TECHNICAL MANUAL

PSB®

Reinforcement against punching failure of slabs

Version PEIKKO GROUP 10/2020

PSB®

Reinforcement against punching failure of slabs

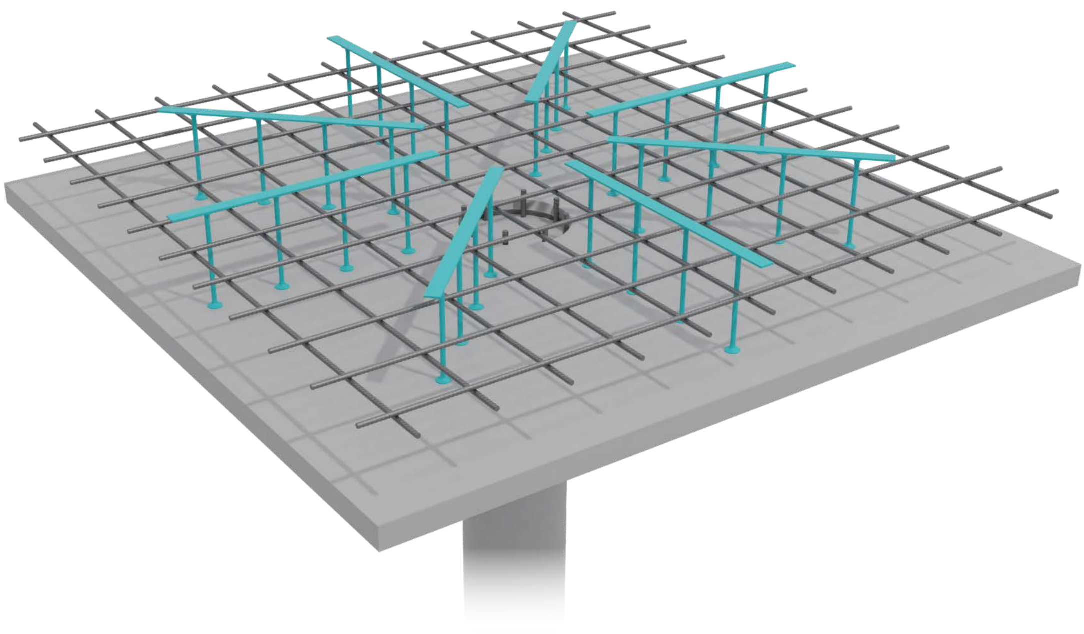
- Higher resistances than stirrups
- Simple and efficient installation
- Optimizing the construction height of the building
- Approved acc. to ETA-13/0151 for static and non-predominantly static loading
- Available in Peikko Designer®

PSB® is a building product mainly used as vertical reinforcement to increase the punching resistance of concrete flat slabs or ground slabs. The type, geometry and dimensions PSB® may be designed and the resistances of concrete members reinforced by PSB® elements may be verified using Peikko Designer®.

The properties of PSB® as well as the resistances of slabs reinforced by PSB® are approved within the European Technical Approval ETA-13/0151.

PSB® is manufactured and delivered in form of reinforcement elements that consist of double headed steel studs connected by an assembly profile. Since the product is designed and pre-fabricated by Peikko, the installation of the product is much simpler than it is for other traditional reinforcement elements (stirrups). This applies for the case when PSB® is used in cast-in situ or in pre-cast elements.

PSB® reinforcement is fully integrated in the concrete slab and is thus an ideal reinforcement system for monolithic slim-floor structures or flat concrete slabs in general. The double headed studs used in PSB® reinforcement elements enable the slab to develop a resistance that is up to 40% higher than the resistance of a slab reinforced by traditional reinforcement techniques such as stirrups.



peikko®

www.peikko.com

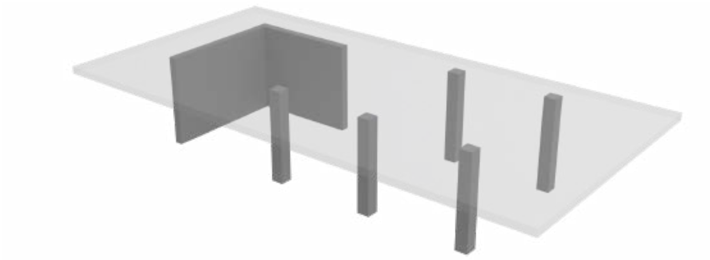
CONTENTS

About PSB®

1. Product properties

Reinforced concrete flat slabs are nowadays one of the most popular structural systems in residential, administrative, industrial and many other types of buildings. The system usually consists of slabs locally supported by columns or walls without down stand beams. Such configuration allows optimizing the space on the floor area and to perform saving with regards to the total height of the building.

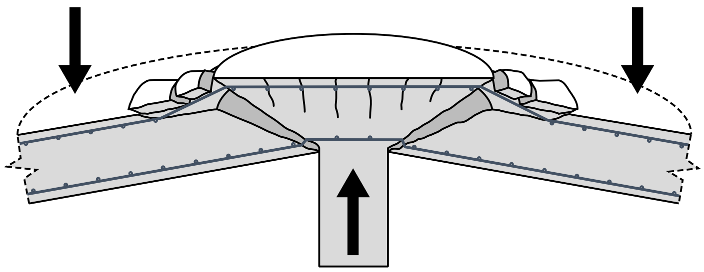
Figure 1. Flat slab supported on columns and walls.



Between supports, the slab is usually designed as a two-way slab to resist bending moments in two orthogonal directions. In support area, the bending moments are combined with transverse loads – reactions from supports. Such combined loading results in a state of stress may lead to failure of the slab by punching. The verification of the punching resistance of the slab is often decisive for the definition of the thickness of the concrete slab.

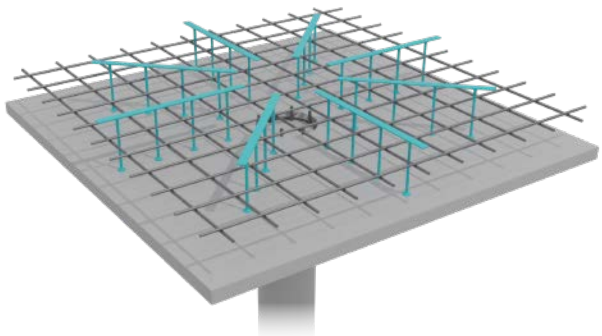
Punching usually occurs so that a concrete cone is separated from the slab, bending reinforcement is pulled away from concrete and the slab falls down due to gravity forces (*Figure 2*). Experience shows that failure by punching is particularly dangerous since it is a brittle phenomenon that happens suddenly without any previous signs of warning (extensive deformations, cracks…). Moreover, the failure of one column may impact on adjacent columns and lead to an in-chain failure of the whole reinforced concrete floor.

Figure 2. Failure of a slab by punching.



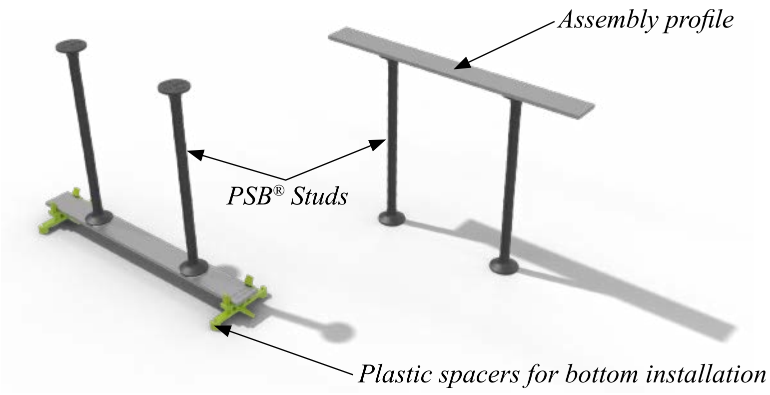
A slab without vertical reinforcement has only a very limited resistance against punching failure. This resistance may be increased by placing PSB® elements in the concrete slab in such a manner that they prevent the concrete cone to develop (*Figure 3*). Besides increasing the resistance of the slab, PSB® also increases its ductility. PSB® is also used in ground slabs in a similar manner as in flat slabs. Other applications (PSB® used as shear reinforcement in beams) are possible as well.

Figure 3. Flat slab reinforced with PSB®.



PSB® elements consist of steel double headed PSB® studs connected together by assembly profiles (*Figure 4*). The assembly bar has no load bearing function; it only guarantees the correct spacing and positioning of the studs during their installation to concrete.

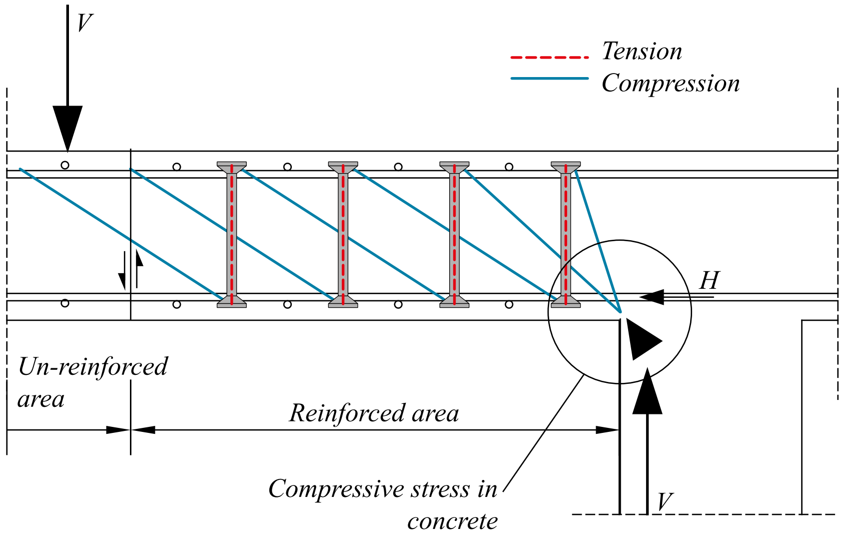
Figure 4. Available types of PSB® elements.



1.1 Structural behavior

PSB® studs are most typically used as vertical reinforcement in concrete slabs that is designed and detailed to prevent the development of inclined punching cracks. The structural behavior of a slab reinforced by PSB® studs may be interpreted by a system of struts and ties (*Figure 5*), where the PSB® studs act as vertical tensile components. The proper functioning of such mechanism is amongst other conditioned by the tensile resistance of the studs and their anchorage capacity in concrete.

Figure 5. Forces in a slab with PSB® punching reinforcement.



The excellent anchorage properties of PSB® studs enable the slabs reinforced with PSB® studs to develop resistances that are significantly higher than the resistances of slabs reinforced with traditional reinforcement (stirrups). The performance of concrete slabs reinforced by PSB® has been demonstrated by full scale laboratory tests performed at the Swiss Federal Institute of Technology (EPFL) in Lausanne during year 2012. The results of the tests have been used as the basis for the development of the European Technical Approval ETA-13/0151 that regulates the use and design of PSB® punching reinforcement. Comprehensive information about the test series and ETA-13/0151 may be found in reference [1].

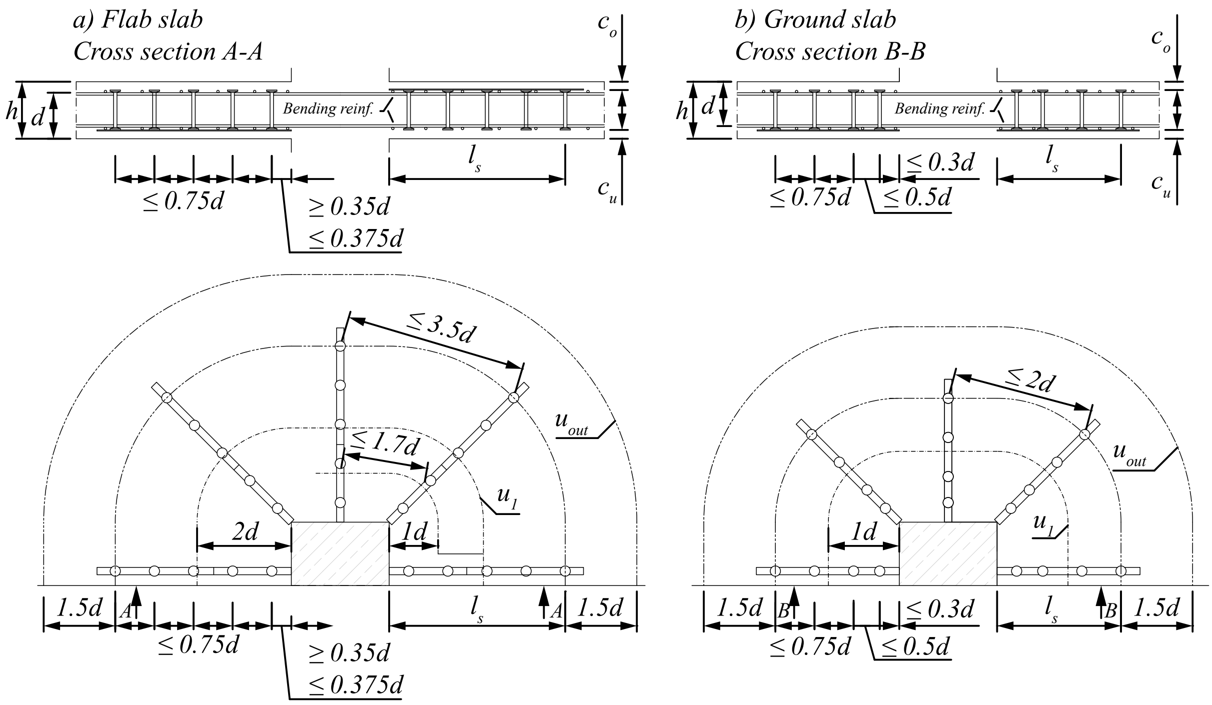
ETA-13/0151 defines a set of rules to determine:

- The resistance of the slab without PSB® reinforcement $V_{Rd,c}$
- The resistance of the slab reinforced with PSB® $V_{Rd,s}$
- The maximum resistance of the slab reinforced with PSB® $V_{Rd,max}$.

[1] Muttoni, A. Bujnak, J. "Performance of slabs reinforced by Peikko PSB® studs demonstrated by full scale tests and validated by ETA approval starting April 2013" Concrete connection 01/2013, Customer magazine of Peikko Group.

The section and top view of a slab reinforced with PSB® in accordance with recommendations of ETA-13/0151 is shown on *Figure 6*. Typically, PSB® elements are organized radially around the column. Alternative arrangements of PSB® elements are possible provided that requirements for the maximum spacing of PSB® studs are fulfilled.

Figure 6. Section and top view of a) flat slab b) ground slab or footing reinforced by PSB® studs.



The resistance of the slab without punching reinforcement at the basic control perimeter is determined according to Eq. (2.10) of EOTA TR 060 as:

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

The shear stress at the basic control perimeter is calculated according to Eq. (2.5) of EOTA TR 060:

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d}$$

where β is the load increase factor defined depending on the position of the column acc. to NA to EN 1992-1-1, u_1 is the length of the basic control perimeter and d is the effective depth of the slab (see *Figure 6*). The slab has to be reinforced by PSB® if:

$$v_{Rd,c} \leq v_{Ed}$$

The minimum number of perimeters of PSB® studs to be placed around the column is determined to enlarge the control perimeter to a value u_{out} determined in accordance with Eq. (2.21) of EOTA TR 060:

$$u_{out} = \frac{\beta_{red} \cdot v_{Ed}}{v_{Rd,c} \cdot d}$$

where $v_{Rd,c}$ is calculated according Eq.(2.10) of EOTA TR 060.

The resistance of PSB® elements is verified by the Eq. (2.18) and Eq. (2.20) of EOTA TR 060 for flat slabs and ground slabs respectively.

1.2 Limitations for application

The minimum depth of a slabs reinforced with PSB® is 180 mm.

The maximum resistance of a slab reinforced by PSB® is verified in accordance with Eq. (2.17) and (2.19) of EOTA TR 060 and 3.1 of ETA-13/0151 as follows:

Flat slabs $$v_{Rd,max} = 1.96 \cdot v_{Rd,c} \geq v_{Ed}$$

Ground slabs and footings $$v_{Rd,max} = 1.62 \cdot v_{Rd,c} \geq v_{Ed}$$

For comparison, the maximum resistance of slabs reinforced by traditional types of reinforcement (stirrups) should be verified in accordance with Eq. (6.53) of EN 1992-1-1:2004+A1:2014 as:

$$v_{Rd,max} = 0.4 \cdot 0.6 \cdot \left[1 - \frac{f_{ck}}{250}\right] \cdot f_{cd} \geq \frac{\beta \cdot v_{Ed}}{u_0 \cdot d}$$

where u_0 is the length of column periphery. The verification in accordance with DIN EN 1992-1-1/NA:2012 for slabs reinforced by stirrups is:

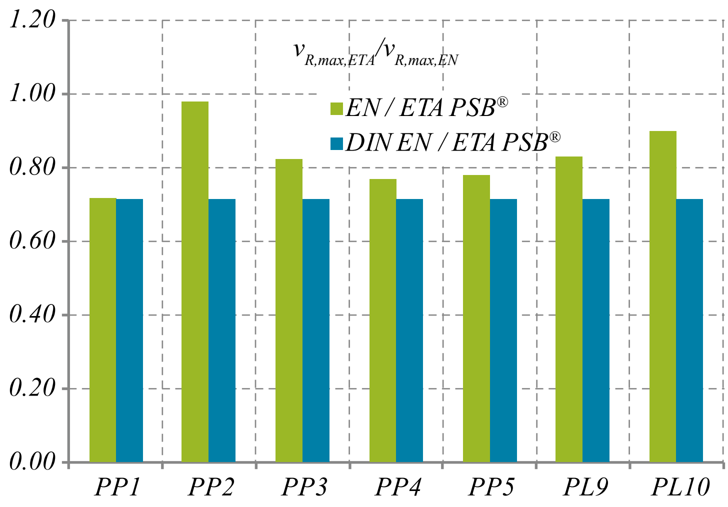
$$v_{Rd,max} = 1.4 \cdot v_{Rd,c} \geq v_{Ed}$$

In case the above verifications of maximum resistance of slab can't be fulfilled, a sufficient level of resistance can't be achieved in slabs reinforced by reinforcing them with vertical steel reinforcement (traditional reinforcement elements or PSB®).

At the same time, the comparison shown in *Figure 7* for slabs tested within Peikko's testing program (see reference [1]) shows that the maximum resistance of slabs reinforced by PSB® studs may be up to 40% higher than the resistance of slabs reinforced by traditional reinforcement elements determined acc. to EN 1992-1-1:2004+A1:2014 or DIN EN 1992-1-1/NA:2012.

Figure 7. Maximum characteristic values of resistances in slabs reinforced with PSB® and with standard types of reinforcement.

	$v_{R,max,ETA}$ [kN]	$v_{R,max,EN}$ [kN]	$v_{R,max,DIN\ EN}$ [kN]
PP1	774.9	554.9	553.5
PP2	1050.2	1027.7	750.1
PP3	4070.8	3346.2	2907.7
PP4	1856.0	1426.2	1325.7
PP5	1808.1	1408.7	1291.5
PL9	2923.9	2429.1	2088.5
PL10	4606.2	4150.0	3290.1



1.3 Other properties

ETA-13/0151 approves the use of PSB® elements with diameters 10, 12, 14, 16, 20 and 25 mm. Elements using studs with larger diameters (28mm and 32mm) may be produced as well but are not within the scope of ETA-13/0151. The diameter of the heads in all studs corresponds to 3x the diameters of the shaft of the stud.

The PSB® studs and assembly bar have the following material properties:

Assembly bar	S235JR	EN 10025-2
PSB® studs	B500B	EN 10080, DIN 488

The spacers used for bottom installation of PSB® elements are made of plastic material. Standard spacers provide concrete cover 15, 20, 25, 30, 35, 40 and 45 mm. The air temperature during installation of PSB® using plastic spacers should be in the range of -30°C to +35°C.

Peikko Group's production units are controlled externally and audited periodically on the basis of the production certifications and product approvals provided by various independent organizations.

2. Resistances

The characteristic values of resistances of individual PSB® studs in accordance with ETA-13/0151 are summarized in *Table 1*.

Table 1. Characteristic values of tensile resistances of PSB® studs.

Diameter	mm	10	12	14	16	20	25
Resistance	kN	39.3	56.5	77.0	100.5	157.1	245.4

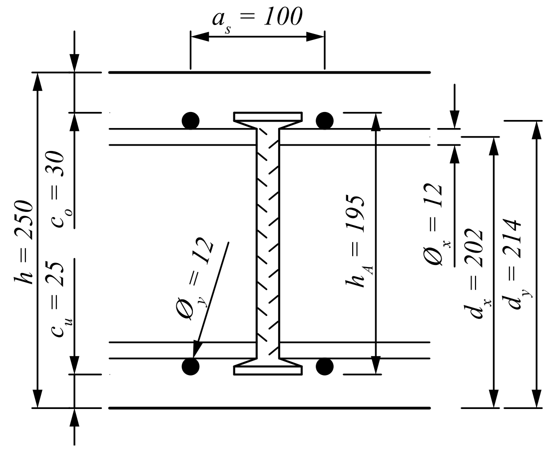
The resistance of a concrete member reinforced by PSB® has to be verified case-by-case for each project. Peikko Designer® may be used to design PSB® and verify the resistances of concrete members reinforced by PSB® according to the requirements of ETA-13/0151.

Selecting PSB®

It is recommended to select the appropriate reinforcement with PSB® using Peikko Designer® individually for each separate case. Peikko Designer® is a design software developed by Peikko, and it is freely available from www.peikko.com.

An example of the procedure used for the design and selection of PSB® in accordance with EOTA TR 060 and ETA-13/0151 used and implemented in Peikko Designer® is presented hereafter.

Input	
Column dimension	a = 300 mm b = 300 mm
Concrete grade	C30/37
Height of slab	h = 250 mm
Concrete cover bottom	c_u = 25 mm
Concrete cover top	c_o = 30 mm
Diameter of bending	Φ_x = 12 mm
Reinforcement	Φ_y = 12 mm
Applied load	V_{Ed} = 730 kN
Position of column	Internal column



Effective depth and bending reinforcement ratio

- Effective depth

$$d_y = h - c_o - \Phi_y / 2 \qquad = 214\ mm$$

$$d_x = h - c_o - \Phi_y - \Phi_x / 2 \qquad = 202\ mm$$

$$d = \frac{d_x + d_y}{2} \qquad = 208\ mm$$

- Bending reinforcement ratio

$$\rho_x = \frac{A_{s,x}}{a_{s,x} \cdot d_x} \cdot 100 \qquad = 0.56\%$$

$$\rho_y = \frac{A_{s,y}}{a_{s,y} \cdot d_y} \cdot 100 \qquad = 0.528\%$$

$$\rho_l = \sqrt{\rho_x \cdot \rho_y} \qquad = 0.544\%$$

Area of one reinforcement bar in x direction

$$A_{s,x} = \frac{\pi \cdot \Phi_x^2}{4}$$

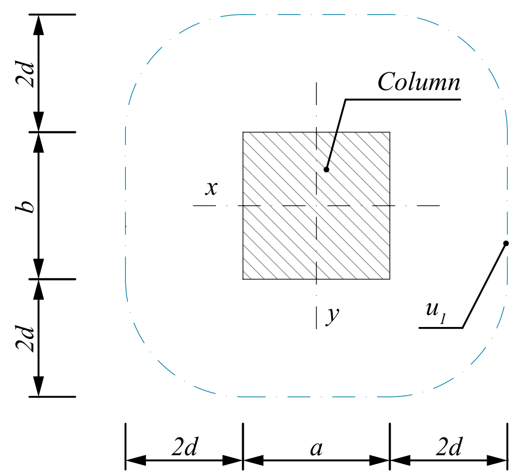
Area of one reinforcement bar in y direction

$$A_{s,y} = \frac{\pi \cdot \Phi_y^2}{4}$$

Basic control perimeter (u_1) and perimeter of column (u_o) (EN 1992-1-1 6.4.2)

$$u_1 = 2\pi \cdot 2 \cdot d + 2 \cdot a + 2 \cdot b \qquad = 3813.8\ mm$$

$$u_0 = 2 \cdot (a + b) \qquad = 1200\ mm$$



Load increase factor β (EN 1992-1-1)

- Recommended value for internal column
  $\beta = 1.15$

Position	β Values (EN 1992-1-1)
Internal column	1.15
Edge column	1.40
Corner column	1.50
End of wall	1.35
Corner of wall	1.20

Punching shear resistance of slab without punching reinforcement (EOTA TR 060)

$$v_{Rd,c} = max\begin{cases}\left[C_{Rd,c}\cdot k_d\cdot(\rho_l\cdot f_{ck})^{1/3}\right]\\ \frac{0.0525}{\gamma_c}\cdot k_d^{3/2}\cdot f_{ck}^{1/2}\end{cases} = 0.603 MPa$$

$$k_d = min\begin{cases}2.0\\ 1+\sqrt{\frac{200}{d}}\end{cases} = 1.98$$

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

$$C_{Rd,c} = \frac{0.18}{\gamma_C}$$

If: $u_0 / d < 4$

$$C_{Rd,c} = \frac{0.18}{\gamma_C}\cdot\left(0.1\cdot\frac{u_0}{d}+0.6\right)\geq\frac{0.15}{\gamma_c}$$

(EOTA TR 060)

$\gamma_c = 1.5$

(EN 1992-1-1 2.4.2.4)

Maximum resistance of slab with punching reinforcement (EOTA TR 060)

$$v_{Rd,max} = k_{pu,sl}\cdot v_{Rd,c} = 1.182 MPa$$

Flat slab $k_{pu,sl} = 1.96$

Ground slab $k_{pu,fo} = 1.62$

(ETA-13/0151)

Design value of the shear stress (EOTA TR 060)

$$v_{Ed} = \frac{\beta\cdot V_{Ed}}{u_1\cdot d} = 1.058 MPa$$

Load bearing capacity of the slab

$$v_{Rd,c} < v_{Ed} < v_{Rd,max}$$
$$0.603 < 1.058 < 1.182$$

PSB® reinforcement can be used.

No PSB® reinforcement is needed if:

$v_{Rd,c} \geq v_{Ed}$

PSB® reinforcement can be used if:

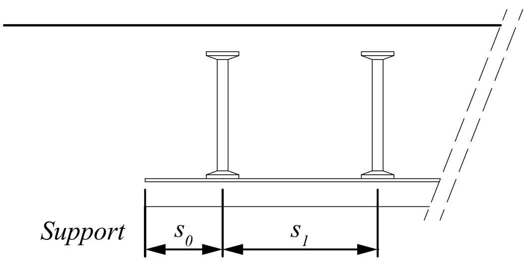
$v_{Rd,c} < v_{Ed} < v_{Rd,max}$

Maximum resistance of slab exceeded if:

$v_{Ed} > v_{Rd,max}$

Dimension of stud (ETA-13/0151)

- Height of studs
  $h_A = h_d - c_u - c_o$ $= 195\ mm$
- Spacing between elements
  s_1 $= 150\ mm$
  s_0 $= 75\ mm$
- Check spacing
  $s_1 = 150 \Rightarrow \frac{s_1}{d} = 0.72 < 0.75$
  $s_0 = 75 \Rightarrow \frac{s_0}{d} = 0.37\begin{cases}< 0.5\\ > 0.35\end{cases}$



$s_1 \leq 0.75\cdot d$

$0.35\cdot d \leq s_0 \leq 0.5d$

(ETA-13/0151)

Number of studs and length of reinforcement elements see *Figure 8* (EOTA TR 060)

- Required length of outer perimeter

$$u_{out,req} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c,out} \cdot d} \qquad = 6695\ mm$$

- Punching shear resistance of slab on outer perimeter

$$v_{Rd,c,out} = max \begin{cases} \frac{0.18}{\gamma_c} \cdot k_d \cdot (\rho_l \cdot f_{ck})^{1/3} \\ \frac{0.0525}{\gamma_c} \cdot k_d^{3/2} \cdot f_{ck}^{1/2} \end{cases} = 0.603 MPa$$

- Required length of reinforcement element

$$l_{s,req} = \frac{u_{out,req} - 2 \cdot (a+b)}{\pi \cdot 2} - 1.5 \cdot d \qquad = 563\ mm$$

- Min. number of PSB® in one element

$$n_{req} = \frac{l_{s,req} - s_0}{s_1} + 1 = 4.25 \Rightarrow n_{prov} \qquad = 5$$

- Provided length of one element

$$l_{s,prov} = s_0 + (n_{prov} - 1) \cdot s_1 \qquad = 675\ mm$$

- Provided control perimeter

$$u_{out,prov} = 2\pi \cdot (l_{s,prov} + 1.5 \cdot d) + 2 \cdot a + 2 \cdot b = 7401.5\ mm$$

- Check outer control perimeter length

$$u_{out,req} \le u_{out,prov} \qquad l_{s,req} \le l_{1,prov}$$
$$6695 < 7401.5 \qquad 563 < 675$$

For internal column $\beta_{red} = 1.15$

$$v_{Rd,c,out} \ge \frac{\beta_{red} \cdot V_{Ed}}{u_{out,req} \cdot d}$$

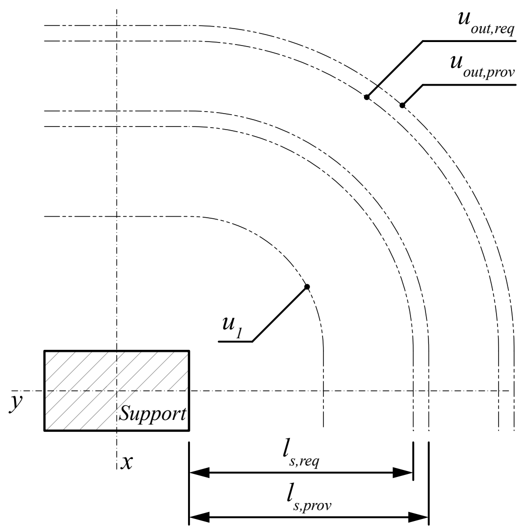
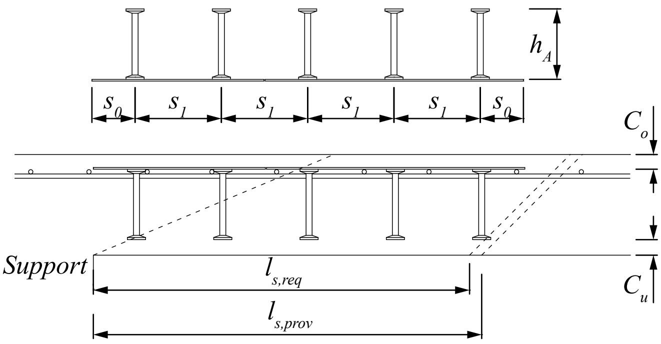


Figure 8. Layout of studs in slab reinforced with PSB®.



Resistance of the slab in outer perimeter (EOTA TR 060)

$$v_{Ed,out} = \frac{\beta_{red} \cdot V_{Ed}}{u_{out,prov} . d} = 0.545 MPa \qquad v_{Ed,out} = \frac{\beta_{red} \cdot V_{Ed}}{u_{out,prov} . d}$$

$$v_{Rd,c,out} \ge v_{Ed,out}$$
$$0.603 > 0.545$$

Number of reinforcement elements (EOTA TR 060)

1. Strength condition – $m_{c,reg}$

$$m_{c,req} \geq \frac{\beta \cdot V_{Ed} \cdot \eta}{n_c A_{si} f_{yd}}$$

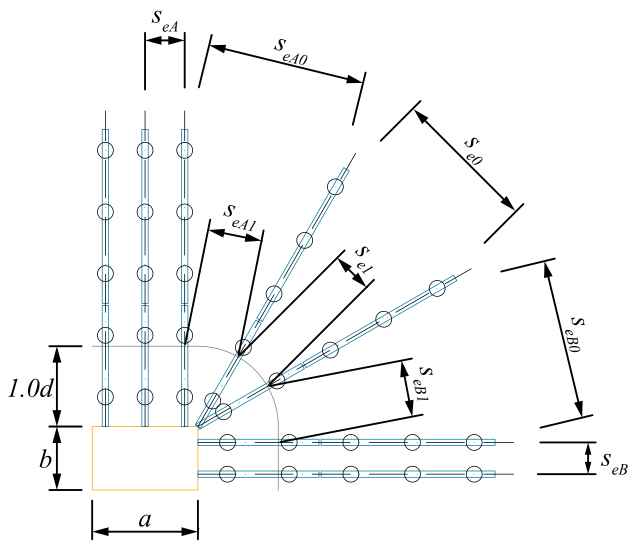
2. Spacing condition – m_{spac}

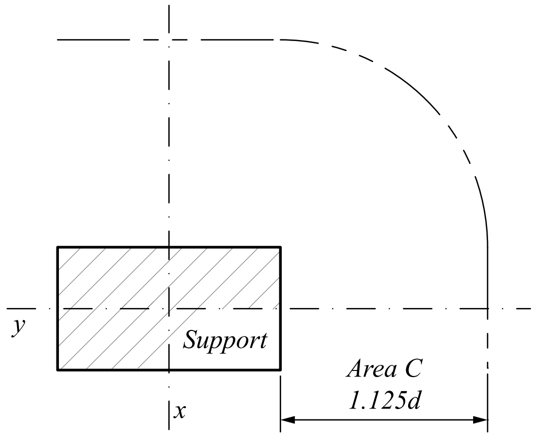
A_{si} – is the cross section area of one stud

$$\eta = \begin{cases} = 1.0 & for\ d \leq 200mm \\ = 1.6 & for\ d \geq 800mm \end{cases}$$

use linear interpolation for other values.

n_c = number of studs in area C
n_c = 2





(ETA-13/0151)

$$max\begin{Bmatrix} s_{eA0} \\ s_{e0} \\ s_{eB0} \end{Bmatrix} \leq 3.5 \cdot d \qquad max\begin{Bmatrix} s_{eA} \\ s_{eA1} \\ s_{e1} \\ s_{eB1} \\ s_{eB} \end{Bmatrix} \leq 1.7 \cdot d$$

Diameter of studs	10	12	14	16	20	25
$m_{c,req}$	12	9	7	5	3	2
$m_{c,spac}$	8	8	8	8	8	8
$m_{c,prov} = max\begin{Bmatrix} m_{c,req} \\ m_{spac} \end{Bmatrix}$	12	9	8	8	8	8

Total resistance of PSB® (EOTA TR 060)

$$V_{Rd,sy} = m_c \cdot n_c \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta} = 1060.3\ kN$$

$$\beta \cdot V_{Ed} \leq V_{Rd,sy}$$

$$839.5 < 1060.3$$

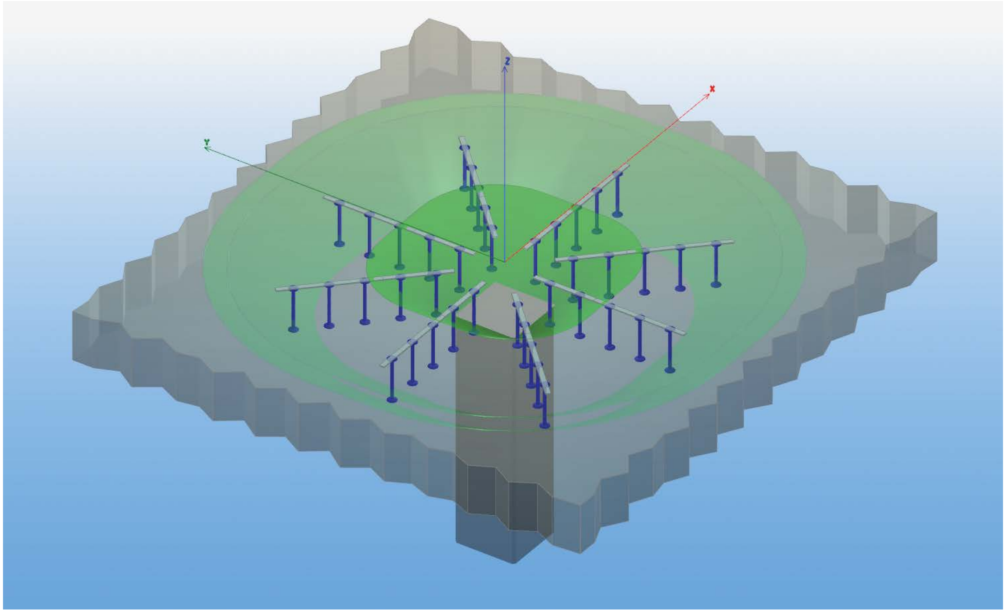
$$V_{Rd,sy} = m_c \cdot n_c \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta}$$

m_c = number of elements
d_A = shaft diameter of PSB®

8×PSB-14/195-2/300 (75/150/75) & 8×PSB-14/195-3/450 (75/150/150/75)

or

8×PSB-14/195-5/750 (75/4×150/75)



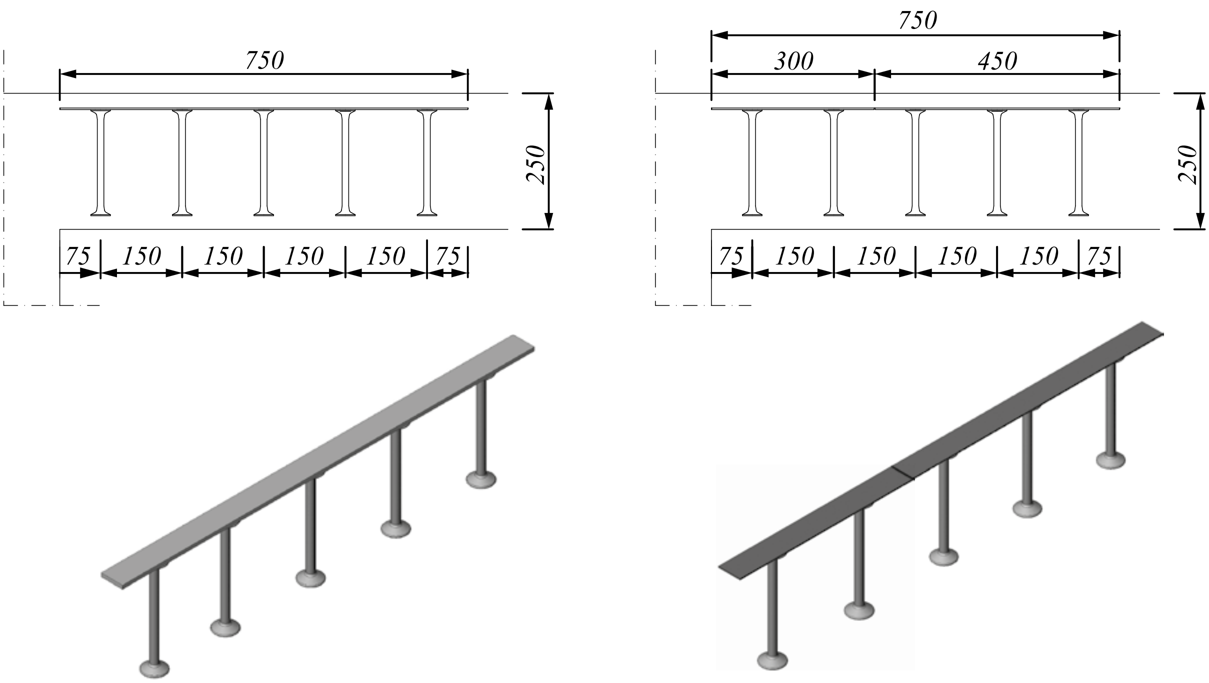
The resulting type and layout of the reinforcement proposed by Peikko Designer® is the most economical one. If needed, the diameter of studs and the number of PSB® elements may be modified manually by the user. The selected PSB® elements are described by a specific code. Plan and section drawings of the selected PSB® reinforcement are also available in the printed outputs of Peikko Designer® or may be exported to DXF files. The printed output of Peikko Designer® also includes a summary of input data and static verifications of resistances for each individual case within each single project. The list of recommended accessories for the installation of PSB® is also available in the printed output of Peikko Designer®.

The reinforcement of flat slabs with PSB® may be provided as a combination of 2/3 stud elements or by complete elements where all studs are welded to one assembly profile. Equivalence between a solution with 2/3 stud elements and a complete element is shown on *Figure 9*.

Figure 9. Complete element and combination of 2/3 stud elements.

8×PSB-14/195-5/750 (75/4×150/75)

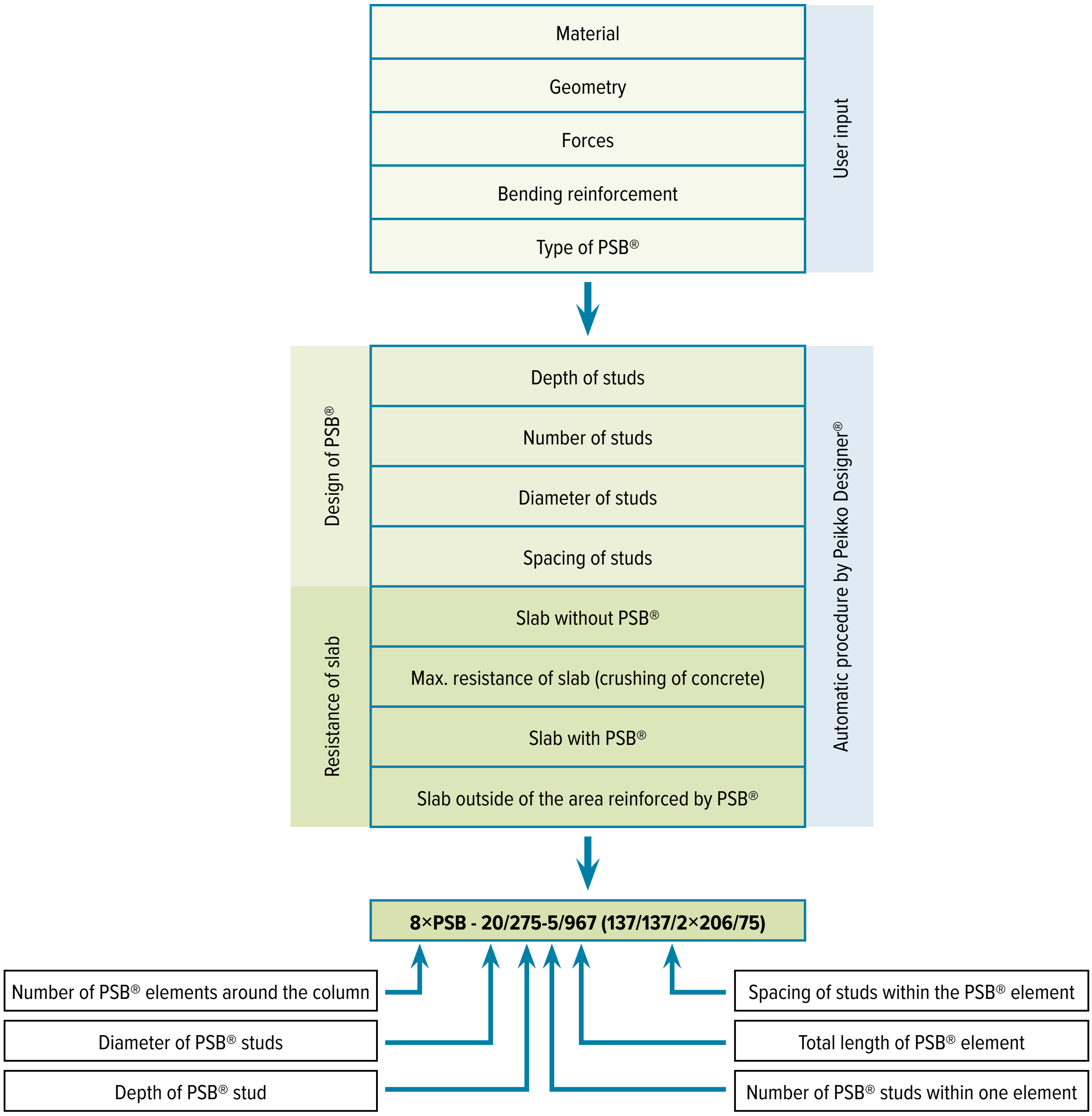
8×PSB-14/195-2/300(75/150/75)
& 8×PSB-14/195-3/450(75/150/150/75)



SELECTING

The typical procedure to select the appropriate type of PSB® using Peikko Designer® is summarized on the diagram in *Figure 10*.

Figure 10. Procedure to select PSB® reinforcement.



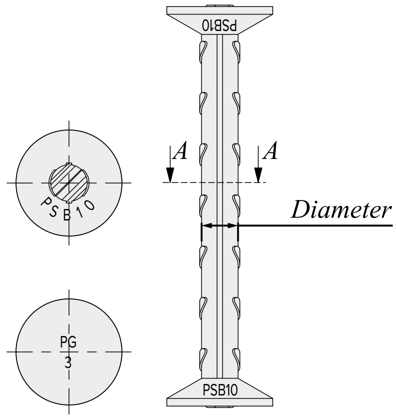
Installation of PSB®

Install the product

PSB® reinforcement is installed in the mould according to design plans. Each PSB® element is identified by a code that is printed on a sticker at the assembly profile.

Double headed PSB® studs are marked with symbol PG or PEIKKO; the symbol PSB® with corresponding diameter of the stud is marked on the opposite side of the head.

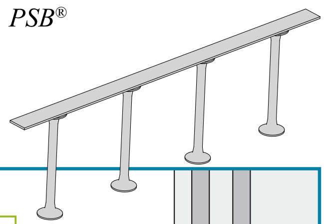
Typical shape of a PSB® stud.

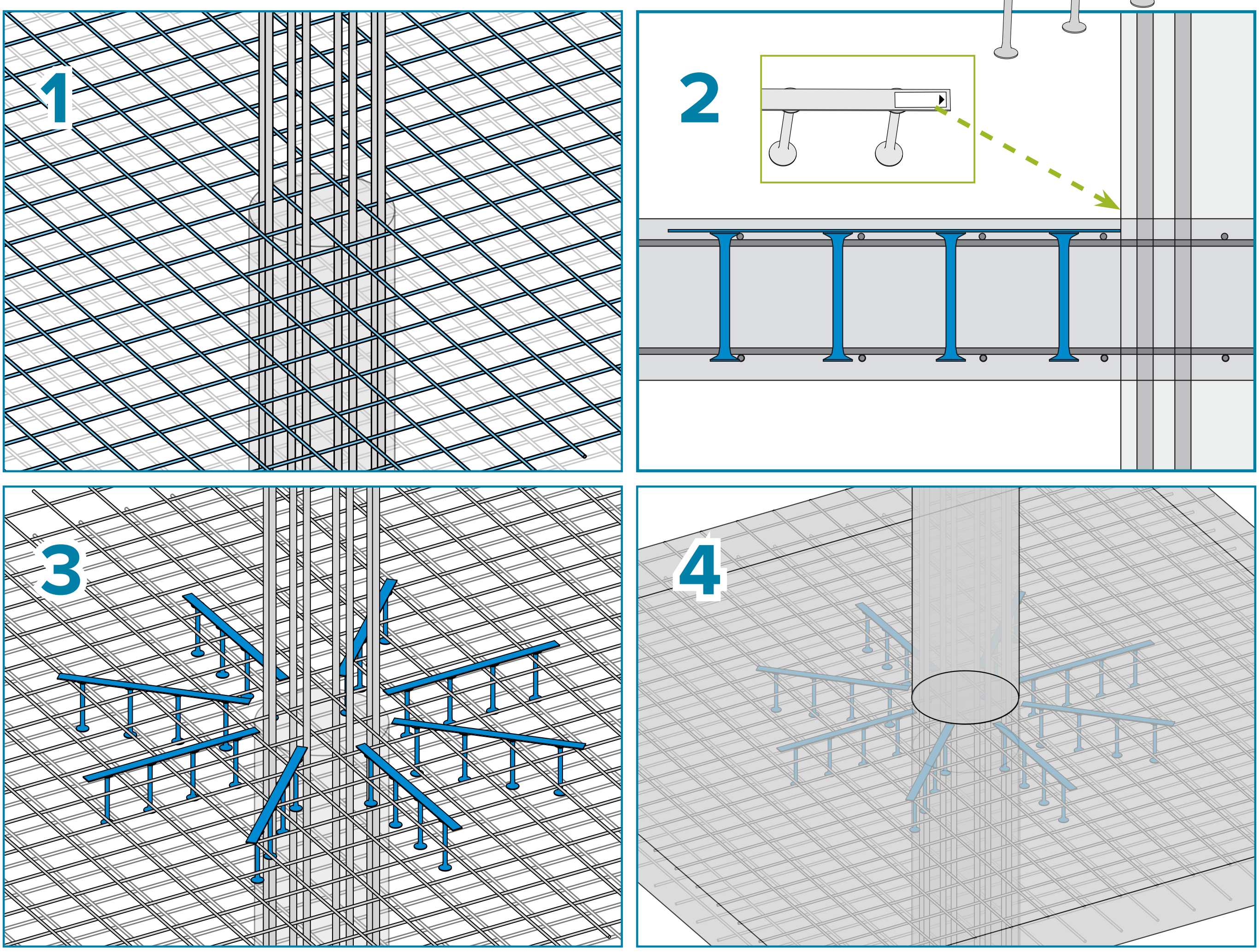


Cast in-situ monolithic slabs and footings

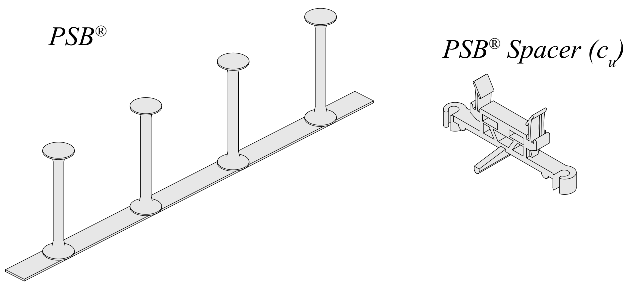
PSB® elements may be installed to cast in-situ monolithic slabs:

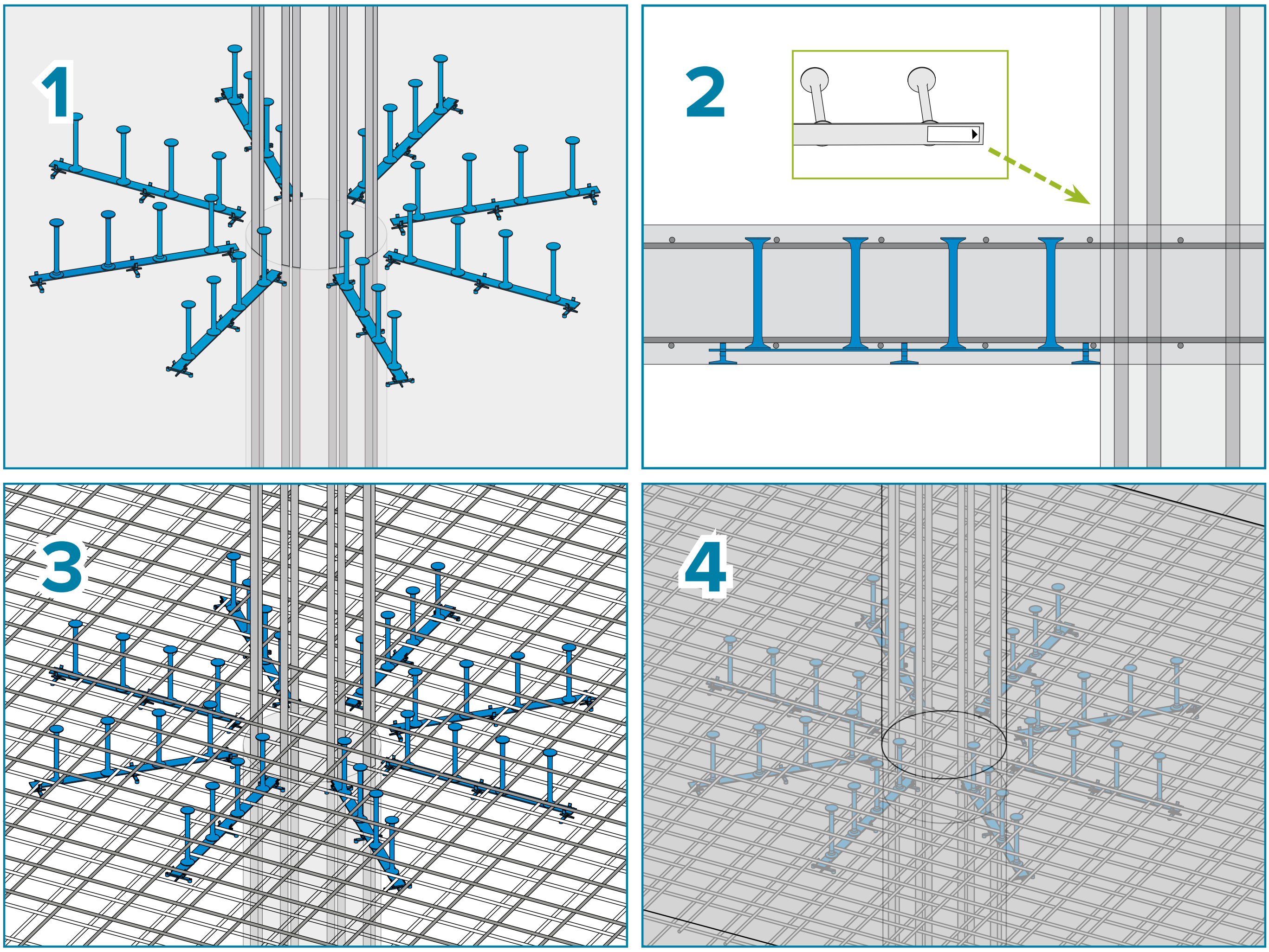
- **Top installation:** The PSB® elements are hanged to the main reinforcement of the slab. The whole bending reinforcement is installed to the mould prior to PSB®.





- **Bottom installation:** PSB® elements are place to the mould of the slab from bottom prior to the installation of the bending reinforcement. In order to achieve sufficient concrete cover of the headed studs, PSB® plastic spacers are mounted to the assembly profile of the PSB® elements. The spacers have to be ordered separately from the PSB® elements.





The type and number or recommended accessories (spacers, cross connectors) for both types of installation are available in the printed outputs of Peikko Designer®.

NOTES

Revisions

Version: PEIKKO GROUP 10/2020. Revision: 005

- Removed PSB-F.

Version: PEIKKO GROUP 06/2013. Revision: 004*

- New cover design for 2018 added.

Resources

DESIGN TOOLS

Use our powerful software every day to make your work faster, easier, and more reliable. Peikko design tools include design software, 3D components for modeling programs, installation instructions, technical manuals, and product approvals of Peikko's products.

peikko.com/design-tools

TECHNICAL SUPPORT

Our technical support teams around the world are available to assist you with all of your questions regarding design, installation etc.

peikko.com/technical-support

APPROVALS

Approvals, certificates, and documents related to CE-marking (DoP, DoC) can be found on our websites under each products' product page.

peikko.com/products

EPDS AND MANAGEMENT SYSTEM CERTIFICATES

Environmental Product Declarations and management system certificates can be found at the quality section of our websites.

peikko.com/qehs

COMPANY WITH
MANAGEMENT SYSTEM
CERTIFIED BY DNV
ISO 9001 ▪ ISO 14001
ISO 45001