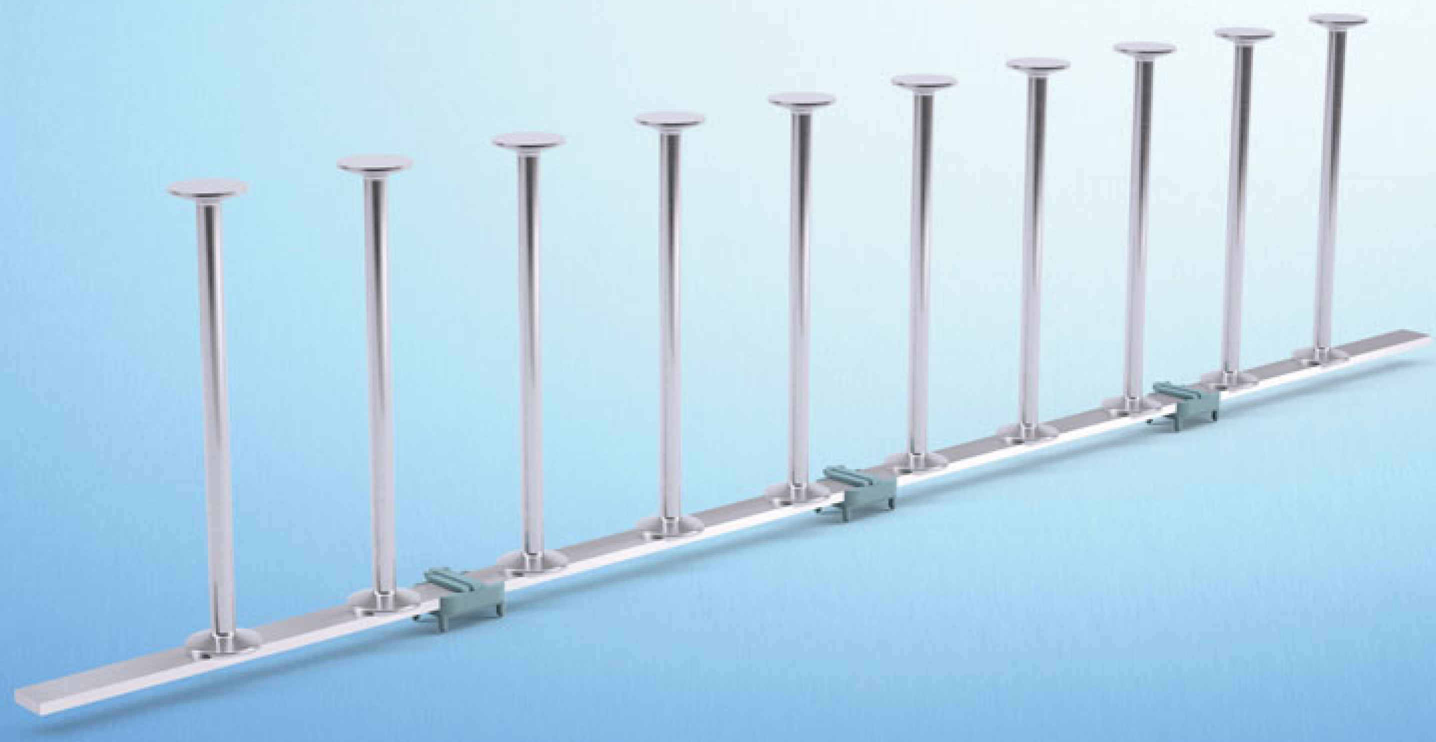


DSA Reinforcement System

To prevent the punching failure of concrete slabs

Version: **US 06/2016**

ESR-3902

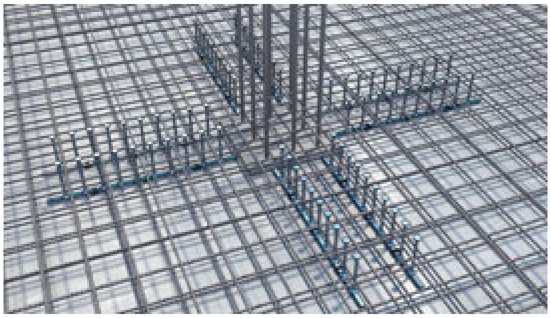
Technical Manual

DSA Reinforcement System

To prevent the punching failure of concrete slabs

- Allows for a slim floor
- Eliminate column capitals and dropdown panels above columns
- Fast and easy installation
- Improves the ductility of the slab
- Flexibility in design and delivery
- Design according to ACI 318-14 for static and seismic loading using Peikko Designer®

DSA Rail



DSA Reinforcement System

Peikko's DSA Reinforcement System is mainly used to increase the punching shear resistance of cast-in-place concrete slabs without increasing the slab's thickness. DSA can be used in slab-on-grade foundations and in elevated slabs, such as reinforced concrete slabs or post-tensioned slabs. When used in elevated slabs, DSA can eliminate the need for drop panels or column caps, thus reducing the costs associated with the formwork of concrete. Moreover, a thinner slab will lead to a lower floor-to-floor height and subsequently, a reduced building height and the possibility of having an extra floor within the same building footprint.

In addition to increasing the resistance of the slab, DSA Reinforcement System also increases its ductility. When compared to other reinforcement systems, DSA has the added benefit of expeditious installation times, leading to reduced labor costs.

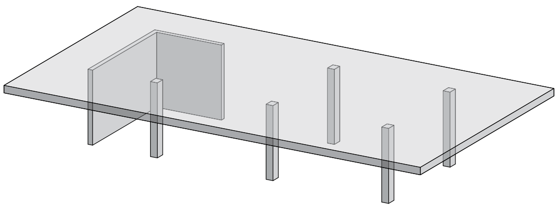
DSA Rails consist of double headed studs attached to a steel shape. The type, geometry and dimensions of DSA Rails may be designed and the resistances of the concrete members reinforced by DSA Rails may be verified using Peikko Designer® in accordance with the requirements of ACI 318-14.

Contents

1. Product properties

Reinforced concrete slabs are currently one of the most popular structural systems used in residential and commercial buildings, parking garages and many other types of structures. The system usually consists of slabs that are locally supported by columns or walls without down stand beams (*Figure 1*). Such a configuration allows for the optimal space of the floor area, and significant savings with regards to the total height of the building.

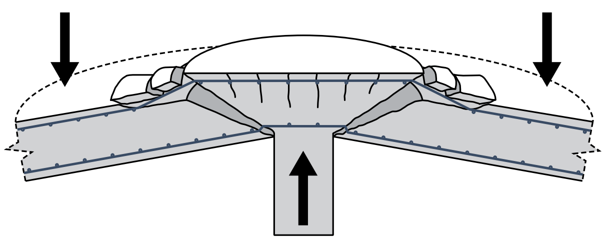
Figure 1. Flat slab supported on columns and walls.



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

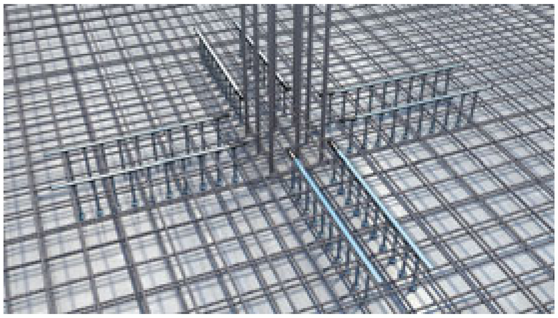
Punching usually occurs when a concrete cone is separated from the slab, bending reinforcement is pulled away from concrete, and the slab falls down due to gravity forces (*Figure 2*). Experience shows that failure by punching is particularly dangerous since it is a brittle phenomenon that happens suddenly without any previous signs of warning (extensive deformations, cracks, etc.). Moreover, the failure of one column may impact the 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 a very limited resistance against punching failure. This resistance may be increased by placing DSA Rails in the concrete slab in such a manner that it prevents the concrete cone to develop (*Figure 3*). Besides increasing the resistance of the slab, DSA Rails also increase its ductility. DSA Rails are also used in foundation slabs in a similar manner as in floor slabs. Other applications are possible as well, e.g. DSA Rails can be used as shear reinforcement in beams and in walls.

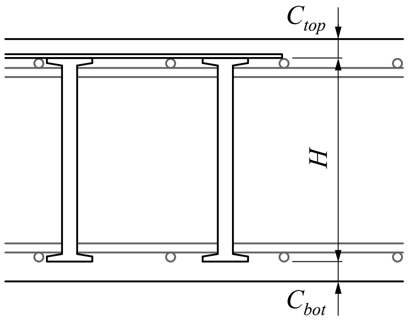
Figure 3. Flat slab reinforced with DSA Rails.



DSA Rails consists of steel double headed DSA Studs welded to a steel shape (*Figure 4*). The steel shape has no load bearing function; it only guarantees the correct spacing and positioning of the studs during their installation in concrete as prescribed by ASTM-A1044 (2010).

Figure 4a. Example of a DSA Rail.

Figure 4b. Height and cover of DSA stud within the slab.

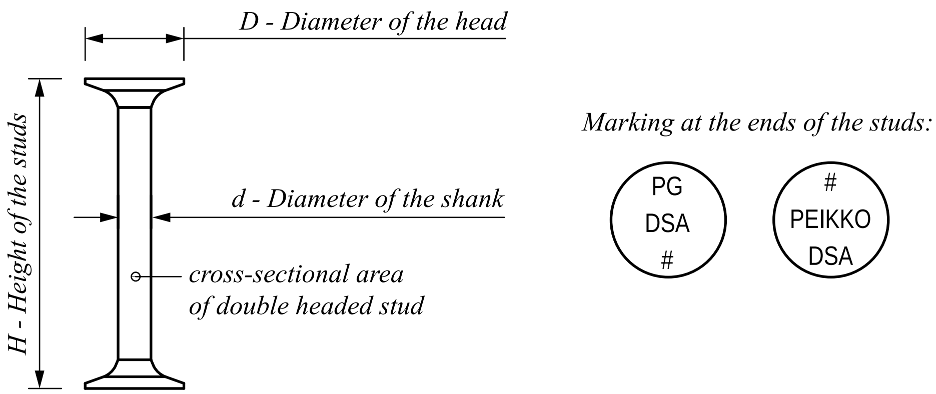


H: height
C: cover top and bottom

The height of the DSA Studs depends on the thickness of the slab and concrete cover of the bending reinforcement of the slab (*Figure 4*b). The head of the studs is considered to be fully anchored into the concrete so that the maximum tensile resistances of DSA Studs can be developed.

DSA studs are available in diameters 3/8″, 1/2″, 5/8″, 3/4″ and 1″ and may be identified with marking PEIKKO DSA or PG DSA and factory number (*Figure 4*c).
DSA studs are produced with height increments of half inch (0.5″). Studs with quarter inch increments will be rounded down to the nearest half inch increment based on Section 8.7.7.1.1 of ACI 318-14, and Chapter 6 of ACI 421.1R-10. Example: 8.75″ long studs will be rounded down to 8.5″ long studs.

Figure 4c. Marking of DSA studs.



1.1 Structural behavior

The static model of a locally supported slab without punching reinforcement is shown on *Figure 5* and *Figure 6*. The external loads of the slab are balanced by a system of concrete struts and ties. The punching resistance of the slab is limited by the tensile strength of the ties.

Figure 5. Forces in the slab without DSA before failure.

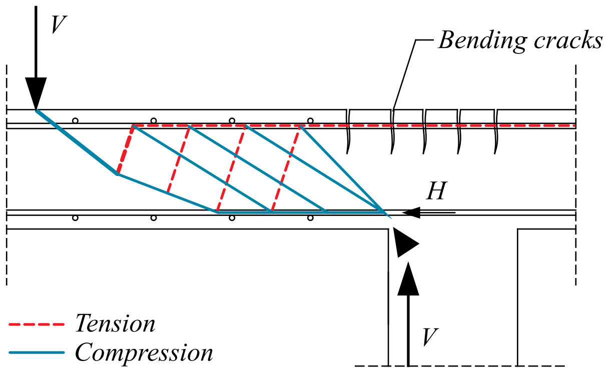
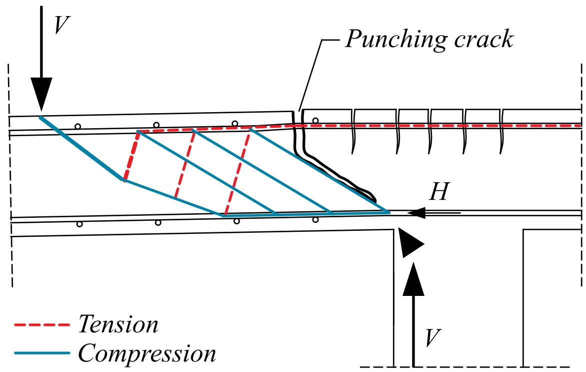


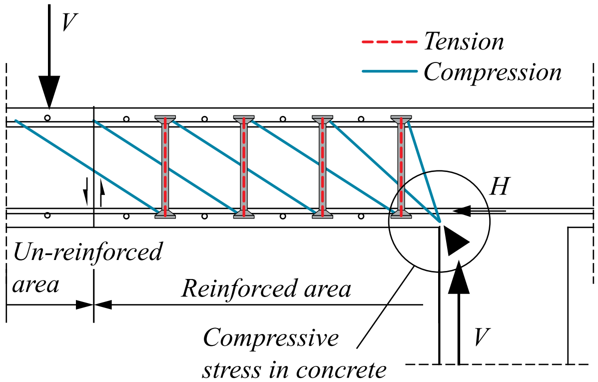
Figure 6. Forces in the slab without DSA at failure.



Reinforcing the slab with DSA consists of replacing the concrete ties by vertical steel reinforcement elements (*Figure 7*). The tensile force is developed in the shank of the DSA Studs and anchored to concrete at both ends of the studs by the heads. The diameter and number of steel elements to be placed in the slab has to be determined so that:

- DSA Studs adjacent to the loaded area/column have sufficient resistance to prevent the development of a punching cone
- DSA reinforcement assembly spreads the load further onto the span of the slab

Figure 7. Forces in a slab with DSA Reinforcement System.



1.2 Limitations for application

The DSA Studs act as vertical tensile components within the system of internal forces in the slab. They have a limited influence on the resistance of the compressive component of this system (concrete struts). The design and detailing of both DSA Rails and the slab reinforced by DSA Rails is performed on a case by case basis for each project and approved by the Engineer of Record. A comprehensive set of rules for the verification of the resistance of slabs reinforced by Rail elements under static and seismic loads is provided by ACI 318-14.

1.3 Material properties

The DSA Studs are fabricated in accordance with ASTM-A1044 (2010). The strength and ductility requirements are:

Tensile strength, min	65,000 psi [450 MPa]
Yield strength, min	51,000 psi [350 MPa]
Elongation in 2”, min	20%
Reduction of area, min	50%

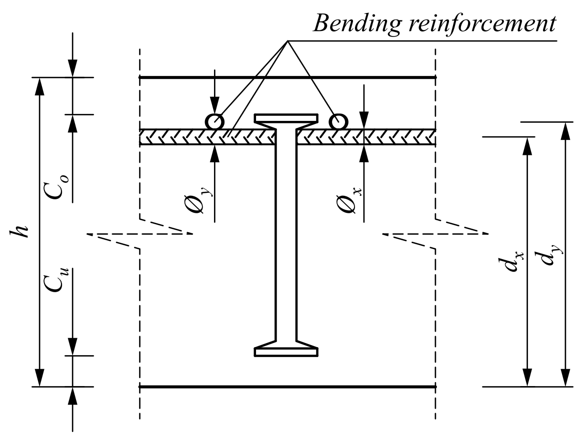
2. Resistances

The resistance of a concrete member reinforced by DSA Rails has to be verified case-by-case for each project. Peikko’s Design software (Peikko Designer®) is available online and can be used to design DSA Rails type and size, and to verify the resistances of the concrete members reinforced by the DSA Rails in accordance with ACI 318-14.

Select DSA

An example of the procedure used for the design and selection of DSA in accordance with ACI 318-14 created and implemented in Peikko Designer® is presented below.

Column dimension	a =	15 in.
	b =	15 in.
Concrete strength	$f'c$ =	5500 psi
Concrete density	Normal	
Slab thickness	h =	17 in.
Concrete cover bottom	c_u =	1 in.
Concrete cover top	c_o =	1 in.
Diameter of bending reinforcement	Φ_x = No. 8	
	Φ_y = No. 8	
Applied load	V_u =	750 kips
Bending moments	M_{uOx} =	20.0 kip-ft
	M_{uOy} =	25.0 kip-ft
Position of column	Internal column	



1. Effective depth of slab

» Effective depth

$d_y = h - ct - \Phi_y / 2 \quad = \quad 15.5 \text{ in.}$

$d_x = h - ct - \Phi_y - \Phi_x / 2 \quad = \quad 14.5 \text{ in.}$

$$d = \frac{d_x + d_y}{2} \quad = \quad 15.0 \text{ in.}$$

2. Critical section (b_0) and Area of critical section (A_c) (ACI 318-14 22.6.4.2)

$b_0 = 2 \cdot (a + d + b + d) \quad = \quad 120 \text{ in.}$

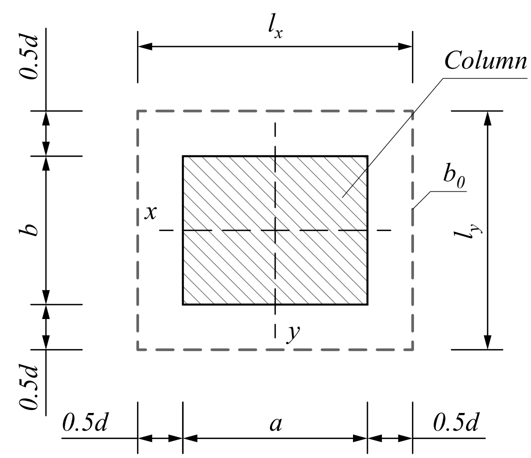
$A_c = b_0 \cdot d \quad = \quad 1800 \text{ in.}^2$

3. Geometrical characteristics of critical section

» Centroid of critical section

$$x_0 = \frac{\sum l_{x,i} \cdot r_i}{\sum l_{x,i}} \quad = \quad 0 \text{ in.}$$

$$y_0 = \frac{\sum l_{y,i} \cdot r_i}{\sum l_{y,i}} \quad = \quad 0 \text{ in.}$$



» Neutral axis properties

Moment of inertia

$J_x = d \cdot \sum l_{x,i} \cdot r_i^2 \quad = \quad 2.7x10^5 \text{ in.}^4$

$J_y = d \cdot \sum l_{y,i} \cdot r_i^2 \quad = \quad 2.7x10^5 \text{ in.}^4$

$J_{xy} \quad = \quad 0 \text{ in.}^4$

» Principal axis properties

Moment of inertia

$J_1 = 2.7x10^5 \text{ in.}^4$

$J_1 = 2.7x10^5 \text{ in.}^4$

» Rotation of principal axis

$\Theta = 90°$

4. Design value of punching shear stresses (ACI 318-14 8.4.4)

» Moment coefficients

$$\gamma_{v,x} = 1 - \frac{1}{1 + \frac{2}{3} \cdot \sqrt{\frac{l_2}{l_1}}} = \quad 0.4 \qquad \gamma_{v,y} = 1 - \frac{1}{1 + \frac{2}{3} \cdot \sqrt{\frac{l_1}{l_2}}} = \quad 0.4$$

» Moments with eccentricity

$M_{u1} = M_{ux} \cdot cos\Theta + M_{uy} \cdot sin\Theta \quad = \quad 25$ *kip-ft*

$M_{u2} = -M_{ux} \cdot sin\Theta + M_{uy} \cdot cos\Theta \quad = \quad -25$ *kip-ft*

» Shear stress at critical section

$$v_{u,i} = \frac{V_u \cdot 10^3}{A_c} - \frac{\gamma_{v1} \cdot M_{u1} \cdot 12 \cdot 10^3 \cdot 2_i}{J_1} + \frac{\gamma_{v2} \cdot M_{u2} \cdot 12 \cdot 10^3 \cdot 1_i}{J_2} = \quad 428.671\ psi$$

5. Resistance of slab without punching reinforcement at critical section (ACI 318-14 22.6)

» Nominal shear strength for the two-way members without shear reinforcement

$$v_n = v_c$$

$$v_c = \Phi \cdot \min \begin{cases} \left(2 + \frac{4}{\beta}\right) \cdot \lambda \cdot \sqrt{f'_c} \\ \left(\frac{\alpha_s \cdot d}{b_0} + 2\right) \cdot \lambda \cdot \sqrt{f'_c} \\ 4 \cdot \lambda \cdot \sqrt{f'_c} \end{cases} = \quad 222.485\ psi$$

$\lambda \Rightarrow$ depends on density of concrete

$\beta \Rightarrow$ depends on shape of column

$\alpha_s \Rightarrow$ depends on position of column

» Maximum shear strength for the two-way members

$$\Phi \cdot 8 \cdot \sqrt{f'_c} = \quad 444.971\ psi$$

6. Load bearing capacity of the slab

$$v_n < v_u < \Phi \cdot 8 \cdot \sqrt{f'_c}$$

$$222.485 < 428.671 < 444.971 \quad [psi]$$

DSA reinforcement can be used

No DSAR reinforcement is needed if:

$v_n \geq v_u$

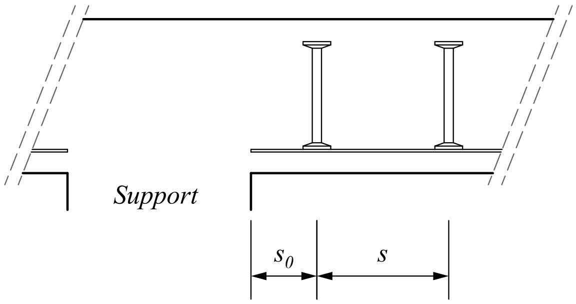
DSAR reinforcement can be used if:

$v_n < v_u \leq \Phi \cdot 8 \cdot \sqrt{f'_c}$

Maximum resistance of slab exceeded if:

$v_u > \Phi \cdot 8 \cdot \sqrt{f'_c}$

7. Dimension of stud (ACI 318-14 8.7.7)



» Height of studs
DSA studs are produced with height increments of half inch (0.5”). Studs with quarter inch increments will be rounded down to the nearest half inch increment based on Section 8.7.7.1.1 of ACI 318-14, and Chapter 6 of ACI 421.1R-10. Example: 8.75” long studs will be rounded down to 8.5” long studs.
$h_{st} = h_d - c_t - c_b \quad = \quad 15\ in.$

» Spacing between elements
$s_0 \quad = \quad 7.5\ in.$
$s \quad = \quad 7.5\ in.$

» Check spacing
$s_0 = 7.5 \Rightarrow s_0 / d = 0.5 \leq 0.5$ Correct
$s = 7.5 \Rightarrow s / d = 0.5 \leq 0.5$ Correct

Conditions:
$s_0 \leq 0.5 \cdot d$
$IF: v_u \leq \Phi 6\sqrt{f'c} \Rightarrow s \leq 0.75d$
$IF: v_u > \Phi 6\sqrt{f'c} \Rightarrow s \leq 0.5d$
(ACI 318-14 Table 8.7.7.1.2)

8. Outer critical section b1 (ACI 318-14 22.6.8)

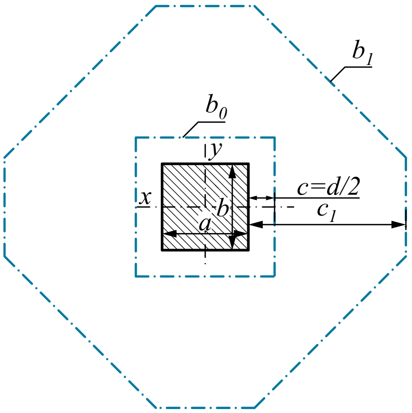
» Nominal shear strength for the two-way members at outer critical section

$$v_n = v_{c,out}$$

$$v_{c,out} = \Phi \cdot 2 \cdot \lambda \cdot \sqrt{f'_c}$$

$$\Phi \cdot 2 \cdot \lambda \cdot \sqrt{f'_c} \geq v_{u,out}(b_1) \Rightarrow itteration \begin{cases} b_1 - Length\ of\ outer\ critical\ section \\ A_{c,out} - Area\ of\ outer\ critical\ section \\ c_1 - Dimension\ from\ column\ to\ outer\ crit.\ section \end{cases}$$

$b_1 = \quad 490.987\ in.$
$A_{c,out} = \quad 7364.8\ in.^2$



9. Geometrical characteristics of outer critical section

- » Centroid of critical section

$$x_0 = \frac{\sum l_{x,i} \cdot r_i}{\sum l_{x,i}} = 0\ in.$$

$$y_0 = \frac{\sum l_{y,i} \cdot r_i}{\sum l_{y,i}} = 0\ in.$$

» Neutral axis properties
Moment of inertia
$J_{x,prov} = d \cdot \sum l_{x,i} \cdot r_i^2 \quad = \quad 2.011x10^7\ in.^4$
$J_{y,prov} = d \cdot \sum l_{y,i} \cdot r_i^2 \quad = \quad 2.011x10^7\ in.^4$
$J_{xy,prov} \quad = \quad 0\ in.^4$

» Principal axis properties
Moment of inertia
$J_{1,prov} = 2.011x10^7\ in.^4$
$J_{1,prov} = 2.011x10^7\ in.^4$

» Rotation of principal axis
$\Theta = 90°$

10. Design value of punching shear stresses at outer critical section

» Shear stress at critical section

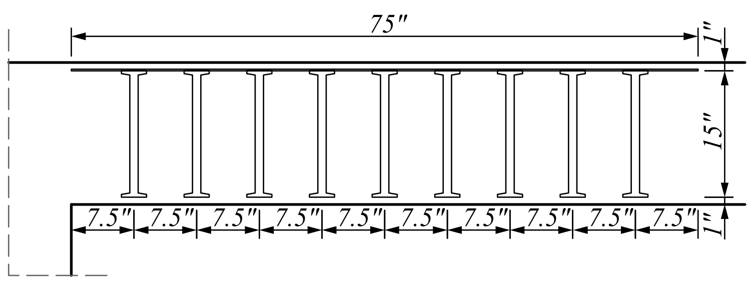
$$v_{u,out} = \frac{V_u \cdot 10^3}{A_{c,out}} - \frac{\gamma_{v1} \cdot M_{u1,prov} \cdot 12 \cdot 10^3 \cdot 2_i}{J_{1,prov}} + \frac{\gamma_{v2} \cdot M_{u2,prov} \cdot 12 \cdot 10^3 \cdot 1_i}{J_{2,prov}} = \quad 102.379 \ \ psi$$

11. Resistance of slab with punching reinforcement at outer critical section

$$v_u \le v_n$$
$$v_n = v_{c,out} \Rightarrow v_{c,out} = \Phi \cdot 2 \cdot \lambda \cdot \sqrt{f'_c}$$
$$v_{u,out} \le \Phi \cdot 2 \cdot \lambda \cdot \sqrt{f'_c}$$
$$102.379 > 111.243 \quad [psi]$$

12. Number of DSA studs between column and outer perimeter

$$n_{req} = \frac{(c_1 - 0.5d) - s_0}{s} + 1 = 9$$



13. Number of DSA Rails around column

1. Strength condition – $m_{c,req}$

$$v_s = \frac{v_u}{\Phi} - v_c \qquad v_c = \lambda \cdot \frac{\sqrt{f_c`}}{4} \qquad m_{req} \ge \frac{v_s \cdot b_0 \cdot s}{f_{yt} \cdot A_A}$$

2. Spacing condition - m_{spac}

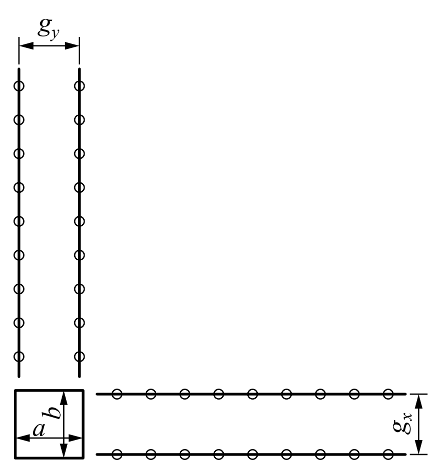
   Spacing must fulfill conditions acc. ACI 318-14 8.7.7

   $g_x \le 2 \cdot d$

   $g_y \le 2 \cdot d$

Total number of Rails around column

$$m = \max \begin{cases} m_{req} \\ m_{spac} \end{cases} = 8$$



A_A - The cross section area of one stud

s - Spacing between adjacent studs

b_0 - Length of critical control perimeter

f_{yt} - Specified yield strength of the DSA Stud

14. Resistance of slab with DSA at critical section

$$v_{s,prov} = \frac{A_v \cdot f_{yt}}{b_0 \cdot s} = \quad 356.044 \; psi$$

$$v_{c,prov} = 3 \cdot \lambda \cdot \sqrt{f`_c} = \quad 222.485 \; psi$$

$$v_{n,prov} = \Phi \cdot (v_{c,prov} + v_{s,prov}) = \quad 433.897 \; psi$$

A_v - the cross-sectional area of the shear reinforcement on one peripheral line parallel to the perimeter of the column section.

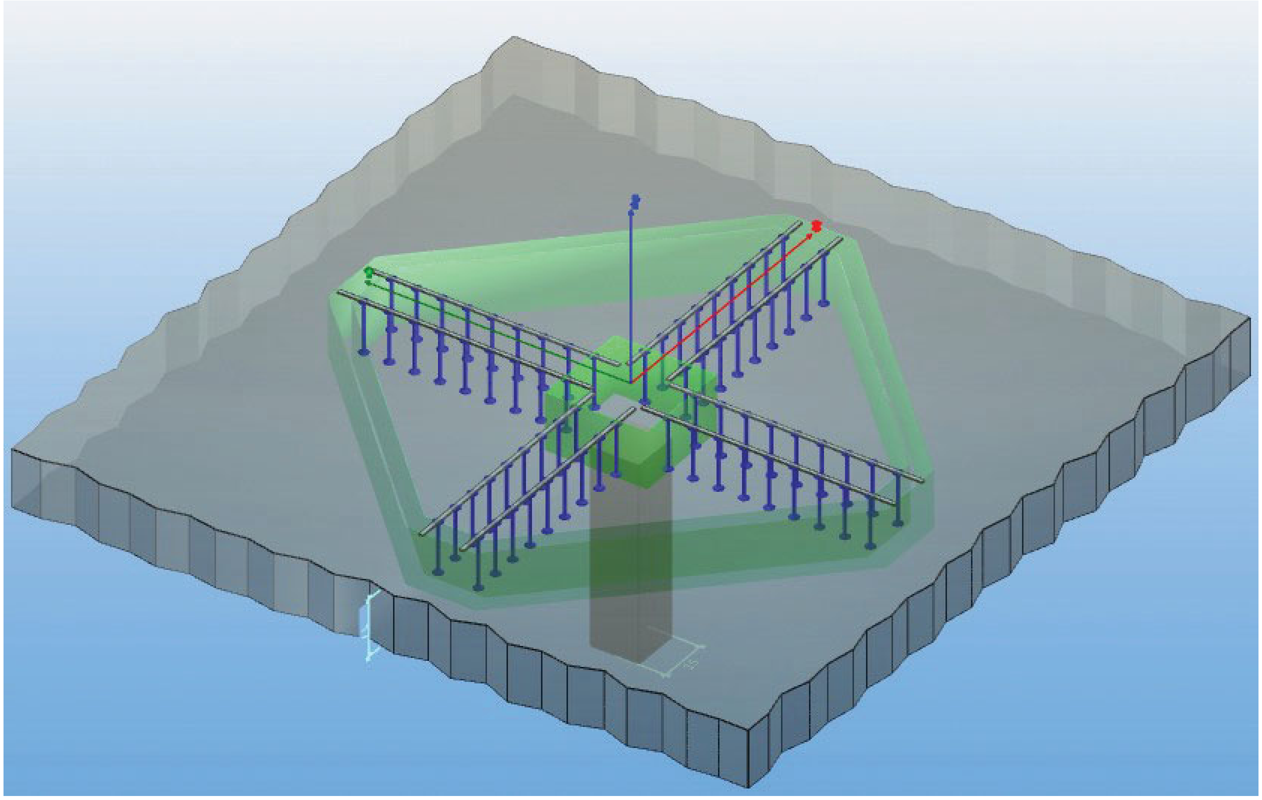
$$v_{n,prov} \geq v_u$$

$$433.897 > 428.671 \; [psi]$$

15. Result

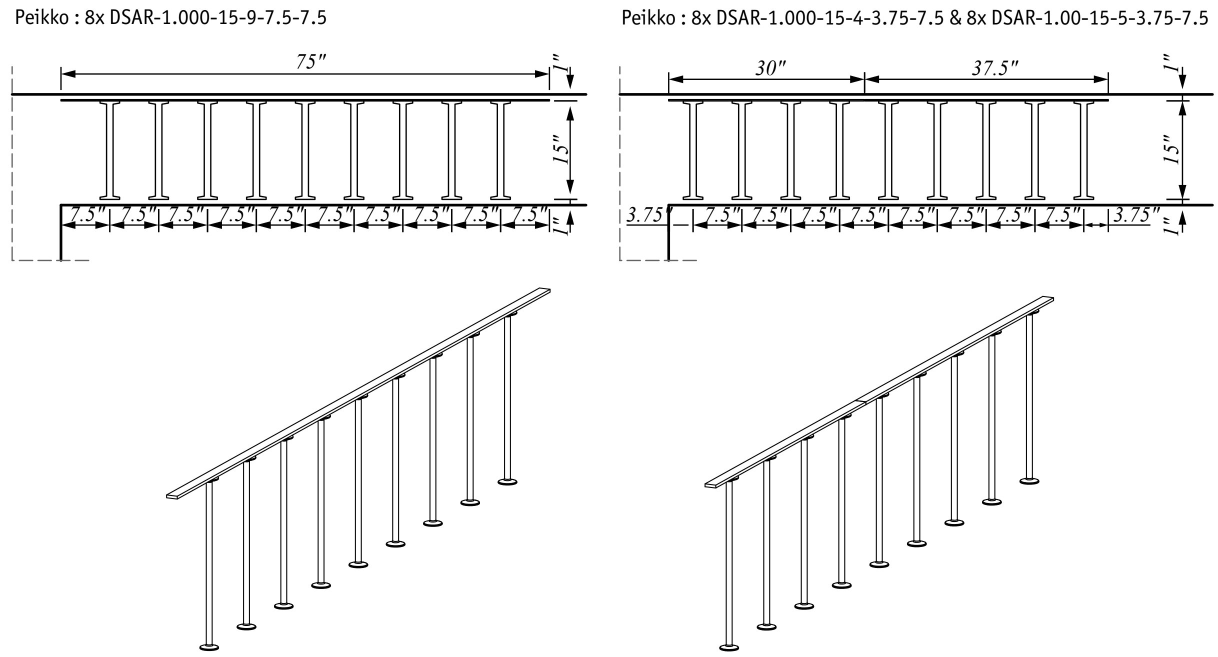
» Complete DSA Rails
8x DSA R-1.000-15-9-7.500-7.500 .

» Combined DSA Rails
8x DSAR-1.000-15-4-3.750-7.500
& 8x DSAR-1.000-15-5-3.750-7.500



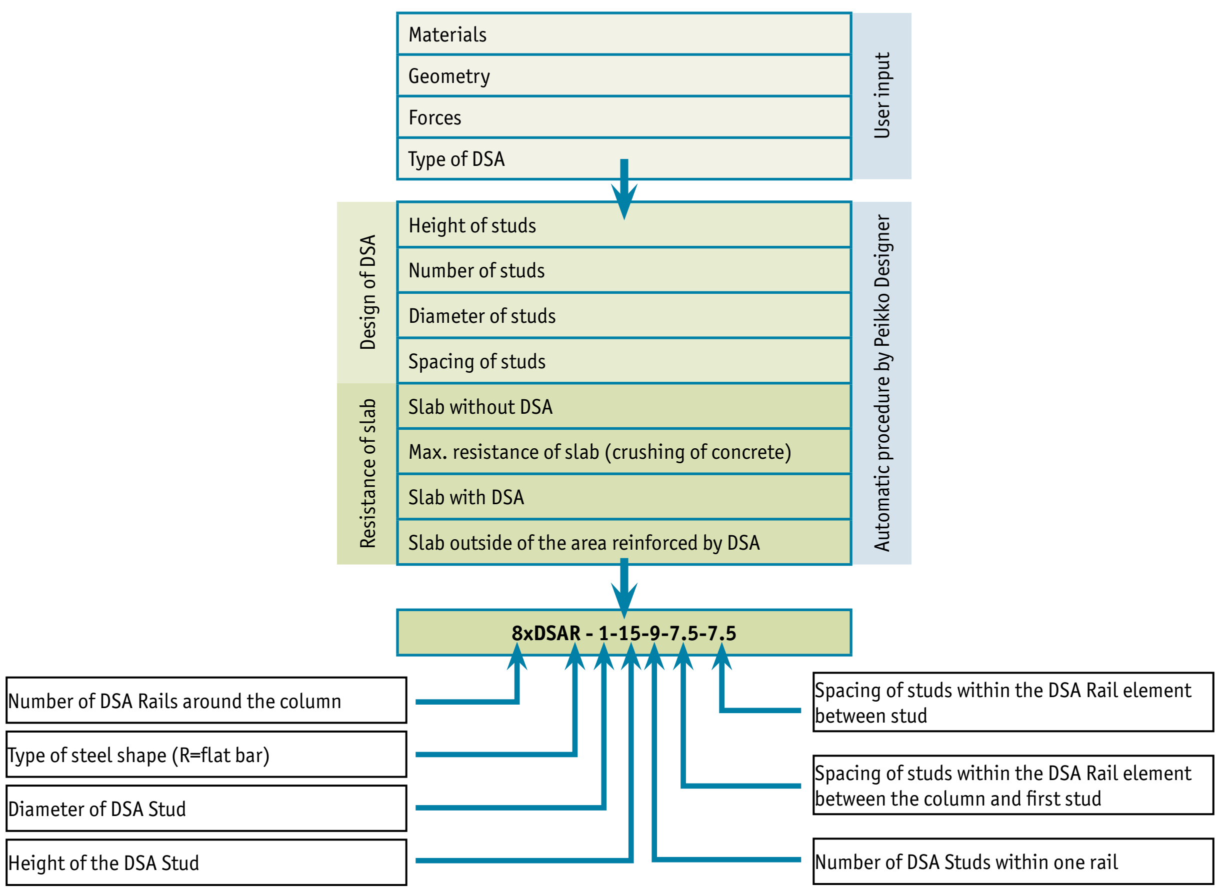
The resulting type and layout of the reinforcement proposed by Peikko Designer® is the most economical design. If needed, the diameter of studs and the number of DSA Rails can be manually modified by the user. The designed DSA reinforcement assembly will be defined by a unique Peikko item code. The plan and section drawings of the selected DSA reinforcement are also available in the printed outputs of Peikko Designer® or may be exported to DWG 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 DSA is also available in the printed output of Peikko Designer®. The DSA Rail may be provided either as a complete element (with all DSA Studs welded to one steel shape) or may be assembled on site from two or more shorter symmetrical DSA Rails (*Figure 8*).

Figure 8. Complete DSA Rail and equivalent solution with a combination of shorter DSA Rails.



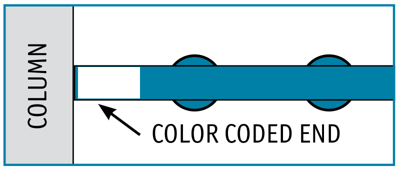
The typical procedure to select the appropriate type of DSA using Peikko Designer is summarized on the diagram in *Figure 9*.

Figure 9. Procedure to select DSA.

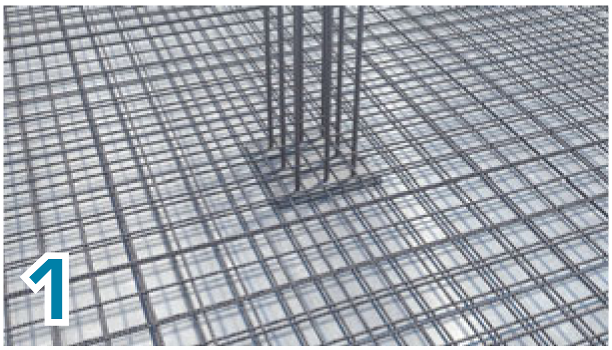


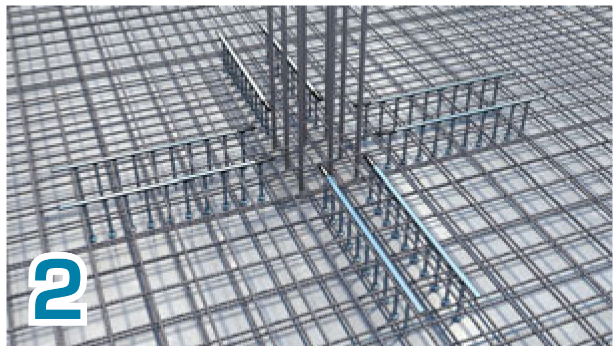
Install DSA

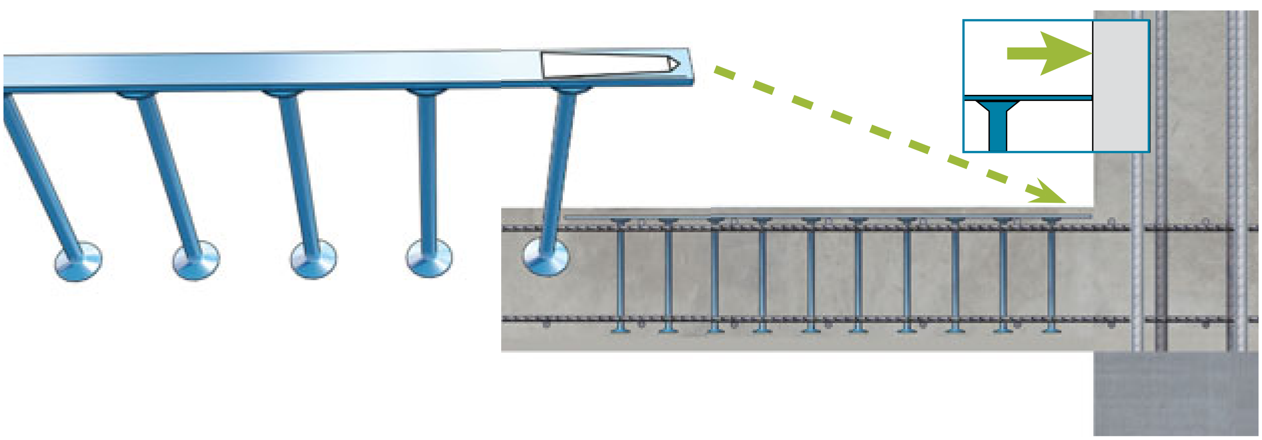
DSA Rail is installed in the slab according to the design plans. Each DSA Rail is identified by a color code located at the end of the rail. The color code is determined by the number of Rail configurations for each column for a specific project. Example: SR-1 is red and SR-2 is blue.

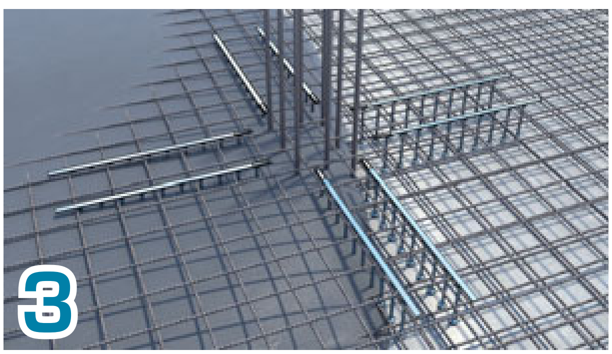


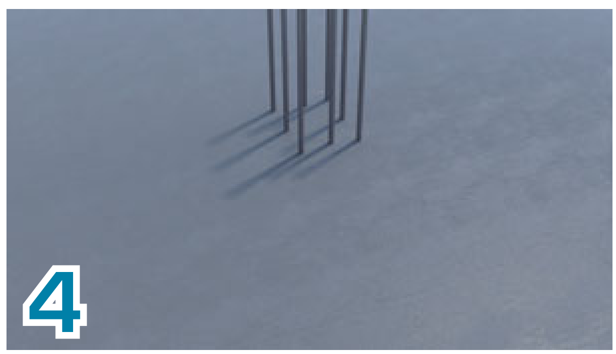
- Top installation: The DSA Rail is placed on top of the main reinforcement of the slab. All bending reinforcement is installed prior to the DSA Rail.



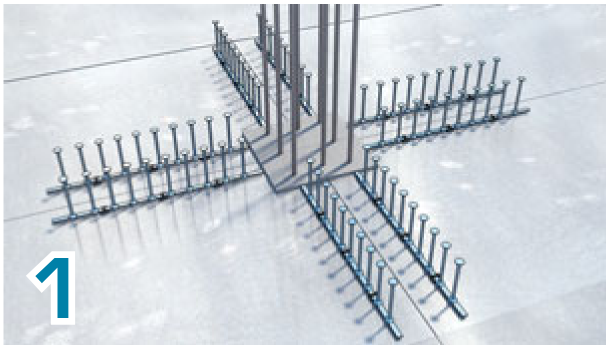


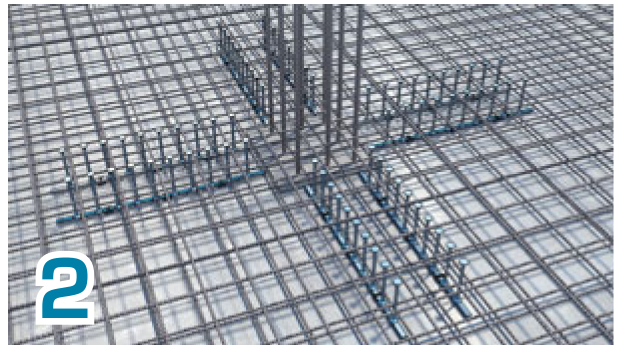


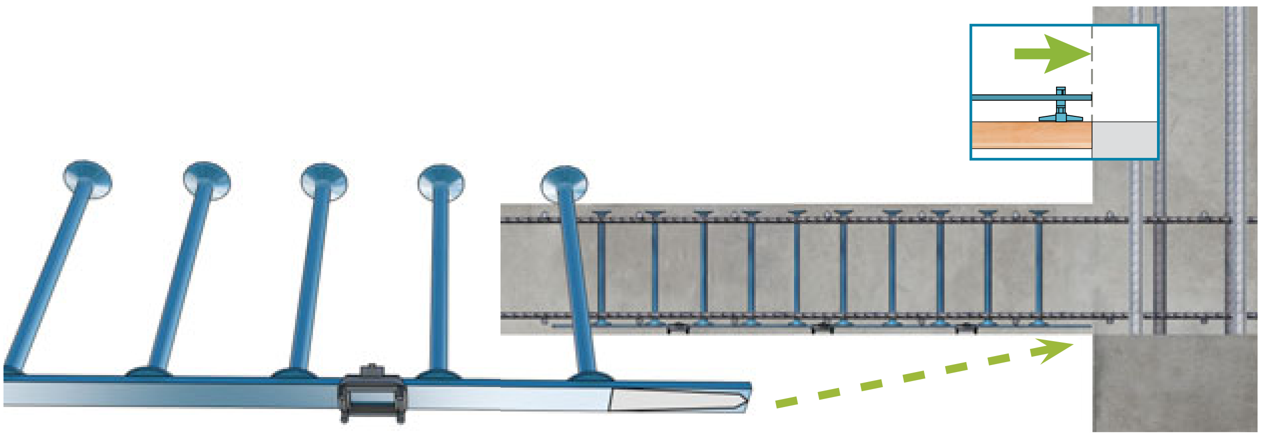


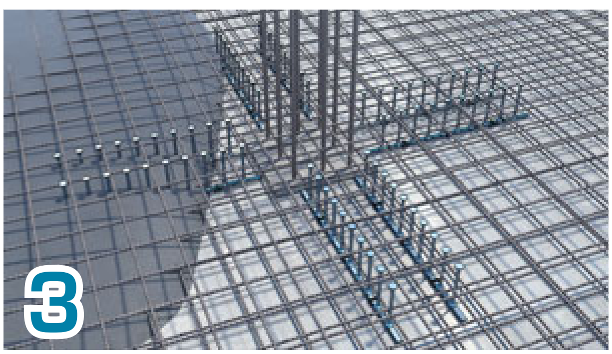


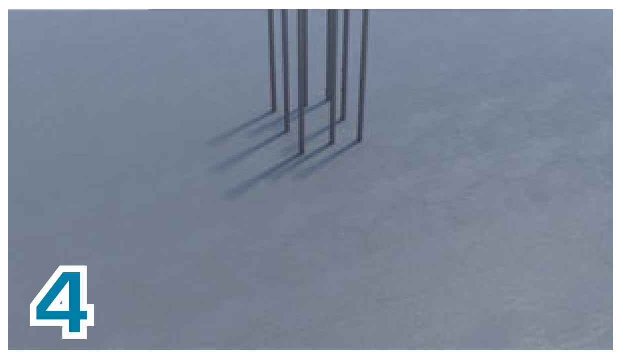
- **Bottom installation:** DSA Rail is placed below the main reinforcement of the slab prior to the installation of the bending reinforcement. In order to achieve a sufficient concrete cover of the headed studs, plastic spacers are mounted to the DSA Rail. Spacers are ordered separately.











PEIKKO GROUP CORPORATION

Peikko Group Corporation is a leading global supplier of concrete connections and composite structures. Peikko's innovative solutions make the customers' building process faster, easier and more reliable. Peikko has subsidiaries in over 30 countries in Asia-Pacific, Europe, the Middle East, and North America, with manufacturing operations in 9 countries. Our aim is to serve our customers locally with leading solutions in the field in terms of quality, safety, and innovation.

Peikko is a family-owned and run company with over 1200 professionals. Peikko was founded in 1965 and is headquartered in Lahti, Finland.