PSB® Punching Reinforcement
Shear Reinforcement for Concrete Structures
PSB
Reinforcement against punching failure of slabs

System benefits

• 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 precast 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.
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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 $V_{Rd,max}$

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. (A3) of ETA-13/0151 as:

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

The shear stress at the basic control perimeter is calculated according to Eq. (A1) of ETA-13/0151:

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

where $\beta$ is the load increase factor defined depending on the position of the column acc. to ETA-13/0151 Eq. (A2), $u_1$ 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. (A4) of ETA-13/0151:

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

where $v_{Rd,c}$ is calculated according Eq. (A3) of ETA-13/0151 with $C_{Rd,c} = 0.15/\gamma_c$.

The resistance of PSB elements is verified by the Eq. (A7) and Eq. (A9) of ETA-13/0151 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. (A8) and (A10) 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+AC2:2010 as:

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

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+AC2:2010 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

<table>
<thead>
<tr>
<th></th>
<th>( v_{R,max,ETA} ) [kN]</th>
<th>( v_{R,max,EN} ) [kN]</th>
<th>( v_{R,max,DIN EN} ) [kN]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP1</td>
<td>774.9</td>
<td>554.9</td>
<td>553.5</td>
</tr>
<tr>
<td>PP2</td>
<td>1050.2</td>
<td>1027.7</td>
<td>750.1</td>
</tr>
<tr>
<td>PP3</td>
<td>4070.8</td>
<td>3346.2</td>
<td>2907.7</td>
</tr>
<tr>
<td>PP4</td>
<td>1856.0</td>
<td>1426.2</td>
<td>1325.7</td>
</tr>
<tr>
<td>PP5</td>
<td>1808.1</td>
<td>1408.7</td>
<td>1291.5</td>
</tr>
<tr>
<td>PL9</td>
<td>2923.9</td>
<td>2429.1</td>
<td>2088.5</td>
</tr>
<tr>
<td>PL10</td>
<td>4606.2</td>
<td>4150.0</td>
<td>3290.1</td>
</tr>
</tbody>
</table>

About PSB
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 (28 mm and 32 mm) 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:

<table>
<thead>
<tr>
<th>Material</th>
<th>Grade</th>
<th>Standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assembly bar</td>
<td>S235JR</td>
<td>EN 10025-2</td>
</tr>
<tr>
<td>PSB studs</td>
<td>B500B</td>
<td>EN 10080, DIN 488</td>
</tr>
</tbody>
</table>

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 externally controlled and periodically audited on the basis of production certifications and product approvals by various organizations, including Inspecta Certification, VTT Expert Services, Nordcert, SLV, TSUS and SPSC among others.

2. Resistances

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

<table>
<thead>
<tr>
<th>Diameter (mm)</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance (kN)</td>
<td>39,3</td>
<td>56,5</td>
<td>77,0</td>
<td>100,5</td>
<td>157,1</td>
<td>245,4</td>
</tr>
</tbody>
</table>

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 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 reinforcement: Φ_x = 12 mm, Φ_y = 12 mm
- Applied load: V_Ed = 730 kN
- Position of column: Internal column

**Effective depth and bending reinforcement ratio**

- Effective depth:
  - \(d_x = h - c_0 - \frac{Φ_y}{2} = 214 \text{ mm}\)
  - \(d_y = h - c_0 - \frac{Φ_x}{2} = 202 \text{ mm}\)
  - \(d = \frac{d_x + d_y}{2} = 208 \text{ mm}\)

- Bending reinforcement ratio:
  - \(ρ_x = \frac{A_{s,x}}{a_{s,x} \cdot d_x} \cdot 100 = 0.56\%\)
  - \(ρ_y = \frac{A_{s,y}}{a_{s,y} \cdot d_y} \cdot 100 = 0.528\%\)
  - \(ρ_l = \sqrt{ρ_x \cdot ρ_y} = 0.544\%\)

**Basic control perimeter \((u_i)\) and perimeter of column \((u_o)\)**

\(u_i = 2π \cdot 2 \cdot d + 2 \cdot a + 2 \cdot b = 3813.8 \text{ mm}\)
\(u_o = 2 \cdot (a+b) = 1200 \text{ mm}\)
Load increase factor $\beta$ (ETA-13/0151)

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

Position $\beta$ values
- Internal column 1.15
- Edge column 1.4
- Corner column 1.5
- End of wall 1.35
- Corner of wall 1.20

Punching shear resistance of slab without punching reinforcement (ETA-13/0151)

$$v_{Rd,c} = \frac{C_{Rd,c} \cdot k_d \cdot (p_1 \cdot f_{ck})^{1/3}}{\gamma_c} = 0.603 \text{ MPa}$$

$$k_d = \min \left\{ \frac{2.0}{1 + \sqrt{\frac{200}{d}}} \right\} = 1.98$$

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

Maximum resistance of slab with punching reinforcement (ETA-13/0151)

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

Design value of the shear stress (ETA-13/0151)

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

Load bearing capacity of the slab

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

$0.603 < 1.058 < 1.182$

PSB reinforcement can be used

Dimension of stud (ETA-13/0151)

- Height of studs
  $$h_A = h_d - c_u - c_0 = 195 \text{ mm}$$

- Spacing between elements
  $$s_1 = 150 \text{ mm}$$
  $$s_0 = 75 \text{ mm}$$

Support

- $s_1 \leq 0.75 \cdot d$
- $0.35 \cdot d \leq s_0 \leq 0.5d$

(ETA-13/0151)
• Check spacing
\[ s_1 = 150 \Rightarrow \frac{s_1}{d} = 0.72 < 0.75 \]
\[ s_0 = 75 \Rightarrow \frac{s_0}{d} = 0.37 \left\{ \begin{array}{ll} < 0.5 \\ > 0.35 \end{array} \right. \]

**Number of studs and length of reinforcement elements**
see Figure 8 (ETA-13/0151)

• Required length of outer perimeter
\[ u_{out,req} = \frac{\beta_{red} \cdot V_{Ed}}{v_{rd,c,out} \cdot d} = 6695 \text{ mm} \]

• Punching shear resistance of slab on outer perimeter
\[ v_{rd,c,out} = \max \left[ \frac{0.18}{\gamma_c} \cdot k_d \cdot (\rho_1 \cdot f_{ck})^{1/3}, \frac{0.0525}{\gamma_c} \cdot k_d^{3/2} \cdot f_{ck}^{1/2} \right] = 0.603 \text{ MPa} \]

• Required length of reinforcement element
\[ l_s = \frac{u_{out,req} - 2 \cdot (a + b)}{\pi \cdot 2} - 1.5d = 563 \text{ mm} \]

• Min. number of PSB in one element
\[ n_{req} = \frac{l_{s,req} - s_0}{s_1} + 1 = 4.25 \Rightarrow n_{prov} = 5 \]

• Provided length of one element
\[ l_{s,prov} = s_0 + (n_{prov} - 1) \cdot s_1 = 675 \text{ mm} \]

• Provided control perimeter
\[ u_{out,prov} = 2\pi(l_{s,prov} + 1.5d) + 2a + 2b = 7401.5 \text{ mm} \]

• Check outer control perimeter length
\[ u_{out,req} \leq u_{out,prov} \]
\[ l_{s,req} \leq l_{s,prov} \]
\[ 6695 < 7401.5 \]
\[ 563 < 675 \]

**Resistance of the slab in outer perimeter (ETA-13/0151)**
\[ v_{Ed,out} = \frac{\beta_{red} \cdot V_{Ed}}{u_{out,prov} \cdot d} = 0.545 \text{ MPa} \]

For internal column \( \beta_{red} = 1.15 \)
\[ v_{rd,c,out} \geq \frac{\beta_{red} \cdot V_{Ed}}{u_{out,req} \cdot d} \]

**Figure 8. Layout of studs in slab reinforced with PSB**
Number of reinforcement elements (ETA-13/0151)

1. Strength condition – \( m_{c,\text{req}} \)

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

2. Spacing condition – \( m_{c,\text{spac}} \)

\[
\max \left\{ \frac{s_{A0}}{s_{A}}, \frac{s_{B0}}{s_{B}} \right\} \leq 3.5 \cdot d
\]

\[
\max \left\{ \frac{s_{A}}{s_{A}}, \frac{s_{B}}{s_{B}} \right\} \leq 1.7 \cdot d
\]

Where:

- \( A_{si} \) is the cross section area of one stud
- \( \beta \) depends on the diameter of the stud:
  - \( = 1.0 \) for \( d \leq 200\text{mm} \)
  - \( = 1.6 \) for \( d \geq 800\text{mm} \)
- \( \eta \) is linear interpolation for other values
- \( n_c = \) number of studs in area “C”
- \( n_c = 2 \)

Selecting PSB

<table>
<thead>
<tr>
<th>Diameter of stud</th>
<th>10</th>
<th>12</th>
<th>14</th>
<th>16</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>( m_{c,\text{req}} )</td>
<td>12</td>
<td>9</td>
<td>7</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>( m_{c,\text{spac}} )</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>( m_{c,\text{prov}} = \max \left{ m_{c,\text{req}} , m_{c,\text{spac}} \right} )</td>
<td>12</td>
<td>12</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

Total resistance of PSB (ETA-13/0151)

\[
V_{Rd,xy} = m_c \cdot n_c \cdot \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta} = 1060.3\text{kN}
\]

\( \beta \cdot V_{Ed} \leq V_{Rd,xy} \)

839.5 < 1060.3

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

Or

8xPSB-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

8xPSB-14/195-5/750 (75/4*150/75) & 8xPSB-14/195-3/450(75/150/150/75)

8xPSB-14/195-2/300(75/150/75) & 8xPSB-14/195-3/450(75/150/150/75)
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**

1. **Materials**
2. **Geometry**
3. **Forces**
4. **Bending reinforcement**
5. **Type of PSB**

**User input**

**Design of PSB**

- Depth of studs
- Number of studs
- Diameter of studs
- Spacing of studs
- Slab without PSB
- Max. resistance of slab (crushing of concrete)
- Slab with PSB
- Slab outside of the area reinforced by PSB

**Automatic procedure by Peikko Designer**

- **Number of PSB elements around the column**
- **Diameter of PSB studs**
- **Depth of the PSB stud**
  - **Spacing of studs within the PSB element**
  - **Total length of PSB element**
  - **Number of PSB studs within one element**

**8xPSB - 20/275-5/967 (137/137/2*206/75)**
Installation of PSB

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.

Cast in-situ monolithic slabs

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 placed 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 of recommended accessories (spacers, cross connectors) for both types of installation are available in the printed outputs of Peikko Designer®.
**In precast factory**

**Precast slabs**

A special type of PSB elements (PSB-F) is available for the use within filigree slabs. The assembly profile of the PSB-F elements is installed to the formwork from bottom on plastic spacers prior to the reinforcement of the filigree slab. The reinforcement of the filigree slab (bending reinforcement and lattice girders) may thereafter be installed manually or by automatized process without being limited by the presence of studs. The studs are installed on the assembly profile only once the reinforcement process of the filigree slab is finished. They are simply clicked on the assembly profiles; the slotted holes on the assembly profiles offer mounting tolerances to ensure the proper installation of the studs.
Technical Manual Revisions

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

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

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

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peikko.com/qehs