European technical assessment ETA 13/0076

Schöck Bole®

March 2018

Deutsches Institut für Bautechnik DIBt

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General Part

Technical Assessment Body issuing the European Technical Assessment:	Deutsches Institut für Bautechnik
Trade name of the construction product	Punching reinforcement Schöck Bole®
Product family to which the construction product belongs	Double headed studs as punching reinforcement for flat slabs and Footings
Manufacturer	Schöck Bauteile GmbH Vimbucher Straße 2 76534 Baden-Baden (Steinbach)
Manufacturing plant	Schöck Herstellwerke
This European Technical Assessment contains	14 pages including 2 annexes which form an integral part of this assessment
This European Technical Assessment is issued in accordance with Regulation (EU) No 305/2011, on the basis of	EAD 160003-00-0301
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Specific Part

1 Technical description of the product

The Schöck Bole® double headed studs with ribbed shafts are made of weldable ribbed reinforcement bars with nominal characteristic yield strength of 500 MPa. The mechanical properties of the steel fulfill the requirement according to EN 1992-1-1, Annex C.

They have a head at both ends with a diameter of three times the shaft diameter.

The diameters of the shafts are 10, 12, 14, 16, 20 and 25 mm.

The studs are assembled to form reinforcement elements comprising at least two studs (s. figure 1). The studs are tack welded or clamped at one end to a non-structural steel rail or steel bars (reinforcing bars or round bars) for securing the position of the double headed studs when pouring the concrete. They also may be tack welded or clamped to steel bars at the shaft. In this case the bars shall have a diameter of $d_s = 6$ mm (for studs with diameter $d_A < 20$ mm) and $d_s = 8$ mm (for studs with $d_A \geq 20$ mm). For use in semi-prefabricated slabs only, plasic bars and special plastic clips are used to secure the placement during casting. All studs of one of those reinforcement element shall have the same diameter.

The bars used to secure the stud's position during casting (assembling bars or -rails) are made of weldable reinforcing steel $d_s = 6$ mm to $d_s = 10$ mm or structural steel (smooth steel bars) $d_s = 6$ mm to $d_s = 8$ mm and the rails are made of structural steel. The Material for the structural steel (bars or rails) shall be acc. to EN 10025-2 or non-corrosive steel acc. to EN 10088-5 or acc. EN 10088-3 or according technical documentation. The material of the plastic bars and plastic clips for use in semi-prefabricated slabs is specified within the technical documentation deposited with Deutsches Institut für Bautechnik.

The detailed product description is given in Annex A.

2 Specification of the intended use in accordance with the applicable European Assessment Document

The performances given in Section 3 are only valid if the Product is used in compliance with the specifications and conditions given in Annex B.

The verifications and assessment methods on which this European Technical Assessment is based lead to the assumption of a working life of the Product of at least 50 years. The indications given on the working life cannot be interpreted as a guarantee given by the producer, but are to be regarded only as a means for choosing the right products in relation to the expected economically reasonable working life of the works.

3 Performance of the product and references to the methods used for its assessment

3.1 Mechanical resistance and stability (BWR 1)

Essential characteristic	Performance
Increasing factor for punching shear resistance	$k_{pu,sl} = 1,96$ $k_{pu,fo} = 1,50$
characteristic fatigue strength for $N = 2 \cdot 10^6$ load cycles	$\Delta\sigma_{Rsk,n=2 \cdot 10^6} = 70$ MPa

3.2 Safety in case of fire (BWR 2)

Essential characteristic	Performance
Reaction to fire	class A1

4 Assessment and verification of constancy of performance (AVCP) system applied, with reference to its legal base

In accordance with EAD No. 160003-00-0301 the applicable European legal act is: [97/597/EC(EU)].

The system(s) to be applied is (are): [1+]

In addition, with regard to reaction to fire for products covered by this EAD the applicable European legal act is: [2001/596/EC(EU)]

The system to be applied is: [4]

5 Technical details necessary for the implementation of the AVCP system, as provided for in the applicable EAD

Technical details necessary for the implementation of the AVCP system are laid down in the control plan deposited with Deutsches Institut für Bautechnik.

Issued in Berlin on 12 March 2018 by Deutsches Institut für Bautechnik

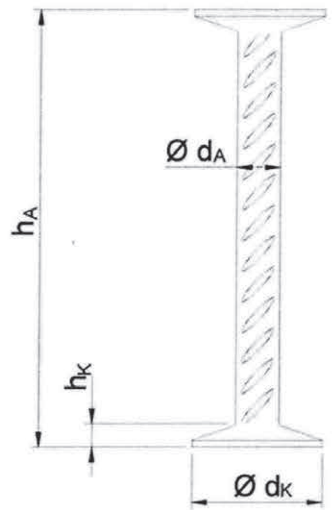
BD Dipl.-Ing. Andreas Kummerow
Head of Department

beglaubigt:
Schüler

Material of stud:

- reinforcing steel with $f_{yk} \geq 500$ N/mm² acc. to EN 1992-1-1, Annex C and provided data sheet.

Dimensions:



Marking:

S : symbol of manufacturing plant
20 : example for stud-Ø 20

stud diameter d_A [mm]	head diameter d_K [mm]	head thickness min. h_K [mm]	cross section area A_A [mm²]	load capacity $F_{Rk} = A_A * f_{yk}$ [kN]	studheight h_A [mm]
10	30	5	79	39,27	
12	36	6	113	56,55	$h_A = h - c_o - c_u$
14	42	7	154	76,97	
16	48	7	201	100,53	h : slabthickness
20	60	9	314	157,08	c_o: upper concrete cover
25	75	12	491	245,44	c_u: lower concrete cover

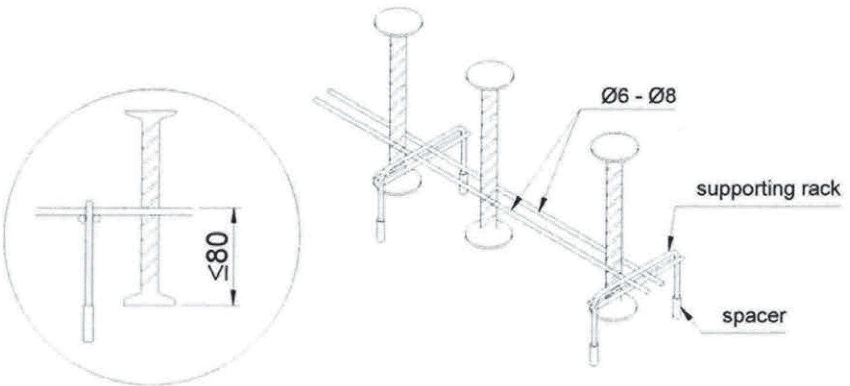
Punching reinforcement Schöck Bole®

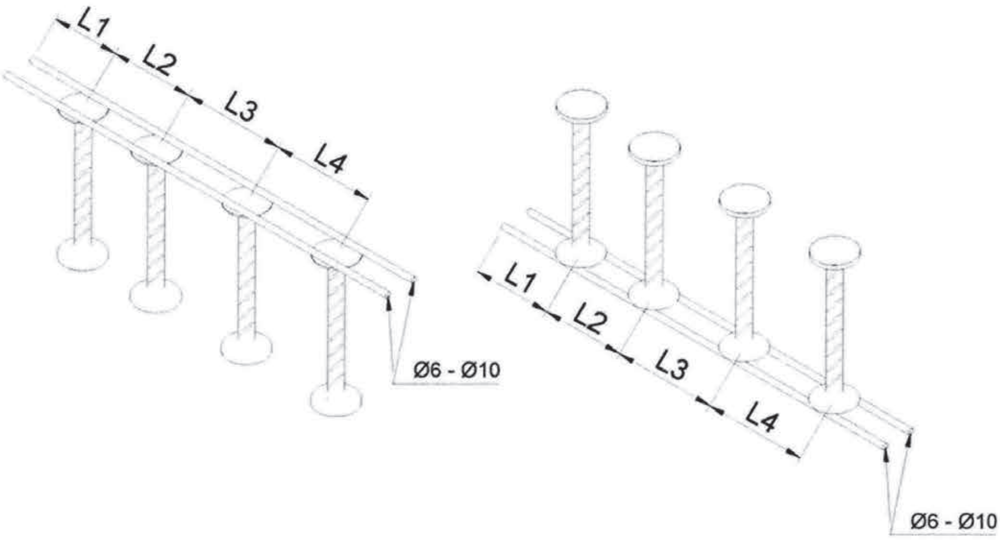
Product description
Dimensions and load capacity of double headed studs

Annex A1

Schöck Bole®

Mounting bar made of reinforcing or round steel





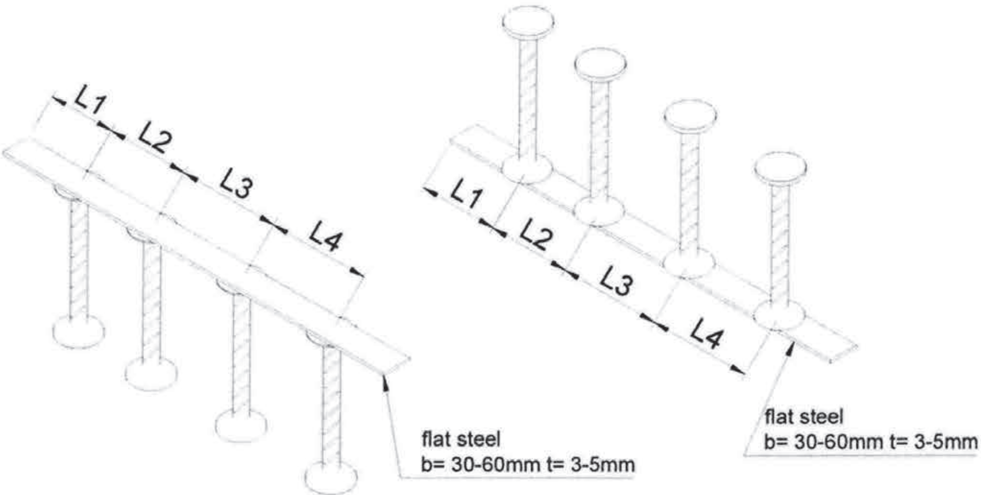
Materials for mounting bar

-B500 A/B according to EN 1992-1-1, Annex C and data sheet
-B500 NR or stainless round steel according to EN 1993-1-4, EN 10088-3 and EN 10088-5
-Construction steel according to EN 10025-2 and data sheet

Unit [mm]

Punching reinforcement Schöck Bole®	Annex A2
Product description Materials and arrangement mounting bars	

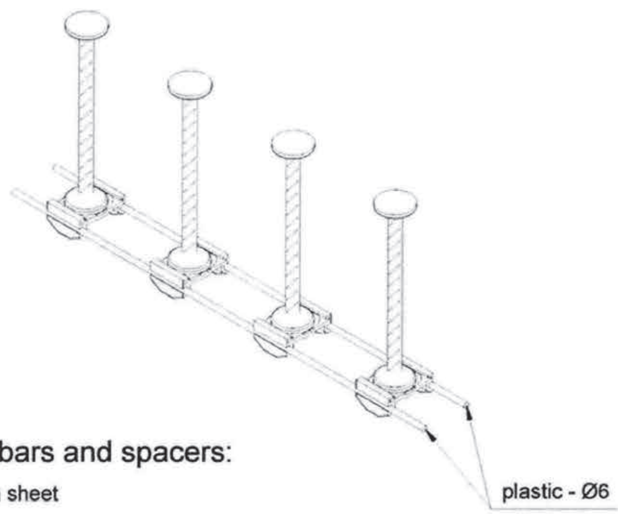
Mounting rail made of flat steel



Material of assembling rail:

- Stainless steel according to EN 1993-1-4, EN 10088-3 and EN 10088-5
- Structural steel according to EN 10025-2 and data sheet

Assembling bar made of plastic for prefabricated ceiling



Material of plastic bars and spacers:

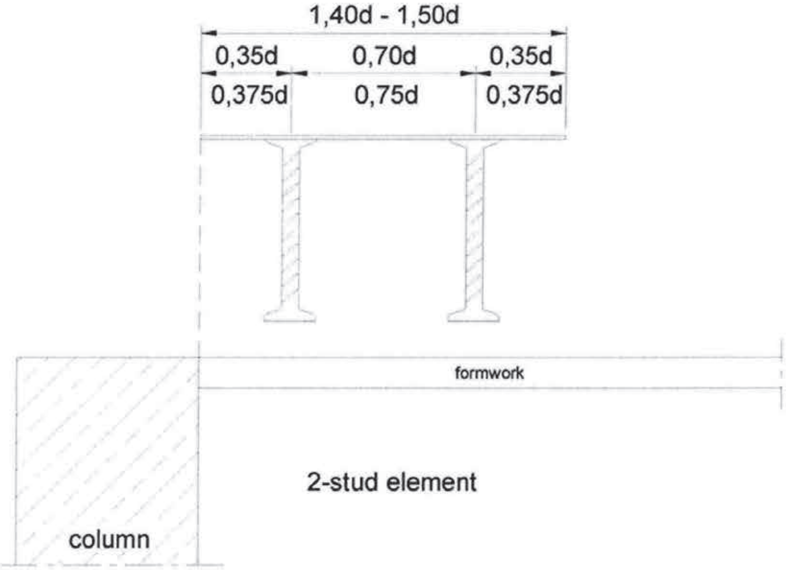
- plastic according to data sheet

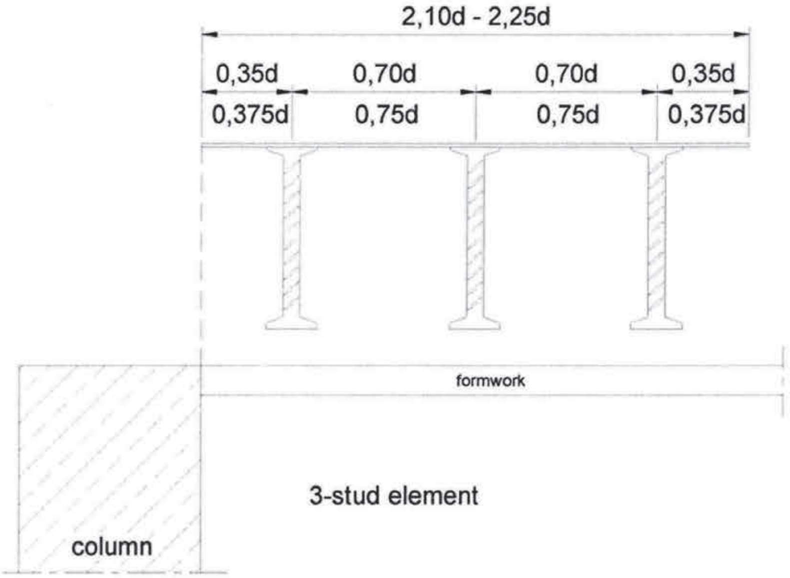
Unit [mm]

Punching reinforcement Schöck Bole®	Annex A3
Product description Materials and design of mounting rails made of flat steel or plastic	

Design of Schöck Bole®

Due to the symmetric design of the Schöck Bole element, the radial distances between the studs can be assured, if several elements are placed in one row. The first element starts at the face of the column.





Punching reinforcement Schöck Bole®	Annex A4
Product description Design of the reinforcement element	

Specification of intended use

The double headed studs are used to increase the punching shear resistance of flat slabs, ground slabs and footings under static, quasi-static and fatique loading.
The calculation of the punching shear resistance and the arrangement of the double headed studs is done in accordance with EOTA TR 060.

The intended use covers the following specifications:

- flat slabs, footings and ground slabs made of reinforced normal weight concrete of strength class C20/25 to C50/60 according to EN 206-1:2000
- flat slabs, footings and ground slabs with a minimum height of h = 180 mm
- reinforcement elements with double headed studs of the same diameter in the punching area around a column or high concentrated load
- reinforcement elements with double headed studs installed in an upright (rail at the bottom of the slab) or hanging position
- reinforcing steel for the studs according to EN 1992-1-1 may be used with $f_{yk} \geq 500$ N/mm², in design only f_{yk} = 500 N/mm² is allowed
- reinforcement elements with double headed studs positioned such that the double headed studs are perpendicular to the surface of flat slab, footing or ground slab
- reinforcement elements with double headed studs directed radially towards the column or high concentrated load and distributed evenly in the critical punching area
- reinforcement elements with double headed studs positioned such that the upper heads of the studs reach at least to the outside of the uppermost layer and the lower heads of the studs reach at least to the uppermost layer of the flexural reinforcement
- reinforcement elements with double headed studs positioned such that the concrete cover complies with the provisions according to EN 1992-1-1
- reinforcement elements with double headed studs positioned such that the minimum and maximum distances between the double headed studs on an element and between the elements as arranged around a column or area of high concentrated load complies with the provisions according to EOTA TR 060, section 3
- The provisions according to EOTA TR 060, section 3 are kept on site with an accuracy of 0,1 h (h height of the slab)
- reinforcement elements with double headed studs can also be used for semi-prefabricated slabs in combination with lattice girders, if the respective ETA's or national guidelines are observed. Double headed studs are also effective as bond reinforcement between precast and in-situ concrete.

Installation of double headed studs

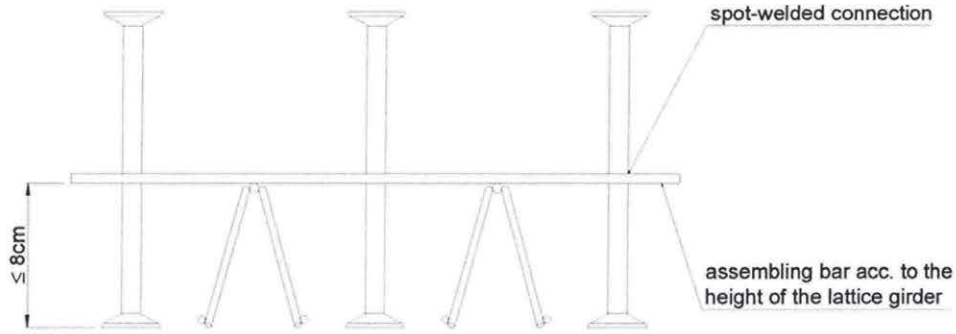
- When installed correctly, the double headed studs have sufficient robustness to resist usual actions before and during concreting.
- When the double headed studs are used in semi-prefabricated slabs, there aren't requirements in terms of robustness as mentioned before, if safe transport and positioning is ensured.
- If semi-prefabricated slabs need to be joined in the punching area, the recess between the prefabricated elements shall be at least 40 mm wide and has to be carefully filled with concrete on site.
- In the punching area the semi-prefabricated slabs can be put on the column up to 10 mm or placed with a joint to the edge of the column up to 40 mm. Therefore, the following requirements shall be considered on site:
  - The joint in the compression zone between the semi-prefabricated plate and the column have to be filled up carefully with appropriate concrete of the same strength as the in-situ concrete.
  - The provisions for the distances between the double headed studs and the edge of the column have to be observed.
  - If the semi-prefabricated plate is put on the column, the joint between the plate and the column have to be filled with mortar, in order to transfer the loads from upper floors reliably.
  - The concrete of the semi-prefabricated plates must not be damaged due to chiselling work.
  - The concrete has to be compacted carefully in the bearing area.
  - The upper edge of the previously concreted column shall be below the bottom edge of the semi-prefabricated slab.

Transport and storage

Special considerations shall be given to the transport of prefabricated elements to avoid any damage to the anchorage of the headed studs in the pre-cast concrete slab. (see Annex B6)

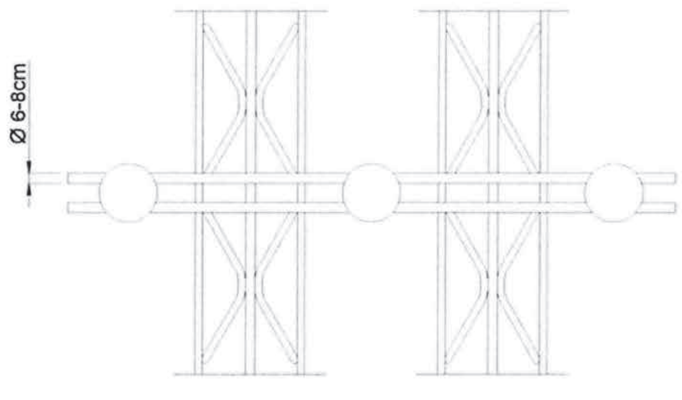
Schöck Bole® for assembling in prefabricated slabs

Type: Schöck Bole® elements with mounting bars are placed on lattice girders



Material of assembling bars:

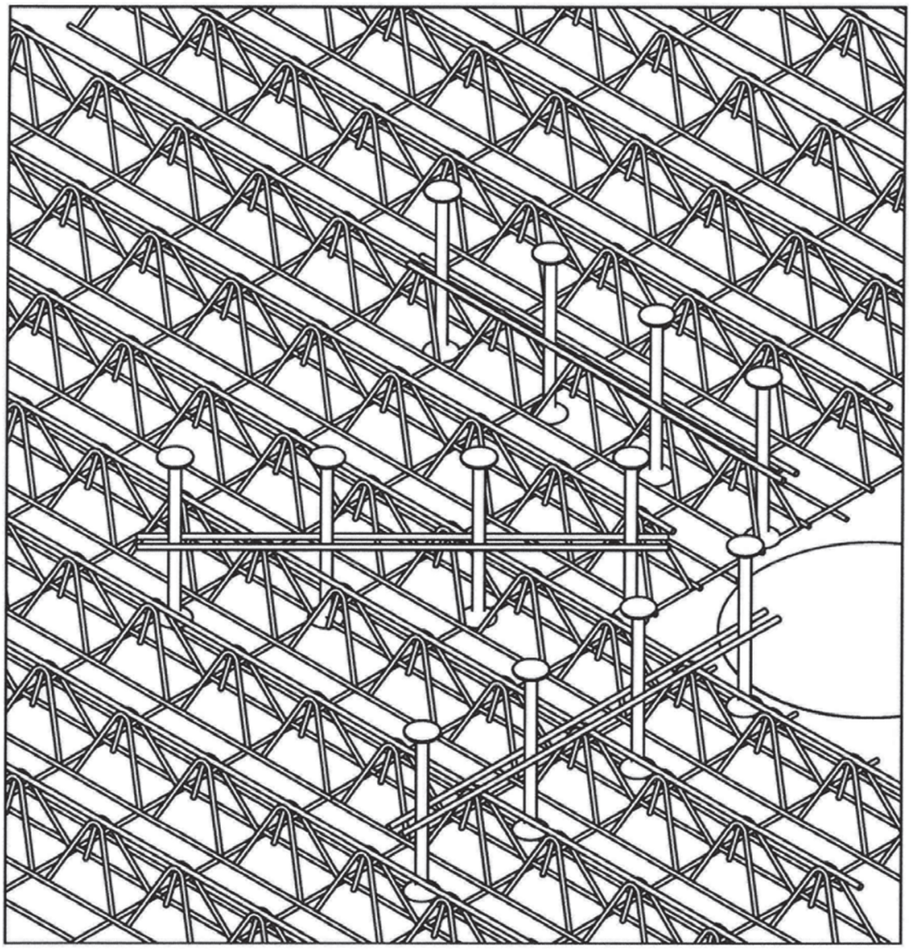
-B500 A/B according to EN 1992-1-1, Annex C and data sheet
-B500 NR or stainless round steel according to EN 1993-1-4, EN 10088-3 and EN 10088-5
-structural steel according to EN 10025-2 and data sheet



Punching reinforcement Schöck Bole®	Annex B3
Intended use Installation of reinforcement elements in prefabricated slabs	

Installation of Schöck Bole® with welded mounting bars in prefabricated slabs

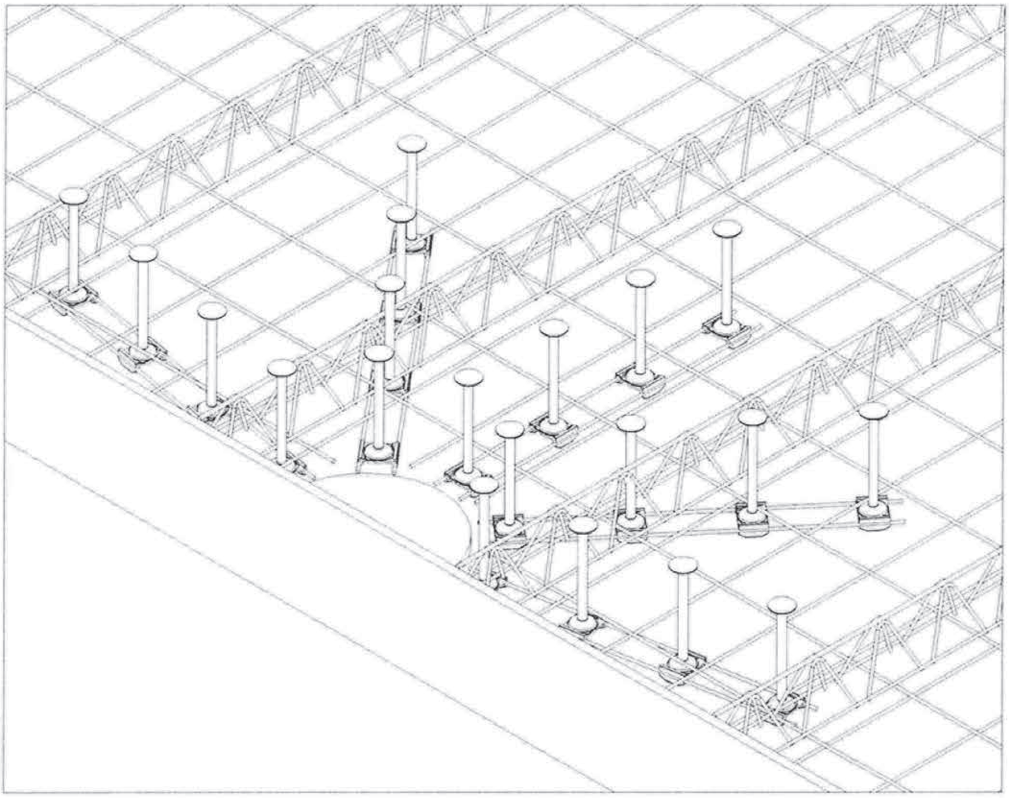
Schöck Bole® elements are placed with the mounting bars at the lattice girder



Punching reinforcement Schöck Bole®	Annex B4
Intended use Installation of reinforcement elements in prefabricated slabs	

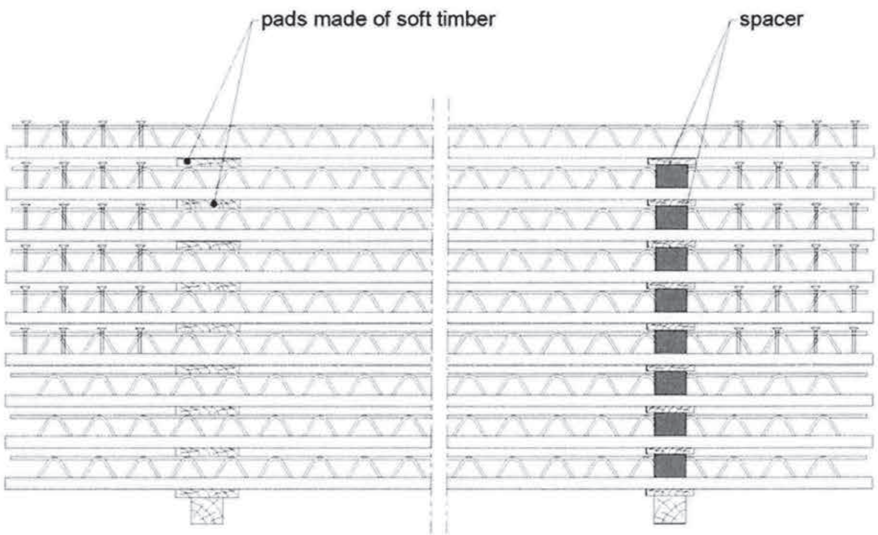
Placing of Schöck Bole® with mounting rail made of plastic in prefabricated flat

Separate installation of mounting rail below the reinforcement bars and double headed studs after placing of reinforcement bars



Punching reinforcement Schöck Bole®	Annex B5
Intended use Installation of reinforcement elements in prefabricated slabs	

Example of bearing and transport of prefabricated ceiles with Schöck Bole®



Punching reinforcement Schöck Bole®	Annex B6
Intended use Storage and transport	

EOTA®

TECHNICAL REPORT

Increase of punching shear resistance of flat slabs or footings and ground slabs – double headed studs – Calculation Methods

TR 060

November 2017

EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT

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1 GENERAL

1.1 Scope

This Technical Report contains a method for punching shear calculation of flat slabs or footings and ground slabs under static, quasi-static and fatigue loading.

Reinforcement elements according to Annex A are used for the increase of the punching shear resistance of flat slabs or footings and ground slabs under static, quasi-static and fatigue loading.

The reinforcement elements are located adjacent to columns or high concentrated loads.

This TR covers the following specifications of the intended use:

- flat slabs or footings and ground slabs made of reinforced normal weight concrete of strength class C20/25 to C50/60 according to EN 206-1:2000
- flat slabs or footings and ground slabs with a minimum height of h = 180 mm
- flat slabs or footings and ground slabs with a maximum effective depth of d = 300 mm (only for double headed studs with smooth shafts)
- reinforcement elements with double headed studs of the same diameter and type (ripped or smooth) in the punching area around a column or high concentrated load
- reinforcing steel for the studs acc. to EN1992-1-1 may be used with $f_{yk} \geq 500$ N/mm^2, in design only f_{yk} = 500 N/mm^2 is allowed
- reinforcement elements with double headed studs installed in an upright (rail at the bottom of the slab) or hanging position
- reinforcement elements with double headed studs positioned such that the double headed studs are perpendicular to the surface of the slab or footing
- reinforcement elements with double headed studs directed radially towards the column or high concentrated load and distributed evenly in the critical punching area
- reinforcement elements with double headed studs positioned such that the upper heads of the studs reach at least to the outside of the uppermost layer of the flexural reinforcement
- reinforcement elements with double headed studs positioned such that the lower heads of the studs reach at least to the outside of the lowest layer of the flexural reinforcement
- reinforcement elements with double headed studs positioned such that the concrete cover complies with the provisions according to EN 1992-1-1
- reinforcement elements with double headed studs positioned such that the minimum and maximum distances between the double headed studs on an element and between the elements as arranged around a column or area of high concentrated load complies with the provisions according to section 3
- The provisions according to section 3 are kept on site with an accuracy of 0,1h (h height of the slab)

This document was written to represent current best practice. However, users should verify that applying its provisions allows local regulatory requirements to be satisfied.

The design for static, quasi-static and fatigue loading of the flat slabs or footings and ground slabs shall base on EN 1992-1-1.

1.2 Assumptions

It is assumed that

- The load-bearing capacity of the column below the shear reinforcement as well as the local compressive stress at the joint between slab and column are each verified individually and by taking into account of national provisions and guidelines.
- The load-bearing capacity of the concrete slab outside the punching shear reinforced area is verified separately and in accordance with the relevant national provisions.
- The moment resistance of the entire slab is verified in accordance with the relevant national provisions.

- In case of cast in-situ slabs, the punching shear reinforced area is poured monolithically with the slab. In case of slabs made out of prefabricated thin elements and additional cast in-situ concrete one head of the punching shear reinforcement is arranged in the prefabricated slab.
- The flexural reinforcement over the column has to be anchored outside the outer perimeter u_{out}.
- The lower reinforcement of the slab is laid over the column.
- The upper reinforcement of the slab is placed continuously over the loaded area.
- If the precast elements need to be joined in the punching area, the distance between the prefabricated elements shall be ≥ 40 mm wide and shall be carefully filled with cast in-situ concrete thoroughly. The distance between prefabricated elements and the edge of the column is limited to -10 mm (prefabricated element extends over the column edge) and 40 mm (see Hegger 2015).
- The position, the type, the size and the length of the double headed studs are indicated on the design drawings. The material of the double headed studs is given additionally on the drawings.
- The lower reinforcement of the slab is laid over the column.
- The upper reinforcement of the slab is placed continuously over the loaded area.

1.3 Specific terms used in this TR

1.3.1 Abbreviations

1.3.2 Indices

E	action effects
R	resistance
V	shear force
c	concrete
d	design value
fo	footing or ground slab
k	characteristic value
max	maximum
min	minimum
pu	punching shear
re	reinforcement
s	steel
sl	flat slab
y	yield

1.3.3 Actions and resistances

γ	partial safety factor
$v_{Rd,max}$	maximum punching shear resistance along the critical diameter u_1
v_{min}	minimum punching shear resistance along the critical diameter u_1
$v_{Rd,c}$	punching shear resistance without shear reinforcement
V_{Ed}	design value of the applied shear force
v_{Ed}:	shear stress calculated along the area defined by the basic perimeter and the effective depth ($u_1 \cdot d$)
f_{cd}	design compressive cylinder strength (150 mm diameter by 300 mm cylinder)
f_{yd}	design steel yield strength
f_{yk}:	characteristic value of yield stress of the stud (≥ 500 MPa)
σ_{cp}	normal stresses in concrete in critical section
f_{ywd}:	design value of the yield strength of the double headed studs

1.3.4 Concrete, reinforcement and double headed studs

ρ	reinforcement ratio
a	distance from column face to control perimeter
u_0	column perimeter
κ	coefficient to take into account size effects
m_C:	number of elements (rows) in the area C
n_C:	number of studs of each element (row) in the area C
d_A:	shaft diameter of the double headed stud
γ_s:	product dependent partial safety factor for double headed studs = 1,15
η	factor to take into account the effective depth
$A_{sw;\,0,8d}$:	cross sectional area of punching reinforcement in a distance between $0{,}3\cdot d$ and $0{,}8\cdot d$ from the column face
A_{crit}:	area within the critical perimeter u_{crit} at the iteratively determined distance a_{crit} from the column face
A:	area of the footing (area within the line of contraflexure for the bending moment in radial direction in a continuous ground slab)
s_r	radial distance between different rows of double headed studs
β	coefficient taking into account the effects of load eccentricity
β_{red}	reduced coefficient taking into account the effects of load eccentricity
d	effective depth according to EN 1992-1-1
u_1	perimeter of the critical section at a distance of $2{,}0\cdot d$ from the column face
l_s	distance between column face and outermost row of stud

2 PUNCHING SHEAR CALCULATION

2.1 General rules and basic control perimeter

The design of punching shear reinforcement typically consists of the following steps:

- Resistance of the slab without punching shear reinforcement at critical perimeter u_1

$$v_{Ed} \leq v_{Rd,c} \tag{2.1}$$

- Maximum resistance of the slabs at critical perimeter u_1

$$v_{Ed} \leq v_{Rd,max} \tag{2.2}$$

- Resistance of the punching shear reinforcement inside zone C:

$$v_{Ed} \leq v_{Rd,s} \tag{2.3}$$

- Resistance of the slabs at outer perimeter u_{out}

$$v_{Ed} \leq v_{Rd,c} \tag{2.4}$$

The verification of the load bearing capacity at ultimate limit state is performed as follows: The ultimate limit state of punching shear shall be assessed along control perimeters. The slab shall be designed to resist a minimum of bending moments according to national guidelines. Outside the control perimeter the verification of the ultimate limit state design for shear and bending shall be carried out according to national guidelines.

For the determination of the punching shear resistance, an inner critical perimeter u_1 perpendicular to the flat slab surface at the distance $2{,}0 \cdot d$ (d = effective depth of the slab) around the column and an outer control perimeter u_{out} at a distance of $1{,}5 \cdot d$ from the outermost row of the punching shear reinforcement are considered. For footings and ground slabs, the distance to the critical perimeter has to be calculated with an iterative method.

The critical perimeter may be determined as stated above for columns with a perimeter u_0 less than $12 \cdot d$ (or according to NA to EN1992-1-1) and a ratio of the longer column side to the shorter column side not larger than 2,0. For columns with an arbitrary shape the perimeter u_0 is the shortest length around the loaded area. The critical perimeters are affine to the perimeter u_0.

If these conditions are not fulfilled, the shear forces are concentrated along the corners of the column and the critical perimeter has to be reduced.

2.2 Verifications

2.2.1 Actions - design shear stress

In a first step, the design value of the action effect of shear v_{Ed} per area ($u \cdot d$) along the basic control perimeter u_1 is calculated:

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d} \tag{2.5}$$

v_{Ed}: shear stress calculated along the area defined by the basic perimeter and the effective depth ($u_1 \cdot d$)

β: coefficient taking into account the effects of load eccentricity.

d: effective depth

V_{Ed}: design value of the applied shear force

u_1: perimeter of the critical section at a distance of $2{,}0 \cdot d$ from the column face

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 %, constant values for β may be used. If not given otherwise in NA to EN1992-1-1, the following values may be used:

interior columns:	$\beta = 1{,}10$	(2.6)
edge columns:	$\beta = 1{,}40$	
corner columns:	$\beta = 1{,}50$	
corner of wall:	$\beta = 1{,}20$	
end of wall:	$\beta = 1{,}35$	

Alternatively the more detailed calculation according to EN 1992-1-1, section 6.4.3 (3) may be used to determine the factor β. The applicability of the reduced basic control perimeter according to EN 1992-1-1, section 6.4.3 (4) may be limited by NA.

2.2.2 Flat slabs

The load bearing capacity of flat slabs with punching shear reinforcement is verified as follows:

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} \quad \text{and} \quad \beta \cdot V_{Ed} \leq v_{Rd,\max} \cdot u_1 \cdot d \tag{2.7}$$

where

β is defined as in section 2.2.1 of this TR

$V_{Rd,sy}$ is determined as in section 2.4.1 of this TR

$v_{Rd,max}$ is determined as in section 2.4.1 of this TR

2.2.3 Footings and ground slabs

The load bearing capacity of footings and ground slabs with punching shear reinforcement is verified as follows:

$$\beta \cdot V_{Ed,red} \leq V_{Rd,s} \quad \text{and} \quad \beta \cdot V_{Ed,red} \leq v_{Rd,\max} \cdot u \cdot d \tag{2.8}$$

where

$V_{Rd,s}$ is determined as in section 2.4.2 of this TR

$v_{Rd,max}$ is determined as in section 2.4.2 of this TR

u is the control perimeter determined by iterative calculation as in section 2.3.2 of this TR

in general: $\beta \cdot V_{Ed,red} = \beta \cdot (V_{Ed} - \Delta V_{Ed}) = \beta \cdot (V_{Ed} - \sigma_{gd} \cdot A_{crit})$

(with σ_{gd} being the mean value of the soil pressure inside the critical area A_{crit})

for a uniform soil pressure distribution: $$\beta \cdot V_{Ed,red} = \beta \cdot V_{Ed}\left(1 - \frac{A_{crit}}{A}\right) \tag{2.9}$$

A_{crit}: area within the critical perimeter u_{crit} at the iteratively determined distance a_{crit} from the column face

A: area of the footing (area within the line of contra flexure for the bending moment in radial direction in a continuous flat plate)

If outside of $0{,}8 \cdot d$ further rows of studs are necessary, the required cross-sectional area of each additional row of shear reinforcement may be determined for 33% of the design value of the shear force, taking into account the reduction by the soil pressure within the shear reinforced area.

2.3 Punching shear resistance without shear reinforcement

2.3.1 Flat slabs

In flat slabs, the resistance of the slab without punching reinforcement is calculated either according to Equation (2.10) or according to NA to EN1992-1-1:

$$v_{Rd,c} = C_{Rd,c} \cdot \kappa \cdot \sqrt[3]{100 \cdot \rho_l \cdot f_{ck}} + k_1 \cdot \sigma_{cp} \geq \left(v_{\min} + k_1 \cdot \sigma_{cp}\right) \qquad (2.10)$$

$C_{Rd,c}$ empirical factor, the recommended value is $C_{Rd,c} = 0{,}18/\gamma_c$

γ_c partial safety factor for concrete (recommended value is γ_c = 1,5)

κ coefficient to take into account size effects, d in [mm]

$$\kappa = 1 + \sqrt{\frac{200}{d}} \leq 2{,}0 \qquad (2.11)$$

ρ_l mean reinforcement ratio of y- and z-directions

$$\rho_l = \sqrt{\rho_{lx} \cdot \rho_{ly}} \leq \begin{cases} 2{,}0\% \\ 0{,}5 \cdot f_{cd}/f_{yd} \end{cases} \qquad (2.12)$$

f_{cd} design value of cylinder compressive strength
f_{yd} design value of yield strength of reinforcing steel
k_1 empirical factor, the recommended value is 0,1
σ_{cp} normal stresses in concrete in the critical section

$$v_{\min} = \frac{0{,}0525}{\gamma_c} \cdot \kappa^{1{,}5} \cdot f_{ck}^{0{,}5} \quad \text{for} \quad d \leq 600 \text{ mm} \qquad (2.13)$$

$$v_{\min} = \frac{0{,}0375}{\gamma_c} \cdot \kappa^{1{,}5} \cdot f_{ck}^{0{,}5} \quad \text{for} \quad d > 800 \text{ mm} \qquad (2.14)$$

(intermediate values are linearly interpolated)

In case of small ratios of the column perimeter to the effective depth (u_0/d), the punching resistance has to be reduced.

$$u_0 / d < 4{,}0: \quad C_{Rd,c} = \frac{0{,}18}{\gamma_c} \cdot \left(0{,}1 \cdot \frac{u_0}{d} + 0{,}6\right) \geq \frac{0{,}15}{\gamma_c} \qquad (2.15)$$

2.3.2 Footings and ground slabs

For footings and ground slabs, the punching shear resistance along the basic perimeter is determined as follows.

The punching shear resistance without shear reinforcement $v_{Rd,c}$ for footings and ground slabs is defined according to the following Equation (2.16) or according to NA to EN1992-1-1:

$$v_{Rd,c} = C_{Rd,c} \cdot \kappa \cdot \sqrt[3]{100 \cdot \rho_l \cdot f_{ck}} \cdot \frac{2 \cdot d}{a} \geq v_{min} \cdot \frac{2 \cdot d}{a} \qquad (2.16)$$

$C_{Rd,c}$: $0{,}15/\gamma_c$ for compact footings with $a_\lambda/d \leq 2{,}0$
$0{,}18/\gamma_c$ for slender footings and ground slabs

a: the distance from the column face to the control perimeter considered

The governing distance a (≤ 2 d) leads to the minimum value of $v_{Rd,c}$ and can be determined iteratively.

2.4 Punching shear resistance with shear reinforcement

2.4.1 Flat slabs

The maximum punching shear resistance along the critical perimeter u_1 is defined as the resistance of the slab without shear reinforcement multiplied with the factor $k_{pu,sl}$ according to Equation (2.17):

$$v_{Rd,\max} = k_{pu,sl} \cdot v_{Rd,c} \tag{2.17}$$

The verification acc. to Equ. (6.53) of EN1992-1-1 is not applicable.

The value $k_{pu,sl}$ is product dependent and given in the ETA and $v_{Rd,c}$ in Equation (2.17) is the calculated punching shear resistance according to Equation (2.10) and not according to the NA to EN 1992-1-1, taking into account the relevant partial safety factors for material properties.

The effect of normal compressive stresses shall not be considered for the calculation of the maximum punching shear capacity of the slab if not stated otherwise in the ETA. If inclined pre-stressed tendons reduce the punching shear capacity, the effect shall be included for the dimensioning of the studs with the maximum value of the negative influence. If inclined pre-stressed tendons increase the punching shear capacity, they have to be effective in both areas C and D.

For the purpose of dimensioning of the studs, distinction will be made between the area C (adjacent to the column) and the area D (further away than 1,125·d from the column face). The double headed studs in the area C shall be dimensioned according to the following equation:

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} = n_c \cdot m_c \frac{d_A^2 \cdot \pi \cdot f_{yk}}{4 \cdot \gamma_s \cdot \eta} \tag{2.18}$$

m_C: number of elements (rows) in the area C

n_C: number of studs of each element (row) in the area C

d_A: shaft diameter of the double headed stud

f_{yk}: characteristic value of yield stress of the stud = 500 MPa

γ_s: product dependent safety factor for double headed studs = 1,15

η factor taking into account the effective depth, intermediate values have to be interpolated:

$$\eta = \begin{Bmatrix} 1{,}0 & \text{for } d \leq 200\,\text{mm} \\ 1{,}6 & \text{for } d \geq 800\,\text{mm} \end{Bmatrix}$$

Alternative values for η may be given in the ETA.

In the area D, the dimensioning of the studs is governed by the rules for positioning of the studs as given in clause 3.1.

2.4.2 Footings and ground slabs

The maximum punching shear resistance in the critical perimeter u_{crit} is defined by a multiple value of the resistance of the footing without shear reinforcement:

$$v_{Rd,\max} = k_{pu,fo} \cdot v_{Rd,c} \quad \text{footings and ground slabs} \tag{2.19}$$

The verification acc. to Equ. (6.53) of EN1992-1-1 is not applicable

The value $k_{pu,fo}$ is product dependent and given in the ETA and $v_{Rd,c}$ in Equation (2.19) is the calculated punching shear resistance according to Equation (2.16) and not according to the NA to EN 1992-1-1, taking into account the relevant partial safety factors for material properties.

In footings and ground slabs, the amount of double headed studs shall be dimensioned according to the following equation:

$$V_{Rd,s} = f_{ywd} \cdot A_{sw;0,8d} \tag{2.20}$$

f_{ywd}: design value of the yield strength of the double headed studs

$A_{sw;0,8d}$: cross sectional area of punching reinforcement in a distance between 0,3·d and 0,8·d from the column face

A_{crit}: area within the critical perimeter u_{crit} at the iteratively determined distance a_{crit} from the column face

A: area of the footing (area within the line of contra flexure for the bending moment in radial direction in a continuous ground slab)

If outside of $0{,}8 \cdot d$ further rows of studs are necessary, the required cross-sectional area of each additional row of shear reinforcement may be determined for 33% of the design value of the applied shear force, taking into account the reduction by the soil pressure within the shear reinforced area.

For the calculation of the punching shear resistance outside the shear reinforced zone, it is allowed to subtract the soil pressure inside the outermost row of shear reinforcement.

2.4.3 Outer control perimeter

In the case, that punching shear reinforcement is necessary, an adequate amount of punching reinforcement elements has to be placed in the slab. The control perimeter u_{out} at which shear reinforcement is not required shall be calculated with the following expression

$$u_{out} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c} \cdot d} \tag{2.21}$$

β_{red}: reduced factor for taking into account the effects of eccentricity in perimeter u_{out}

$v_{Rd,c}$: design punching shear resistance without punching shear reinforcement according to Equation (2.10),

with $C_{Rd,c}$ may be taken from the national guidelines for members not requiring design shear reinforcement, i.e. one-way shear (EN 1992-1-1, 6.2.2(1)), the recommended value is $0{,}15/\gamma_c$

For the determination of the shear resistance along the outer perimeter (u_{out}) of edge and corner columns, a reduced factor β_{red} for the verification along the outer perimeter may be used.

Edge columns:

$$\beta_{red} = \frac{\beta}{1{,}2 + \beta/20 \cdot l_s/d} \geq \beta_{int.col} \tag{2.22}$$

Corner columns:

$$\beta_{red} = \frac{\beta}{1{,}2 + \beta/15 \cdot l_s/d} \geq \beta_{int.col} \tag{2.23}$$

Corner of wall; end of wall, interior columns:

$$\beta_{red} = \frac{\beta}{1{,}2 + \beta/40 \cdot l_s/d} \geq \beta_{int.col} \tag{2.24}$$

l_s = distance between the face of the column and the outermost stud

$\beta_{int.col}$ according to NA of EN1992-1-1

3 POSITIONING OF THE REINFORCEMENT ELEMENTS AND THE DOUBLE HEADED STUDS

3.1 Flat slabs

The studs of the first row are placed at a radial distance from the column face between 0,35d and 0,5d.

The studs of the second row are placed at a radial distance from the column face of ≤ 1,125d.

The radial spacing of the studs is ≤ 0,75d.

The tangential spacing of the studs is ≤ 1,7d at a radial distance from the column face of ≤ 1,00d.

The tangential spacing of the studs is ≤ 3,5d at a radial distance from the column face of > 1,00d.

The area with a radial distance from the face of the column of ≤ 1,125d is called area C.

The area with a radial distance from the face of the column of > 1,125d is called area D.

If the number of reinforcement elements in the area D is larger compared to the area C, the additional reinforcement elements in the area D are placed radially to the column and at even tangential spacing.

For thick slabs where reinforcement elements with three or more headed studs are used in area C, the radial distance is reduced according to the following equation:

$$s_{r,area\ D} = \frac{3 \cdot d \cdot m_D}{2 \cdot n_c \cdot m_C} \leq 0,75 \cdot d \qquad (3.1)$$

with
- m_C: number of elements (rows) in the area C
- m_D: number of elements (rows) in the area D
- n_C: number of studs of each element (row) in area C

For double headed studs placed next to free slab edges and recesses, a transverse reinforcement is provided to control the transverse tensile forces.

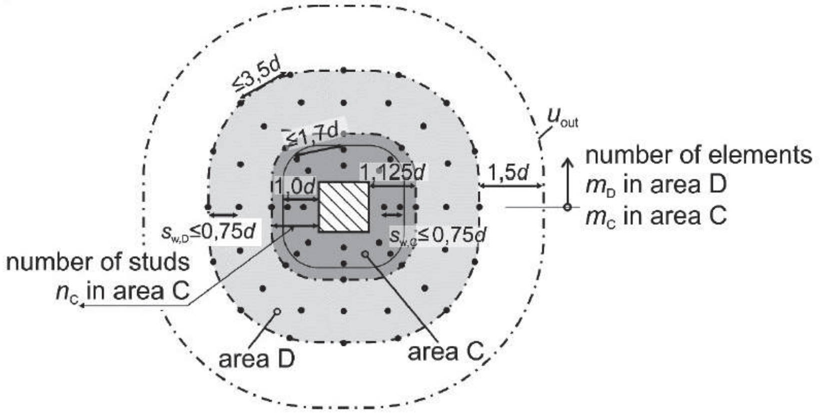


Figure 3: Maximum spacing of studs in area C and D of flat slabs *((s_w ➔ s_t))*

3.2 Footings and ground slabs:

The studs of the first row are placed at a radial distance from the column face of 0,3d.

The studs of the second row are placed at a radial distance from the column face of ≤ 0,8d.

The radial spacing of the studs is ≤ 0,5d.

The tangential spacing of the studs is ≤ 1,5d at a radial distance from the column face of ≤ 0,8d.

The tangential spacing of the studs is ≤ 2,0d at a radial distance from the column face of > 0,8d.

The double headed studs are evenly distributed along the circular sections.

4 REFERENCE DOCUMENTS

As far as no edition date is given in the list of standards thereafter, the standard in its current version is of relevance.

EN 1990:2015	Eurocode: Basis of structural design
EN 1992-1-1:2011	Design of concrete structures – Part 1-1: General rules and rules for buildings
EN 206-1:2000	Concrete Part 1: Specification. Performance and conformity
EAD 160003-00-0301	Double headed studs for the increase of punching shear resistance of flat slabs or footings and ground slabs
Hegger 2015	Gutachterliche Stellungnahme zur Ausbildung des Decke-Stützen-Knotens bei Verwendung von Elementplatten. G13-11 vom 05.02.2015 (Expert Report on the construction of slab-column-connections in semi-precast flat slabs)

ANNEX A SPECIFICATION ON THE REINFORCMENT ELEMENTS

A.1 Reinforcement elements with double headed studs

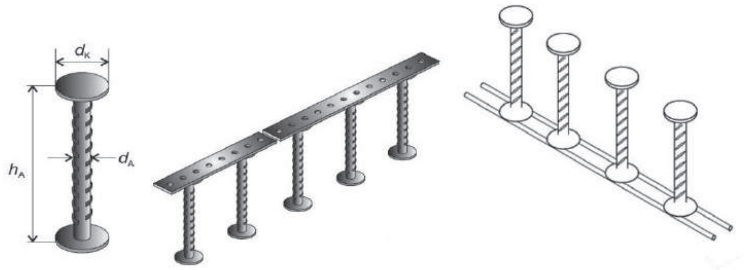
This TR covers double headed studs with an ETA issued on basis of EAD 160003-00-0301.

The double headed studs are connected in one of the following examples:

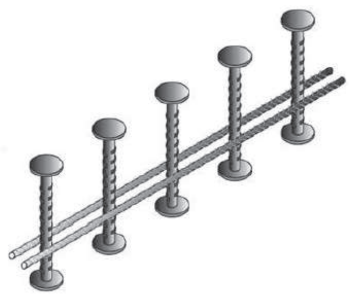
a) by a rail, studs are tack welded or clamped at one end to a rail made of non-structural steel or reinforcing bars or (see Figure A.1 a))

b) by reinforcing bars welded to the shaft, non-structural ribbed reinforcing bars are spot welded to the shaft (see Figure A.1 b))

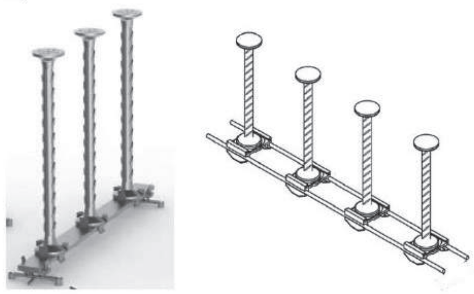
c) clamped with plastic locks to a steel or plastic rail (see Figure A.1 c))



a)



b)



c)

Figure A.1: Examples of connections of double headed studs

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