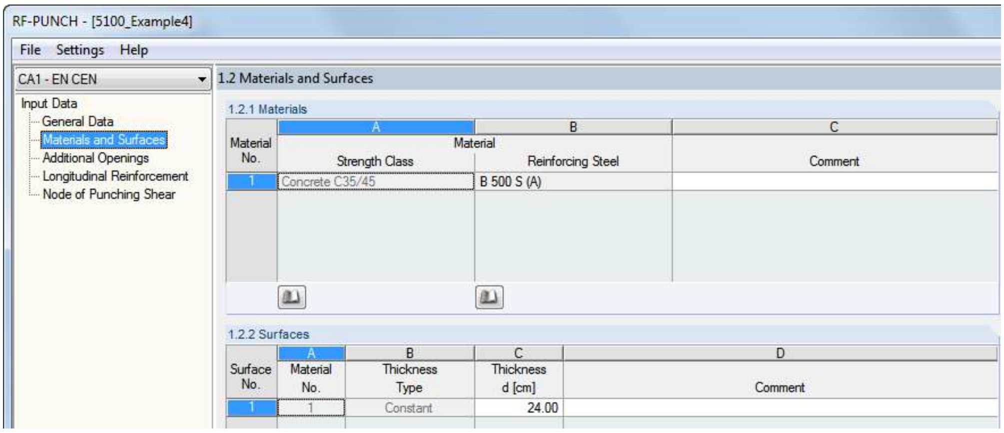


Figure 5.8: Window 1.2 *Materials and Surfaces*

The 1.3 *Additional Openings* window remains empty, because there are no additional openings.

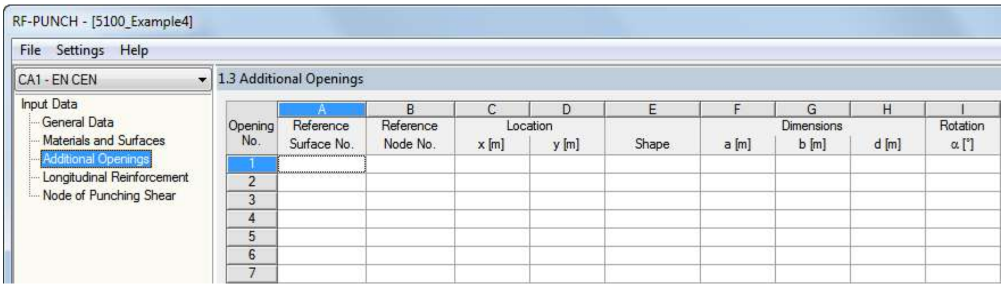


Figure 5.9: Window 1.3 *Additional Openings*

In the 1.4 *Longitudinal Reinforcement* window, the concrete cover of the reinforcement is considered as follows:

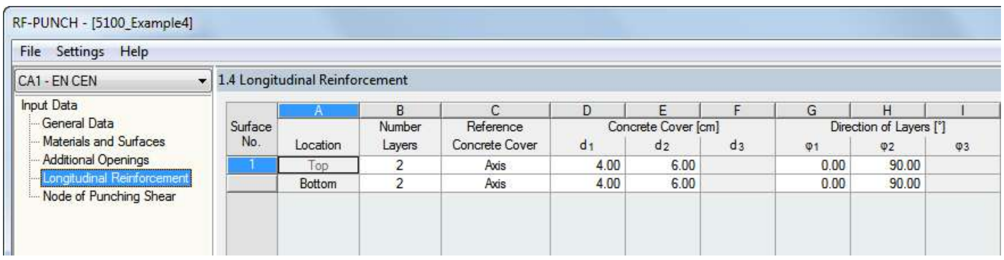


Figure 5.10: Window 1.4 *Longitudinal Reinforcement*

In the 1.5 *Node of Punching Shear* window, we specify the input data for both nodes of punching shear as follows:

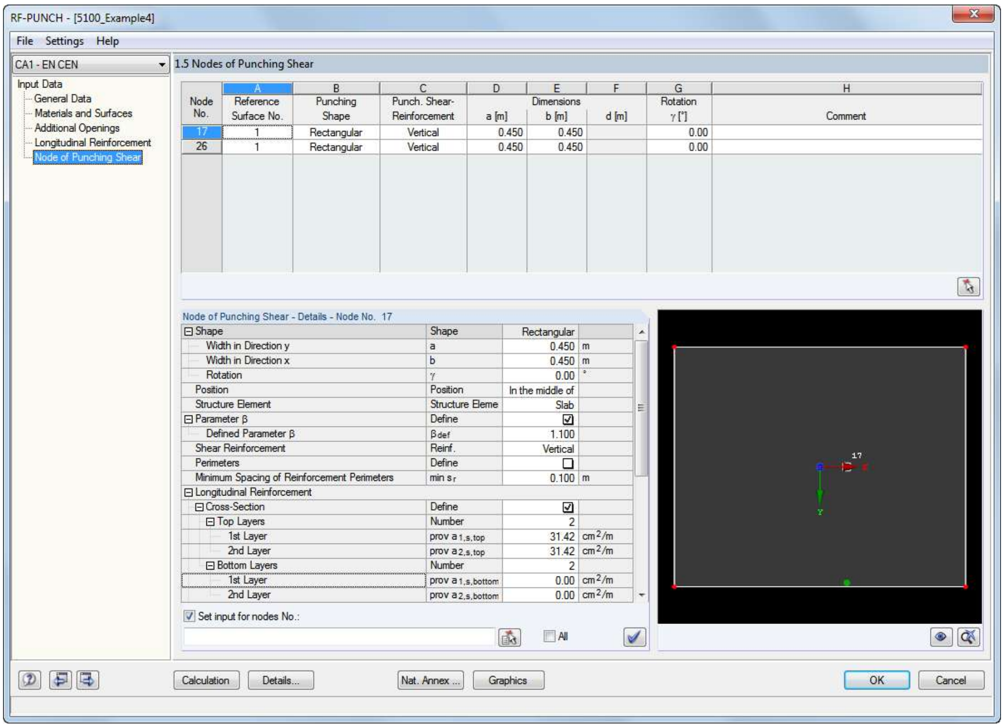


Figure 5.11: Window 1.5 *Node of Punching Shear*

Node 17

The column at node 17 is located **In the middle of** the **Slab**. In this case, the factor β is defined according to [3] and the value min s_r adjusted.

Node of Punching Shear - Details - Node No. 17			
⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.450	m
Width in Direction x	b	0.450	m
Rotation	γ	0.00	°
Position	Position	In the middle of	
Structure Element	Structure Eleme	Slab	
⊟ Parameter β	Define	☑	
Defined Parameter β	$β_{def}$	1.100	
Shear Reinforcement	Reinf.	Vertical	
Perimeters	Define	☐	
Minimum Spacing of Reinforcement Perimeters	min s_r	0.100	m
⊟ Longitudinal Reinforcement			
⊟ Cross-Section	Define	☑	
⊟ Top Layers	Number	2	
1st Layer	prov $a_{1,s,top}$	31.42	cm²/m
2nd Layer	prov $a_{2,s,top}$	31.42	cm²/m
⊟ Bottom Layers	Number	2	
1st Layer	prov $a_{1,s,bottom}$	0.00	cm²/m
2nd Layer	prov $a_{2,s,bottom}$	0.00	cm²/m
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.000	m
2nd Layer	$b_{2,top}$	1.000	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.000	m
2nd Layer	$b_{2,bottom}$	1.000	m
⊟ Punching Load	DefV_{sd}	Enter	
Value	V_{sd}	809.00	kN
Direction	V_{sd}-Direction	In -Z	
Axial Force	N_{cp}	Determine	
⊟ Deductible Surface Load			
Value	q	0.00	N/mm²
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	

Figure 5.12: Details for punching shear node 17 according to CEN

For the factor β, it is possible to select the calculation according to 6.4.3(3) – fully plastic stress distribution, or according to 6.4.3(6) – constant factors according to Figure 6.21N.

We select **Vertical** as punching shear reinforcement.

It is important to **Define** the longitudinal reinforcement of the top surface of the slab in order to take it into account.

For the punching load, we enter the value **809 kN** according to [3]. Alternatively, the program could determine the punching load.

Node 26

The column on node 26 is located at the **Edge** of the **Slab**. The number of this boundary line **2** can be specified graphically. The distance to the edge is shown so that you can check it.

Again, we define the parameter β according to [3], and adjust the value min s_r.

Node of Punching Shear - Details - Node No. 26

⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.450	m
Width in Direction x	b	0.450	m
Rotation	γ	0.00	°
Position	Position	Edge	
⊟ Next Edge	Line No.	2	
Distance to Edge	d_R	0.225	m
Structure Element	Structure Eleme	Slab	
⊟ Parameter β	Define	☑	
Defined Parameter β	β_{def}	1.400	
Shear Reinforcement	Reinf.	Vertical	
Minimum Bending Moments	Consider	☐	
⊟ Perimeters	Define	☑	
⊟ Critical Perimeter			
Distance	$l_{w,crit}$	0.380	m
Perimeter	u_{crit}	2.544	m
Sections for Analysis of Punching Shear Reinforcem	Define	☐	
Outer Section	Define	☐	
Minimum Spacing of Reinforcement Perimeters	min s_r	0.095	m
⊟ Longitudinal Reinforcement			
⊟ Cross-Section	Define	☑	
⊟ Top Layers	Number	2	
1st Layer	prov $a_{1,s,top}$	20.11	cm²/m
2nd Layer	prov $a_{2,s,top}$	31.42	cm²/m
⊟ Bottom Layers	Number	2	
1st Layer	prov $a_{1,s,bottom}$	0.00	cm²/m
2nd Layer	prov $a_{2,s,bottom}$	0.00	cm²/m
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.000	m
2nd Layer	$b_{2,top}$	1.000	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.000	m
2nd Layer	$b_{2,bottom}$	1.000	m
⊟ Punching Load	Def V_{sd}	Enter	
Value	V_{sd}	319.00	kN
Direction	V_{sd}-Direction	In -Z	
Axial Force	N_{cp}	Determine	
⊟ Deductible Surface Load			
Value	q	0.00	N/mm²
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	

Figure 5.13: Details for punching shear node 26 according to CEN

For node 26, we specify the longitudinal reinforcement for the top surface of the slab.

As punching load, we enter the value **319 kN** according to [3].

Now, we copy the data of the design case by using the menu **File** → **Copy Case**.

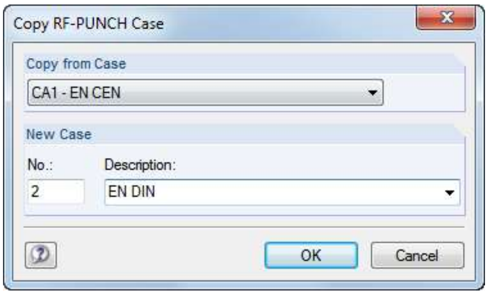


Figure 5.14: Dialog box *Copy RF-PUNCH Case*

To create case No. 2, we specify **EN DIN** as *Description*. We click [OK], and confirm the message

In the 1.1 *General Data* window of the new case, we now change the National Annex to DIN:

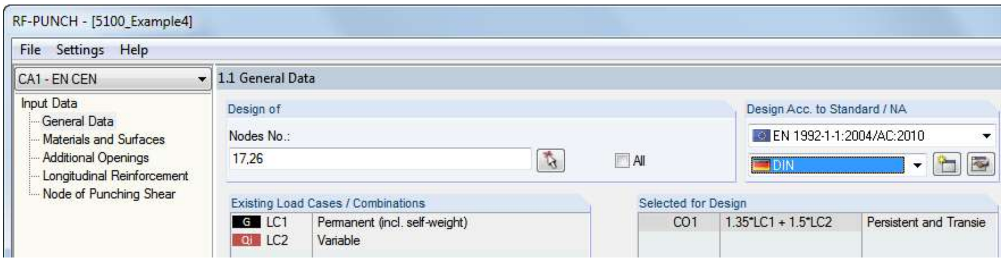


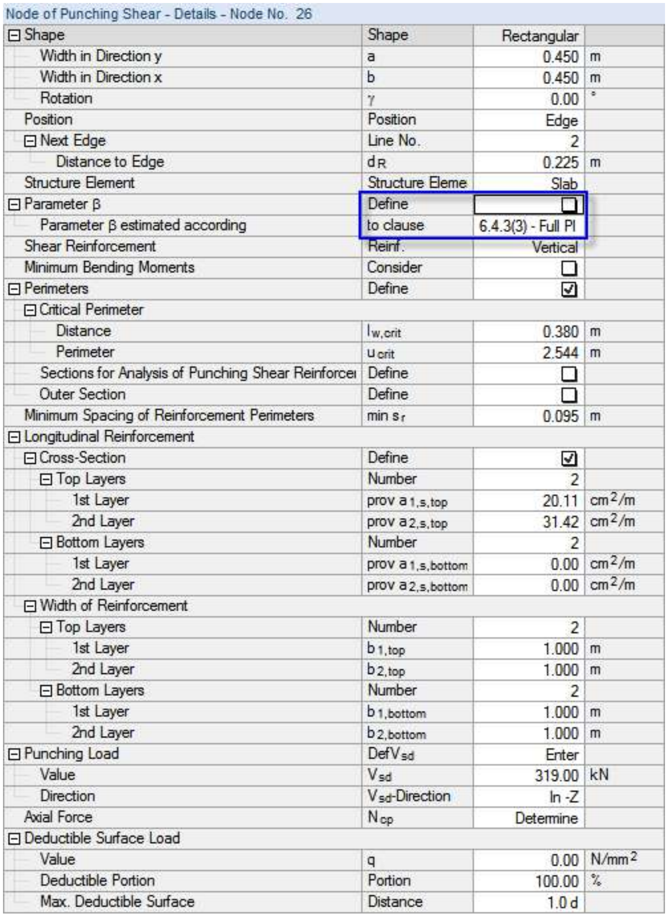
Figure 5.15: Window 1.1 *General Data* for case 2

In the 1.5 *Node for Punching Shear* window, we adjust the data for the nodes 17 and 26:

Node of Punching Shear - Details - Node No. 17

⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.450	m
Width in Direction x	b	0.450	m
Rotation	γ	0.00	°
Position	Position	In the middle of	
Structure Element	Structure Eleme	Slab	
⊟ Parameter β	Define	☑	
Defined Parameter β	β_{def}	1.100	
Shear Reinforcement	Reinf.	Vertical	
Minimum Bending Moments	Consider	☐	
Perimeters	Define	☐	
Minimum Spacing of Reinforcement Perimeters	min s_r	0.142	m
⊟ Longitudinal Reinforcement			
⊟ Cross-Section	Define	☑	
⊟ Top Layers	Number	2	
1st Layer	prov $a_{1,s,top}$	31.42	cm²/m
2nd Layer	prov $a_{2,s,top}$	31.42	cm²/m
⊟ Bottom Layers	Number	2	
1st Layer	prov $a_{1,s,bottom}$	0.00	cm²/m
2nd Layer	prov $a_{2,s,bottom}$	0.00	cm²/m
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.000	m
2nd Layer	$b_{2,top}$	1.000	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.000	m
2nd Layer	$b_{2,bottom}$	1.000	m
⊟ Punching Load	DefV_{sd}	Enter	
Value	V_{sd}	809.00	kN
Direction	V_{sd}-Richtung	In -Z	
Axial Force	N_{cp}	Determine	
⊟ Deductible Surface Load			
Value	q	0.00	N/mm²
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	

Figure 5.16: Details for punching shear node **17** according to EN DIN

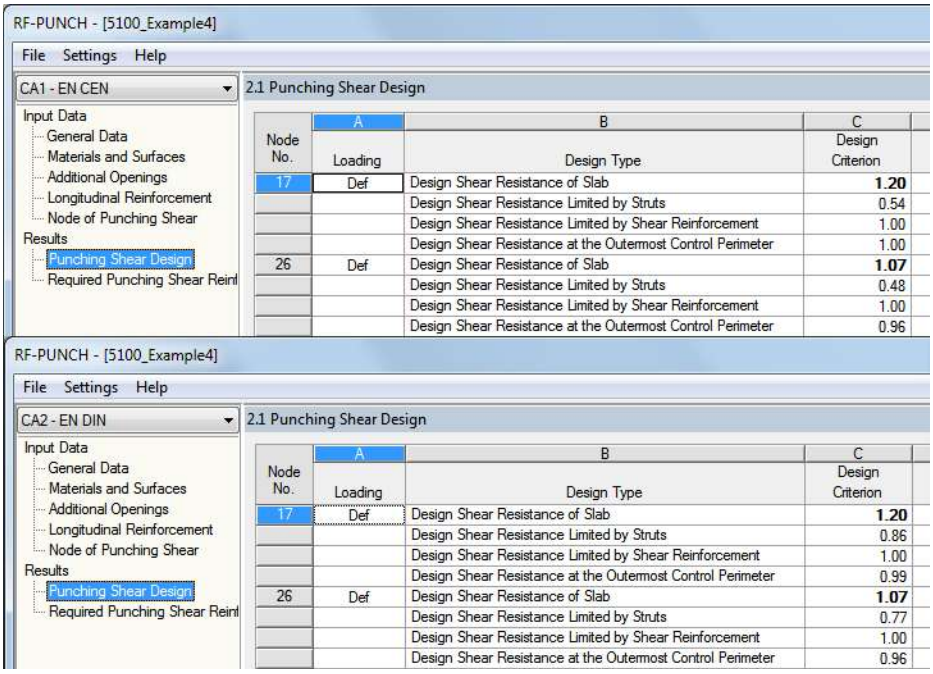

Node of Punching Shear - Details - Node No. 26

⊟ Shape	Shape	Rectangular	
Width in Direction y	a	0.450	m
Width in Direction x	b	0.450	m
Rotation	γ	0.00	°
Position	Position	Edge	
⊟ Next Edge	Line No.	2	
Distance to Edge	d_R	0.225	m
Structure Element	Structure Eleme	Slab	
⊟ Parameter β	Define	☐	
Parameter β estimated according	to clause	6.4.3(3) - Full Pl	
Shear Reinforcement	Reinf.	Vertical	
Minimum Bending Moments	Consider	☐	
⊟ Perimeters	Define	☑	
⊟ Critical Perimeter			
Distance	$l_{w,crit}$	0.380	m
Perimeter	u_{crit}	2.544	m
Sections for Analysis of Punching Shear Reinforce	Define	☐	
Outer Section	Define	☐	
Minimum Spacing of Reinforcement Perimeters	min s_r	0.095	m
⊟ Longitudinal Reinforcement			
⊟ Cross-Section	Define	☑	
⊟ Top Layers	Number	2	
1st Layer	prov $a_{1,s,top}$	20.11	cm^2/m
2nd Layer	prov $a_{2,s,top}$	31.42	cm^2/m
⊟ Bottom Layers	Number	2	
1st Layer	prov $a_{1,s,bottom}$	0.00	cm^2/m
2nd Layer	prov $a_{2,s,bottom}$	0.00	cm^2/m
⊟ Width of Reinforcement			
⊟ Top Layers	Number	2	
1st Layer	$b_{1,top}$	1.000	m
2nd Layer	$b_{2,top}$	1.000	m
⊟ Bottom Layers	Number	2	
1st Layer	$b_{1,bottom}$	1.000	m
2nd Layer	$b_{2,bottom}$	1.000	m
⊟ Punching Load	DefV_{sd}	Enter	
Value	V_{sd}	319.00	kN
Direction	V_{sd}-Direction	In -Z	
Axial Force	N_{cp}	Determine	
⊟ Deductible Surface Load			
Value	q	0.00	N/mm^2
Deductible Portion	Portion	100.00	%
Max. Deductible Surface	Distance	1.0 d	

Figure 5.17: Details for punching shear node **26** according to EN DIN

The data is completely defined. Now, we can start the calculation for the two design cases *EN CEN* and *EN DIN* one by one.

In the following figure, the results in the 2.1 *Punching Shear Design* window are compared.


RF-PUNCH - [5100_Example4]

File Settings Help

CA1 - EN CEN

2.1 Punching Shear Design

Input Data: General Data, Materials and Surfaces, Additional Openings, Longitudinal Reinforcement, Node of Punching Shear

Results: Punching Shear Design, Required Punching Shear Reinf

Node No.	A Loading	B Design Type	C Design Criterion
17	Def	Design Shear Resistance of Slab	**1.20**
		Design Shear Resistance Limited by Struts	0.54
		Design Shear Resistance Limited by Shear Reinforcement	1.00
		Design Shear Resistance at the Outermost Control Perimeter	1.00
26	Def	Design Shear Resistance of Slab	**1.07**
		Design Shear Resistance Limited by Struts	0.48
		Design Shear Resistance Limited by Shear Reinforcement	1.00
		Design Shear Resistance at the Outermost Control Perimeter	0.96

RF-PUNCH - [5100_Example4]

File Settings Help

CA2 - EN DIN

2.1 Punching Shear Design

Input Data: General Data, Materials and Surfaces, Additional Openings, Longitudinal Reinforcement, Node of Punching Shear

Results: Punching Shear Design, Required Punching Shear Reinf

Node No.	A Loading	B Design Type	C Design Criterion
17	Def	Design Shear Resistance of Slab	**1.20**
		Design Shear Resistance Limited by Struts	0.86
		Design Shear Resistance Limited by Shear Reinforcement	1.00
		Design Shear Resistance at the Outermost Control Perimeter	0.99
26	Def	Design Shear Resistance of Slab	**1.07**
		Design Shear Resistance Limited by Struts	0.77
		Design Shear Resistance Limited by Shear Reinforcement	1.00
		Design Shear Resistance at the Outermost Control Perimeter	0.96

Figure 5.18: Punching shear designs according to EN CEN (above) and EN DIN (below)

The lower table of the window lists the intermediate results for the various checks (shear force resistance from slab, strut, shear reinforcement, outer control perimeter). Here, they are shown for node **17** according to **EN CEN**.

⊟ Applied Maximum Shear Stress	v_{Ed}	1118	kN/m²
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Punching Shear Resistance without Punching Reinforcement			
⊟ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	929	kN/m²
Value of National Annex	$C_{Rd,c}$	0.12	
Factor (Influenced by Thickness)	k	2.00	
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	20.00	cm
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Static Depth	d	19.00	cm
⊟ Mean Longitudinal Reinforcement Ratio			
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.016	
Provided Longitudinal Reinforcement	prov $A_{s,1}$	31.42	cm²/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.017	
Provided Longitudinal Reinforcement	prov $A_{s,2}$	31.42	cm²/m
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Longitudinal Reinforcement Ratio	ρ	0.017	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membrane Force	N_{cp}	0.00	kN/m
⊟ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	586	kN/m²
Value of National Annex	v_{min}	586	kN/m²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membran Force	N_{cp}	0.00	kN/m
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m²
⊟ Design			
Applied Maximum Shear Stress	v_{Ed}	1118	kN/m²
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m²
Check Criterion	Criterion	1.20	

Figure 5.19: Intermediate results for node 17 according to EN CEN: design type *Shear force resistance of slab*

For comparison, we run an analysis according to [3].

$d = (d_x + d_y) / 2 = (0.20 + 0.18) / 2 = 0.19$ m

$u_i = 2 \cdot (2 \cdot 0.45 + \pi \cdot 2.0 \cdot 0.19) = 4.19$ m

$v_{ed} = \beta \cdot V_{Ed} / (u_i \cdot d)$

$V_{Ed} = 809$ kN

$\beta = 1.10$

$v_{ed} = 1.10 \cdot 0.809 / (4.19 \cdot 0.19) = 1.118$ MN/m²

$V_{Rd,c} = (0.18 / \gamma_c) \cdot k\,(100 \cdot \rho_l \cdot f_{ck})^{1/3} + 0.10 \cdot \sigma_{cp} \geq v_{min} + 0.10 \cdot \sigma_{cp}$

where $k = 1 + (200 / d)^{1/2} \leq 2.0$

$= 1 + (200 / 190)^{1/2} \leq 2.0$

$v_{min} = (0.0525 / \gamma_c) \cdot k^{3/2} \cdot f_{ck}^{1/2}$

$v_{min} = (0.0525 / 1.5) \cdot 2.0^{3/2} \cdot 35^{1/2} = 0.586$ MN/m²

$\rho_{lx} = 31.42 / (100 \cdot 20) = 0.0157$

$\rho_{lx} = 31.42 / (100 \cdot 18) = 0.0175$

$\rho_{l} = (0.0157 \cdot 0.0175)^{1/2} = 0.0166$

≤ 2.0

$\leq 0.50 \cdot f_{cd} / f_{yd} = 0.5 \cdot 19.8 / 435 = 0.023$

$V_{Rd,c} = (0.18 / 1.5) \cdot 2.0 \cdot (100 \cdot 0.0166 \cdot 35)^{1/3} = 0.928 \text{ MN/m}^2$

$> 0.586 \text{ MN/m}^2 = v_{min}$

$< 1.118 \text{ MN/m}^2 = v_{ed}$

⊟ Applied Maximum Shear Stress	v_{Ed}	2602	kN/m²
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Perimeter of Section	u_0	1.800	m
Distance of Load Area	$l_{w,0}$	0.0	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Design Value of Maximum Punching Shear Resistance			
⊟ Value of National Annex	υ	0.52	
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm²
Design Concrete Compressive Strength	f_{cd}	23.33	N/mm²
Maximum Punching Shear Resistance	$v_{Rd,max}$	4816	kN/m²
⊟ Design			
Applied Maximum Shear Stress	v_{Ed}	2602	kN/m²
Maximum Punching Shear Resistance	$v_{Rd,max}$	4816	kN/m²
Check Criterion	Criterion	0.54	

Figure 5.20: Intermediate results for node 17 acc. to EN CEN: type of check *Shear force resistance limited by struts*

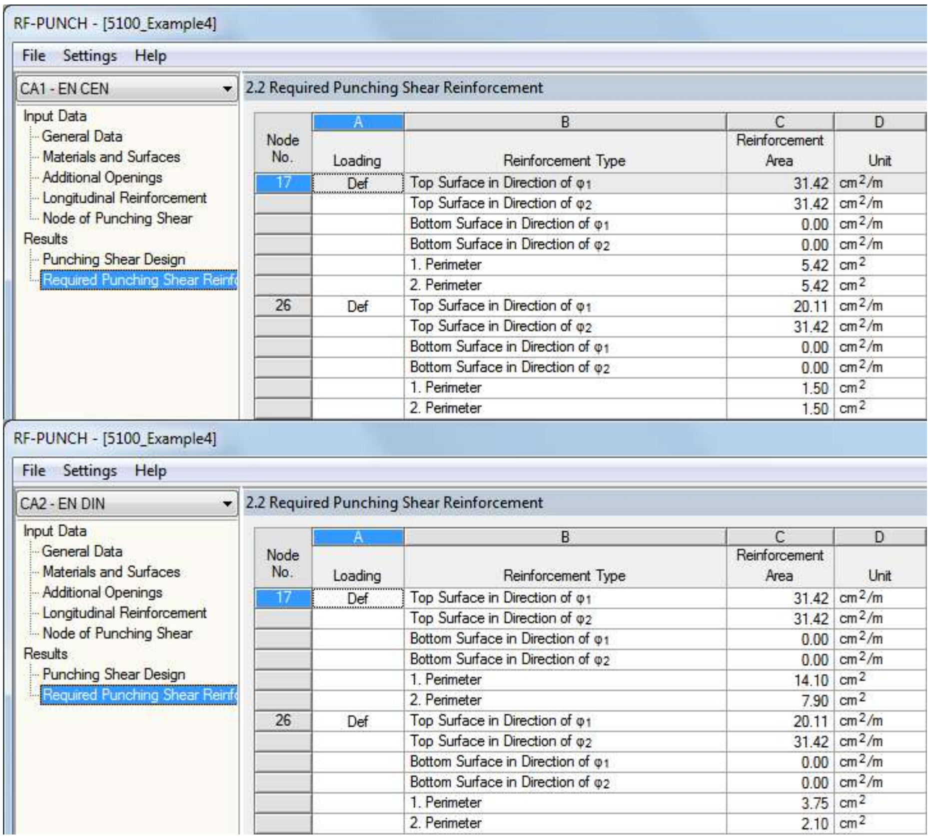
⊟ Applied Maximum Shear Stress	v_{Ed}	1118	kN/m²
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Shear Resistance with Shear Reinforcement	$v_{Rd,cs}$	1118	kN/m²
Punching Shear Resistance without Shear Reinfon	$v_{Rd,c}$	929	kN/m²
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	20.00	cm
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Static Depth	d	19.00	cm
Radial Spacing of Reinforcement Perimeters	s_r	0.137	m
Reinforcement Area of One Perimeter	A_{sw}	5.42	cm²
Effective Strength of Reinforcement	$f_{ywd,ef}$	297.50	N/mm²
Basic Control Perimeter	u_1	4.188	m
Angle Between Shear Reinforcement and Slab	α	90.00	°
⊟ Design			
Applied Maximum Shear Stress	v_{Ed}	1118	kN/m²
Shear Resistance with Shear Reinforcement	$v_{Rd,cs}$	1118	kN/m²
Check Criterion	Criterion	1.00	

Figure 5.21: Intermediate results for node 17 acc. to EN CEN: type of check *Shear Resistance Limited by Shear Reinforcement*

⊟ Applied Maximum Shear Stress	$v_{Ed,out}$	928	kN/m²
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Outermost Control Perimeter	u_a	5.048	m
Distance of Load Area	$l_{w,out}$	0.517	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Punching Shear Resistance without Punching Reinforcement			
⊟ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	929	kN/m²
Value of National Annex	$C_{Rd,c}$	0.12	
Factor (Influence Thickness)	k	2.00	
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	20.00	cm
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Static Depth	d	19.00	cm
⊟ Mean Longitudinal Reinforcement Ratio			
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.016	
Provided Longitudinal Reinforcement	prov $A_{s,1}$	31.42	cm²/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.017	
Provided Longitudinal Reinforcement	prov $A_{s,2}$	31.42	cm²/m
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Longitudinal Reinforcement Ratio	ρ	0.017	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Characteristic Concrete Comprehensive Strengtl	f_{ck}	35.00	N/mm²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membran Force	N_{cp}	0.00	kN/m
⊟ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	586	kN/m²
Value of National Annex	v_{min}	586	kN/m²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membran Force	N_{cp}	0.00	kN/m
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m²
⊟ Design			
Applied Maximum Shear Stress	v_{Ed}	928	kN/m²
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m²
Check Criterion	Criterion	1.00	

Figure 5.22: Intermediate results for node 17 acc. to EN CEN: type of check *Shear Force Resistance at Outermost Control Perimeter*

The 2.2 *Required Punching Shear Reinforcement* window shows the reinforcement surfaces of each reinforcement type.



Node No.	A Loading	B Reinforcement Type	C Reinforcement Area	D Unit
17	Def	Top Surface in Direction of φ1	31.42	cm²/m
		Top Surface in Direction of φ2	31.42	cm²/m
		Bottom Surface in Direction of φ1	0.00	cm²/m
		Bottom Surface in Direction of φ2	0.00	cm²/m
		1. Perimeter	5.42	cm²
		2. Perimeter	5.42	cm²
26	Def	Top Surface in Direction of φ1	20.11	cm²/m
		Top Surface in Direction of φ2	31.42	cm²/m
		Bottom Surface in Direction of φ1	0.00	cm²/m
		Bottom Surface in Direction of φ2	0.00	cm²/m
		1. Perimeter	1.50	cm²
		2. Perimeter	1.50	cm²

Node No.	A Loading	B Reinforcement Type	C Reinforcement Area	D Unit
17	Def	Top Surface in Direction of φ1	31.42	cm²/m
		Top Surface in Direction of φ2	31.42	cm²/m
		Bottom Surface in Direction of φ1	0.00	cm²/m
		Bottom Surface in Direction of φ2	0.00	cm²/m
		1. Perimeter	14.10	cm²
		2. Perimeter	7.90	cm²
26	Def	Top Surface in Direction of φ1	20.11	cm²/m
		Top Surface in Direction of φ2	31.42	cm²/m
		Bottom Surface in Direction of φ1	0.00	cm²/m
		Bottom Surface in Direction of φ2	0.00	cm²/m
		1. Perimeter	3.75	cm²
		2. Perimeter	2.10	cm²

Figure 5.23: Required punching shear reinforcement according to EN CEN (above) and EN DIN (below)

To compare, we run an analysis according to [3] for node 17 according to EN CEN and EN DIN.

$N_{Rd,cs} = 0.75 \cdot v_{Rd,c} + 1.5 \cdot (d / s_r) \cdot A_{sw} \cdot f_{ywd,ef} / (u_1 \cdot d) \cdot \sin \alpha$

where

$f_{ywd,ef} = 250 + 0.25 \cdot d \leq f_{ywd}$

$f_{ywd,ef} = 250 + 0.25 \cdot 190 = 297$ MN/m² < 435 MN//m²

chosen: $s_r = 0.75 \cdot d$

$A_{sw} = (v_{ed} - 0.75 \cdot v_{Rd,c}) \cdot u_1 \cdot d / [1.5 \cdot (d / s_r) \cdot f_{ywd,ef}]$

$A_{sw} = (1.118 – 0.75 \cdot 0.928) \cdot 4.19 \cdot 0.19 / [1.5 \cdot (1 / 0.75) \cdot 297] \cdot 10^4 = 5.66$ cm²

For EN CEN:

req $A_{sw,1}$ = req $A_{sw,2}$ = 5.66 cm²

For EN DIN:

In the first two rows, the amount of reinforcement is increased by using the adjustment factor κ_{sw}.

req $A_{sw,1} = \kappa_{sw,1} \cdot A_{sw,1} = 2.5 \cdot 5.66 = 14.1$ cm²

req $A_{sw,2} = \kappa_{sw,2} \cdot A_{sw,2} = 1.4 \cdot 5.66 = 7.92$ cm²

The lower table shows the details for the individual checks: top surface of the slab in directions φ_1 and φ_2, bottom surface of the slab in direction φ_1 and φ_2, 1st and 2nd control perimeters. They are presented here for the node 17 according to EN CEN.

⊟ For Design Shear Resistance			
⊟ Required Ratio of Longitudinal Reinforcement	ρ	0.020	
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.019	
Required Longitudinal Reinforcement	req $a_{s,1}$	37.95	cm^2/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.021	
Required Longitudinal Reinforcement	req $a_{s,2}$	37.95	cm^2/m
Effective Depth 2nd Layer	d_2	18.00	cm
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Req. Reinforcement	req a_s	37.95	cm^2/m
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{1,t}$	1.000	m
Defined Longitudinal Reinforcement	prov $a_{s,1,t}$	31.42	cm^2/m

Figure 5.24: Intermediate results for node 17 according to EN CEN: type of check *Top surface of slab in direction φ_1*

⊟ For Design Shear Resistance			
⊟ Required Ratio of Longitudinal Reinforcement	ρ	0.020	
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.019	
Required Longitudinal Reinforcement	req $a_{s,1}$	37.95	cm^2/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.021	
Required Longitudinal Reinforcement	req $a_{s,2}$	37.95	cm^2/m
Effective Depth 2nd Layer	d_2	18.00	cm
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Req. Reinforcement	req a_s	37.95	cm^2/m
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{2,t}$	1.000	m
Defined Longitudinal Reinforcement	prov $a_{s,2,t}$	31.42	cm^2/m

Figure 5.25: Intermediate results for node 17 according to EN CEN: type of check *Top surface of slab in direction φ_2*

⊟ For Design Shear Resistance			
The longitudinal reinforcement at this side does not have influence.			
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{1,b}$	1.000	m
Defined Longitudinal Reinforcement	prov $a_{s,1,b}$	0.00	cm^2/m

Figure 5.26: Intermediate results for node 17 according to EN CEN: type of check *Bottom surface of slab in direction φ_1*

⊟ For Design Shear Resistance			
The longitudinal reinforcement at this side does not have influence.			
⊟ Defined Longitudinal Reinforcement			
Width of Reinforcement	$b_{2,t}$	1.000	m
Defined Longitudinal Reinforcement	prov $a_{s,2,b}$	0.00	cm^2/m

Figure 5.27: Intermediate results for node 17 according to EN CEN: type of check *Bottom surface of the slab in direction φ_2*

⊟ Calculation of Number of Inner Perimeters			
Distance Between Second and Last Inner Perimete	x_{in}	0.137	m
Max. Allowed Radial Spacing of Inner Perimeters	max s_r	0.142	m
Calc. Req. Number of Spacings	$n_{dis,calc}$	0.96	
Designed Number of Spacings	n_{dis}	1	
Designed Number of Perimeters	n_{in}	2	
⊟ Position of 1. Section			
Perimeter of Section	u	2.397	m
Distance to Load Area	l_w	0.095	m
⊟ Applied Maximum Shear Stress	v_{Ed}	1118	kN/m²
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Punching Shear Resistance without Punching Reinforcement			
⊟ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	929	kN/m²
Value of National Annex	$C_{Rd,c}$	0.12	
Factor (Influence Thickness)	k	2.00	
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	20.00	cm
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Static Depth	d	19.00	cm
⊟ Mean Longitudinal Reinforcement Ratio			
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.016	
Provided Longitudinal Reinforcement	prov $A_{s,1}$	31.42	cm²/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.017	
Provided Longitudinal Reinforcement	prov $A_{s,2}$	31.42	cm²/m
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Longitudinal Reinforcement Ratio	ρ	0.017	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membran Force	N_{cp}	0.00	kN/m
⊟ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	586	kN/m²
Value of National Annex	v_{min}	586	kN/m²
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m²
Membran Force	N_{cp}	0.00	kN/m
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m²
⊟ Statically Required Shear Reinforcement			
Mean Static Depth	d	19.00	cm
Radial Spacing of Reinforcement Perimeters	s_r	0.137	m
Effective Strength of Reinforcement	$f_{ywd,ef}$	297.50	N/mm²
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
Statically Required Punching Reinforcement	$A_{sw,stat}$	5.42	cm²
⊟ Minimum Shear Reinforcement			
⊟ Minimum Cross-Sectional Area of One Shear Stud	$A_{sw,min,stirrup}$	0.23	cm²
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm²
Characteristic Reinforcement Strength	f_{yk}	500.00	N/mm²
Inclination of Shear Reinforcement	α	90.00	°
Radial Spacing of Reinforcement Perimeters	s_r	0.137	m
⊟ Tangential Spacing of Shear Links	s_t	0.266	m
Perimeter of Section	u_1	2.397	m
Determined Minimum Number	n	9	
⊟ Minimum Number of Shear Studs			
⊟ Calc. Req. Minimum Number	n_{calc}	8.41	
Perimeter of Section	u_1	2.397	m
⊟ Max. Tangential Spacing of Shear Reinforcen	max s	0.285	m
Inner Perimeter Inside Critical Perimeter			
Determined Minimum Number	n	9	
⊟ Minimum Shear Reinforcement	$A_{sw,min}$	2.07	cm²
Determined Minimum Number	n	9	
Minimum Cross-Sectional Area of One Shear Stu	$A_{sw,min,stirrup}$	0.23	cm²
⊟ Governing Punching Reinforcement A_{sw}			
Statically Required Punching Reinforcement	$A_{sw,stat}$	5.42	cm²
Minimum Shear Reinforcement	$A_{sw,min}$	2.07	cm²
Governing Punching Reinforcement	A_{sw}	5.42	cm²

Figure 5.28: Intermediate results for node 17 acc. to EN CEN – type of reinforcement *1st Perimeter*

⊟ Calculation of Number of Inner Perimeters			
Distance Between Second and Last Inner Perimete	x_{in}	0.137	m
Max. Allowed Radial Spacing of Inner Perimeters	max s_r	0.142	m
Calc. Req. Number of Spacings	$n_{dis,calc}$	0.96	
Designed Number of Spacings	n_{dis}	1	
Designed Number of Perimeters	n_{in}	2	
⊟ Position of 2. Section			
Perimeter of Section	u	3.258	m
Distance to Load Area	l_w	0.232	m
⊟ Applied Maximum Shear Stress	v_{Ed}	1118	kN/m^2
⊟ Factor	β	1.10	
Coefficient β is user-defined			
⊟ Applied Shear Force	V_{Ed}	809.00	kN
Load Case	LC	Def	
Unloaded Surface	Side	Upper Surface	
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
⊟ Mean Static Depth	d	19.00	cm
Effective Depth 1st Layer	d_1	18.00	cm
Effective Depth 2nd Layer	d_2	20.00	cm
⊟ Punching Shear Resistance without Punching Reinforcement			
⊟ Basic Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,1}$	929	kN/m^2
Value of National Annex	$C_{Rd,c}$	0.12	
Factor (Influence Thickness)	k	2.00	
⊟ Mean Static Depth			
Effective Depth 1st Layer	d_1	20.00	cm
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Static Depth	d	19.00	cm
⊟ Mean Longitudinal Reinforcement Ratio			
⊟ Reinf. Ratio of 1st Layer	ρ_1	0.016	
Provided Longitudinal Reinforcement	prov $A_{s,1}$	31.42	cm^2/m
Effective Depth 1st Layer	d_1	20.00	cm
⊟ Reinf. Ratio of 2nd Layer	ρ_2	0.017	
Provided Longitudinal Reinforcement	prov $A_{s,2}$	31.42	cm^2/m
Effective Depth 2nd Layer	d_2	18.00	cm
Mean Longitudinal Reinforcement Ratio	ρ	0.017	
Maximum Allowed Ratio of Reinforcement	ρ_{max}	0.020	
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm^2
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m^2
Membran Force	N_{cp}	0.00	kN/m
⊟ Minimum Shear Resistance acc. to (6.47)	$v_{Rd,c,calc,2}$	586	kN/m^2
Value of National Annex	v_{min}	586	kN/m^2
Value of National Annex	k_1	0.10	
⊟ Stress of Concrete	σ_{cp}	0	kN/m^2
Membran Force	N_{cp}	0.00	kN/m
Governing Shear Resistance	$v_{Rd,c}$	929	kN/m^2
⊟ Statically Required Shear Reinforcement			
Mean Static Depth	d	19.00	cm
Radial Spacing of Reinforcement Perimeters	s_r	0.137	m
Effective Strength of Reinforcement	$f_{ywd,ef}$	297.50	N/mm^2
⊟ Basic Control Perimeter	u_1	4.188	m
Distance of Load Area	$l_{w,1}$	0.380	m
Statically Required Punching Reinforcement	$A_{sw,stat}$	5.42	cm^2
⊟ Minimum Shear Reinforcement			
⊟ Minimum Cross-Sectional Area of One Shear Stud	$A_{sw,min,stirrup}$	0.23	cm^2
Characteristic Concrete Comprehensive Strength	f_{ck}	35.00	N/mm^2
Characteristic Reinforcement Strength	f_{yk}	500.00	N/mm^2
Inclination of Shear Reinforcement	α	90.00	°
Radial Spacing of Reinforcement Perimeters	s_r	0.137	m
⊟ Tangential Spacing of Shear Links	s_t	0.271	m
Perimeter of Section	u_2	3.258	m
Determined Minimum Number	n	12	
⊟ Minimum Number of Shear Studs			
⊟ Calc. Req. Minimum Number	n_{calc}	11.43	
Perimeter of Section	u_2	3.258	m
⊟ Max. Tangential Spacing of Shear Reinforcem	max s	0.285	m
Inner Perimeter Inside Critical Perimeter			
Determined Minimum Number	n	12	
⊟ Minimum Shear Reinforcement	$A_{sw,min}$	2.82	cm^2
Determined Minimum Number	n	12	
Minimum Cross-Sectional Area of One Shear Stu	$A_{sw,min,stirrup}$	0.23	cm^2
⊟ Governing Punching Reinforcement A_{sw}			
Statically Required Punching Reinforcement	$A_{sw,stat}$	5.42	cm^2
Minimum Shear Reinforcement	$A_{sw,min}$	2.82	cm^2
Governing Punching Reinforcement	A_{sw}	5.42	cm^2

Figure 5.29: Intermediate results for node 17 acc. to EN CEN – type of reinforcement *2nd Perimeter*

Graphics

We can also look at the [Graphics] in RFEM, which show the following figures:

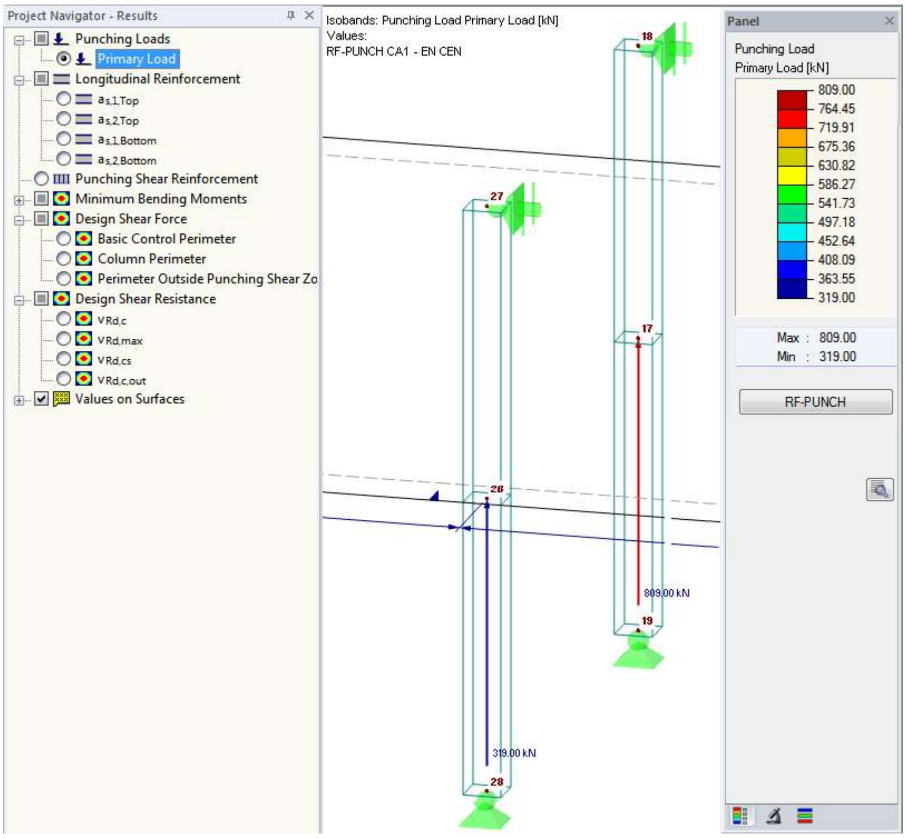


Figure 5.30: Graphic of the primary load (EN CEN)

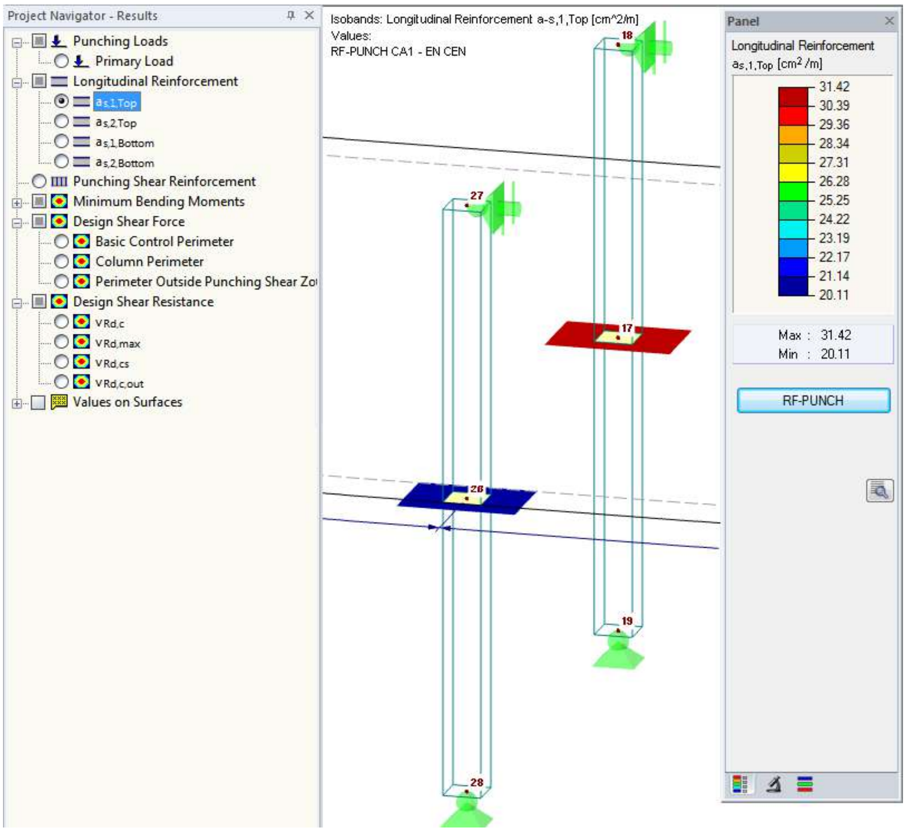


Figure 5.31: Top reinforcement $a_{s,1,top}$ (EN CEN)

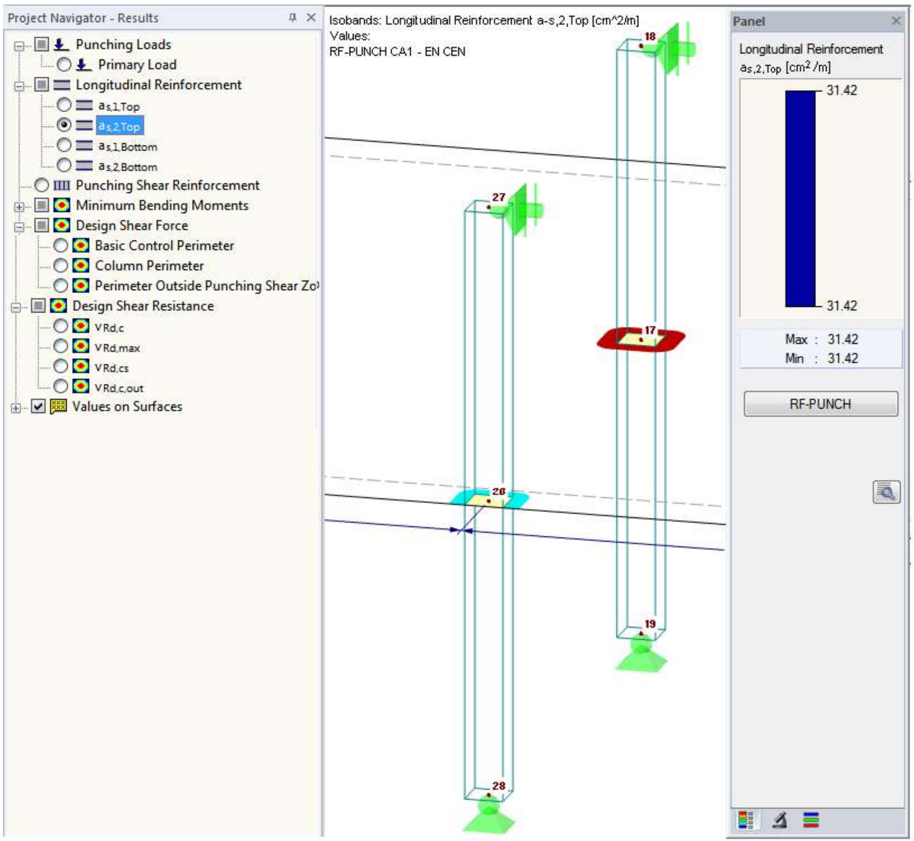


Figure 5.32: Top reinforcement $a_{s,2,top}$ (EN CEN)

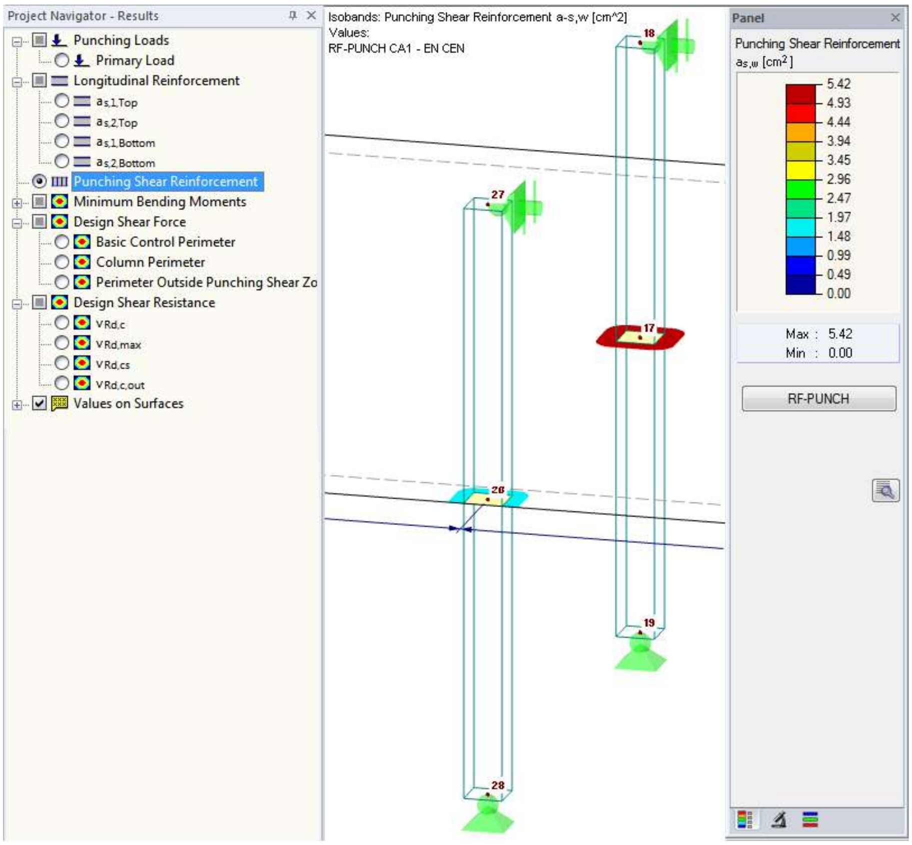


Figure 5.33: Punching shear reinforcement (EN CEN)

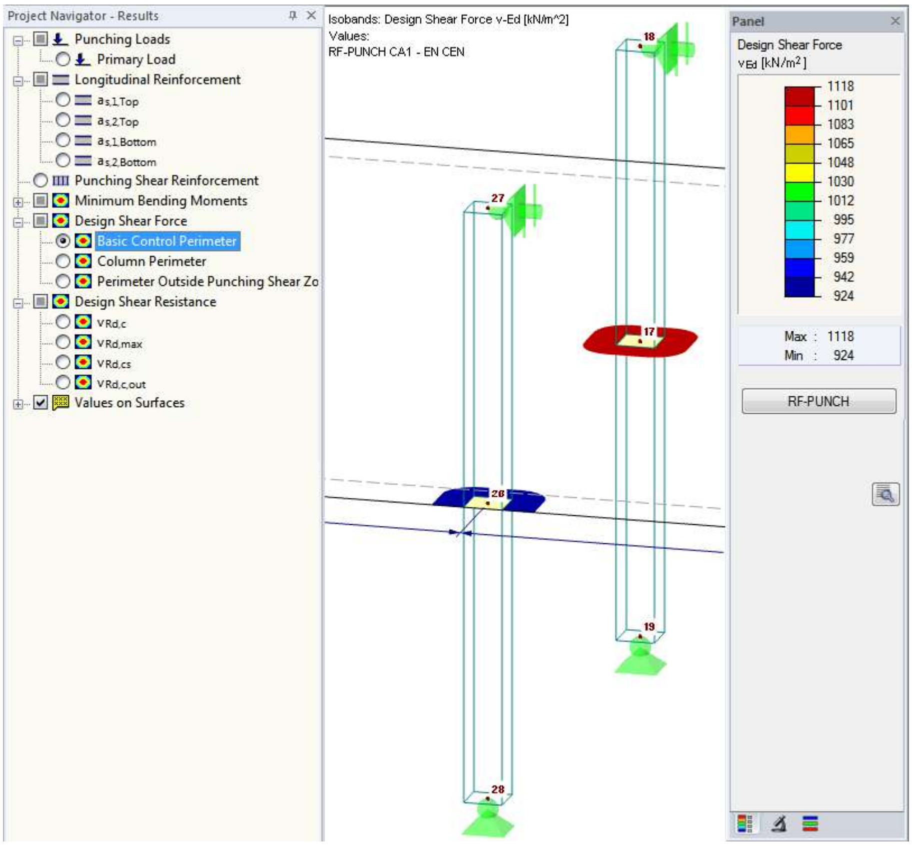


Figure 5.34: Basic control perimeter (EN CEN)

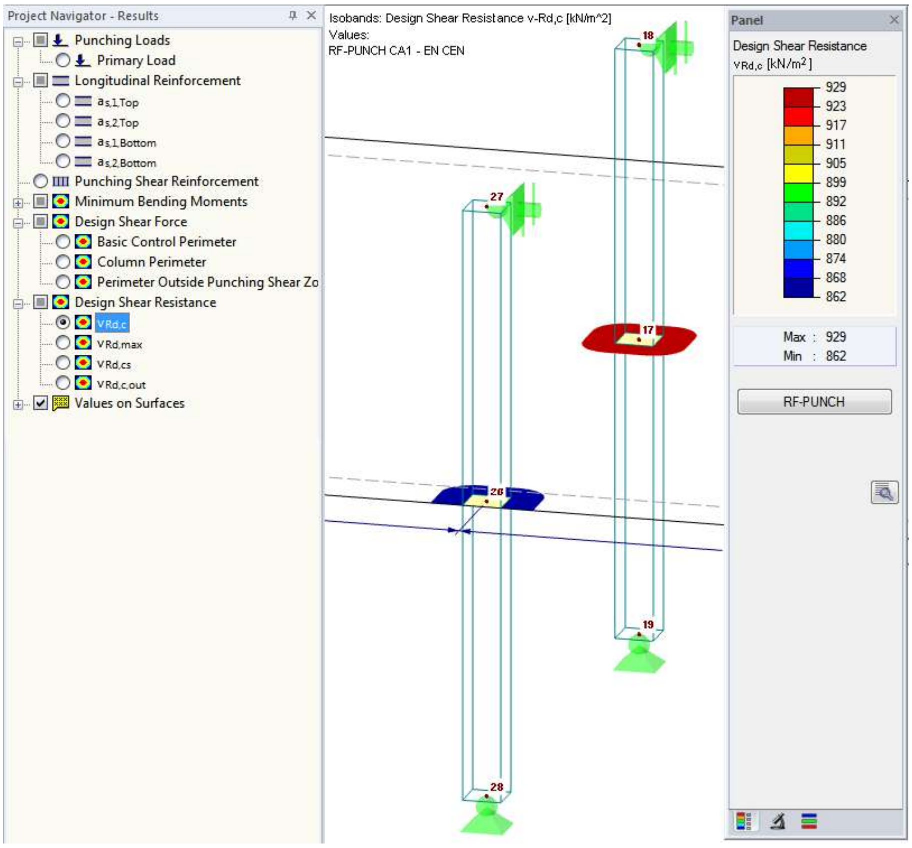


Figure 5.35: Shear force resistance (EN CEN)

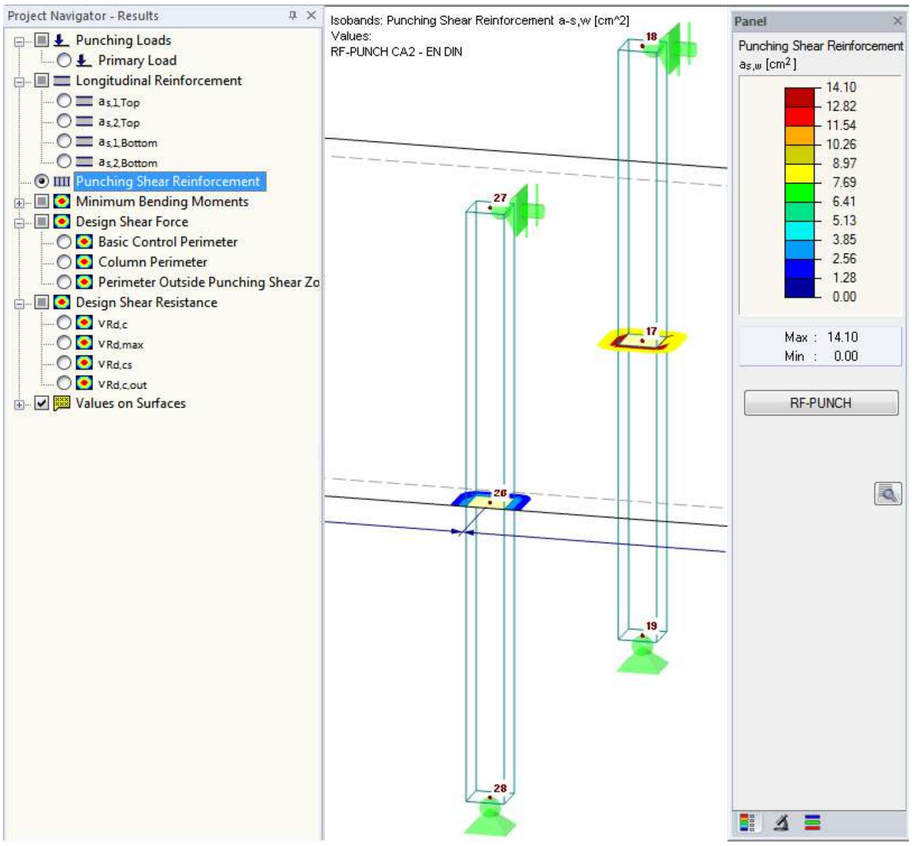


Figure 5.36: Punching shear reinforcement (EN DIN)

All checks are satisfied. The results correspond well to those of the example in [3].

A: Literature

[1] EN 1992-1-1:2005 + AC:2010 : Design of concrete structures – Part 1-1 : General rules and rules for buildings

[2] DIN EN 1992-1-1:2004/AC:2010 -02 Eurocode 2 : Design of concrete structures - Part 1-1 : General rules and rules for buildings

[3] Deutscher Beton-Verein E.V.: Beispiele zur Bemessung von Betontragwerken nach Eurocode 2. Band 1: Hochbau Bauverlag, Wiesbaden und Berlin 2011.

[4] Schneider, Klaus-Jürgen.: Bautabellen für Ingenieure mit Berechnungshinweisen und Beispielen, 16. Auflage. Werner Verlag, Düsseldorf 2004.

B: Index