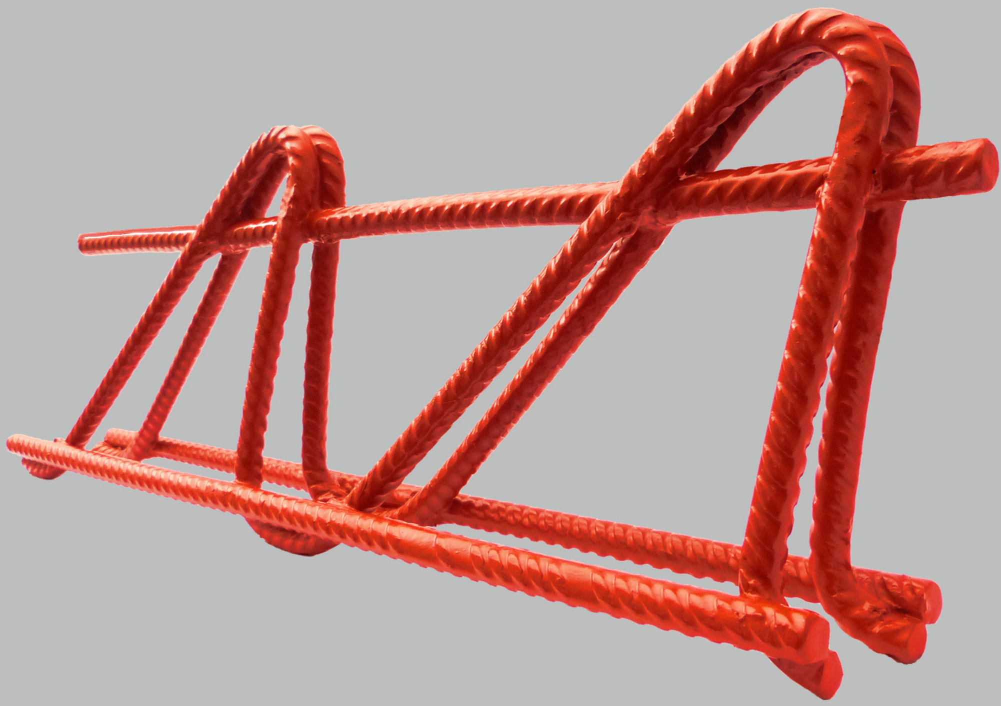

FILIGRAN®-Durchstanzbewehrung FDB

Europäische Technische Bewertung ETA-13/0521

European Technical Assessment ETA-13/0521

14.06.2018

EOTA Technical Report TR 058

June 2017

FILIGRAN®
TRÄGERSYSTEME

www.filigran.de

Approval body for construction products and types of construction

Bautechnisches Prüfamt

An institution established by the Federal and Laender Governments

Designated according to Article 29 of Regulation (EU) No 305/2011 and member of EOTA (European Organisation for Technical Assessment)

European Technical Assessment

ETA-13/0521 of 14 June 2018

English translation prepared by DIBt - Original version in German language

General Part

Technical Assessment Body issuing the European Technical Assessment:	Deutsches Institut für Bautechnik
Trade name of the construction product	Filigran punching reinforcement FDB II
Product family to which the construction product belongs	Filigran lattice girders as punching reinforcement
Manufacturer	Filigran Trägersysteme GmbH & Co. KG Zappenberg 6 31633 Leese DEUTSCHLAND
Manufacturing plant	D-31633 Leese, Zappenberg 6 D-06896 Coswig OT Klieken, Haide Feld 2 PL-42285 Herby, ul. Lubliniecka 15
This European Technical Assessment contains	11 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 160055-00-0301
This version replaces	ETA-13/0521 issued on 13 June 2013

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Specific Part

1 Technical description of the product

The lattice-girders FDB are made of ribbed reinforcement steel with mechanical properties according to EN 1992-1-1, Annex C. The rebars are weldable and have a characteristic yield strength of 500 MPa.

The lattice-girders consist of three rebar chords, connected by a diagonal which is bent as per requirement with a bending-diameter of ≥ 20 mm at the upper chord and at the lower chord of ≥ 36 mm. The loops of the diagonals overlap the chords with defined length. The distance between the diagonals with equal inclination to the chords is 200 mm.

The bent diagonals have a diameter of 9 mm and the chords have a diameter of 10 mm, the length of the lattice-girders is custom-made to meet the static requirements in each individual case. Their height h_L is between 130 mm ≤ h_L ≤ 300 mm, thus allowing a use in slabs of a depth between 180 mm and 400 mm.

For the purpose of the assessment as punching shear reinforcement, only the effective bars of each lattice-girder are taken into account. The bending capacity of the lower and upper chord is not taken into account when assessing the load bearing resistance of the punching area of flat slabs.

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 and EOTA TR 058.

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	$k_{pu,msl}$ = 2,1 $k_{pu,csl}$ = 2,1 $k_{pu,asl}$ = 2,1 $k_{pu,fo}$ = 1,5
Increasing factor for maximum interface shear resistance	$k_{max,i}$ = 1,6
Mechanical characteristic for fatigue loading	$\Delta\sigma_{Rsk,n=0,n} = 66{,}86+336{,}91 \cdot 0{,}999956911^{(\lg n)^{5{,}912631783}}$ [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. 160055-00-0301 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

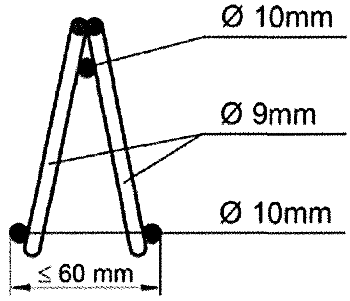
Technical details necessary for the implementation of the AVCP system are laid down in the control plan deposited with Deutsches Institut für Bautechnik.

Issued in Berlin on 14 June 2018 by Deutsches Institut für Bautechnik

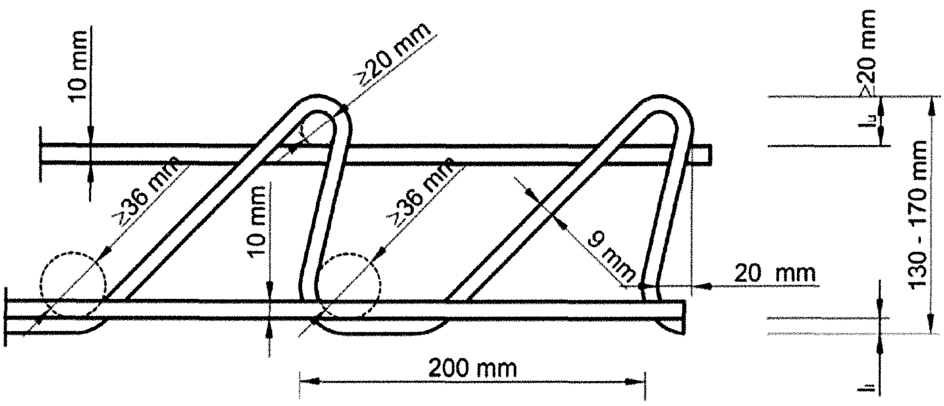
BD Dipl.-Ing. Andreas Kummerow
Head of Department

beglaubigt:
T. Schüler

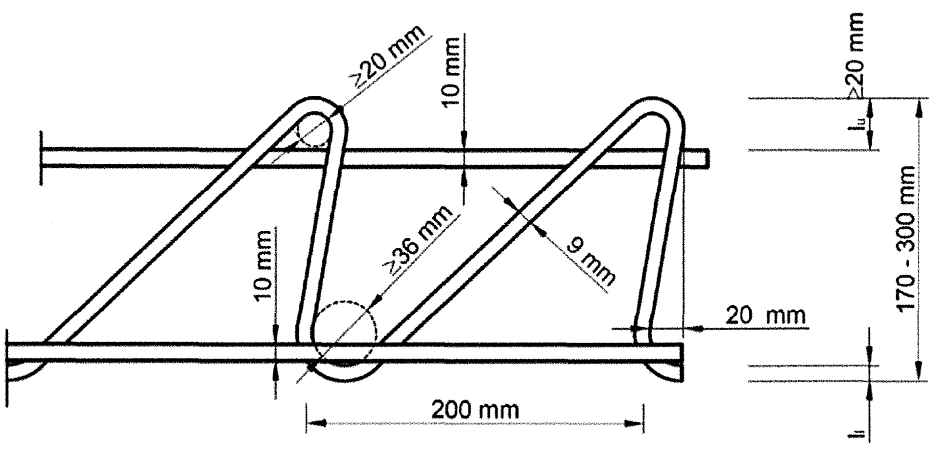
Section of punching shear reinforcement FDB



View of lower punching shear reinforcement FDB



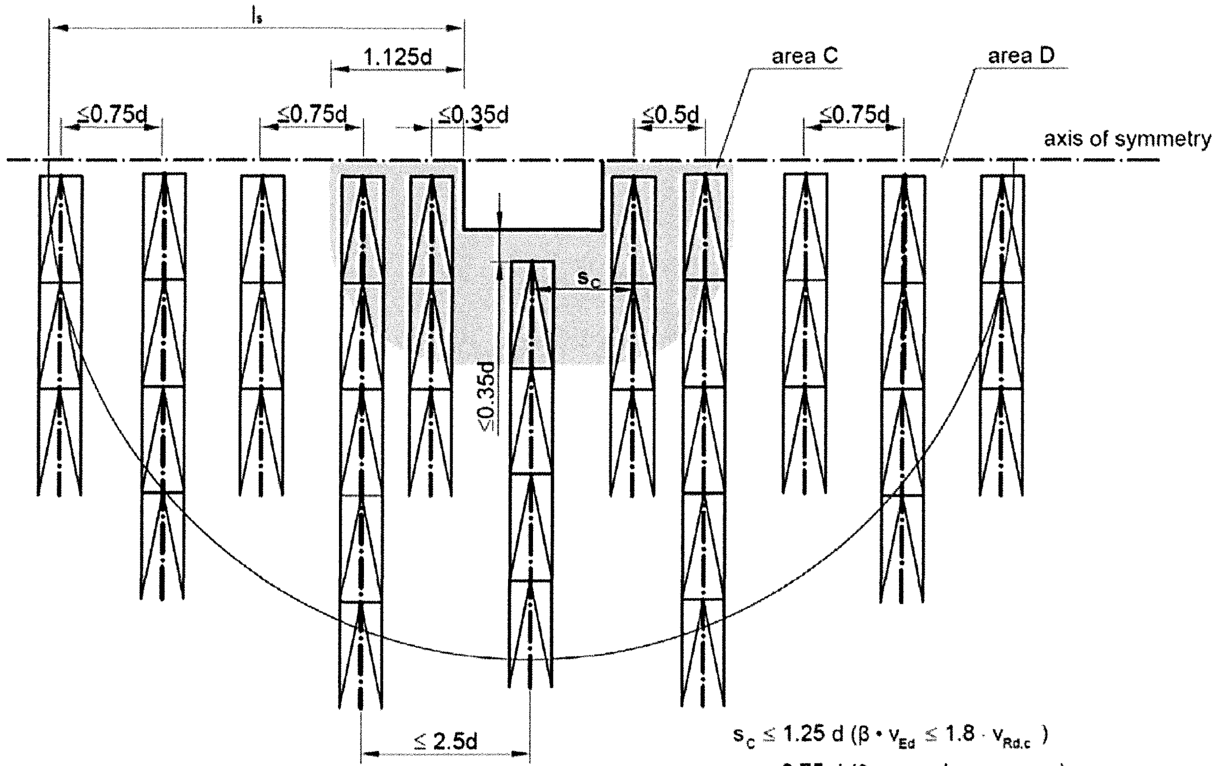
View of higher punching shear reinforcement FDB



Material: reinforcement steel according EN 1992-1-1, Annex C
with a characteristic yield strength of f_{yk} = 500 N/mm²

Filigran® Punching Shear Reinforcement FDB	**Annex A**
Description of Product	

Arrangement and maximum spacing of punching shear reinforcement for inner columns

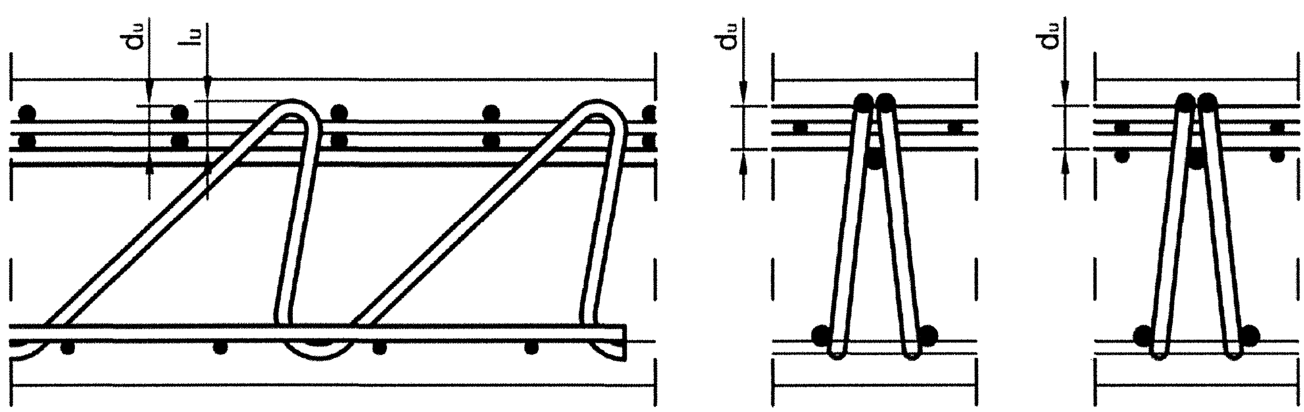


$s_c \leq 1.25\ d\ (\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c})$

$\leq 0.75\ d\ (\beta \cdot v_{Ed} = k_{pu,sl} \cdot v_{Rd,c})$

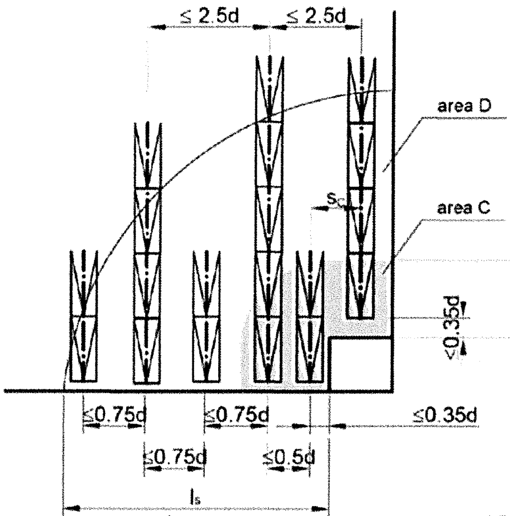
Arrangement of bending reinforcement

$l_u \geq d_u \leq 60$ mm



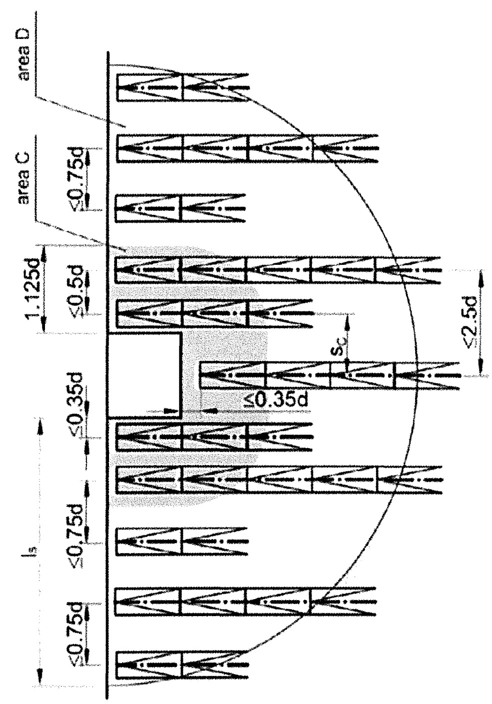
Filigran® Punching Shear Reinforcement FDB	**Annex B1**
Intended Use **Arrangement of Punching Shear Reinforcement and Bending Reinforcement**	

Arrangement and maximum spacing of punching shear reinforcement for corner columns

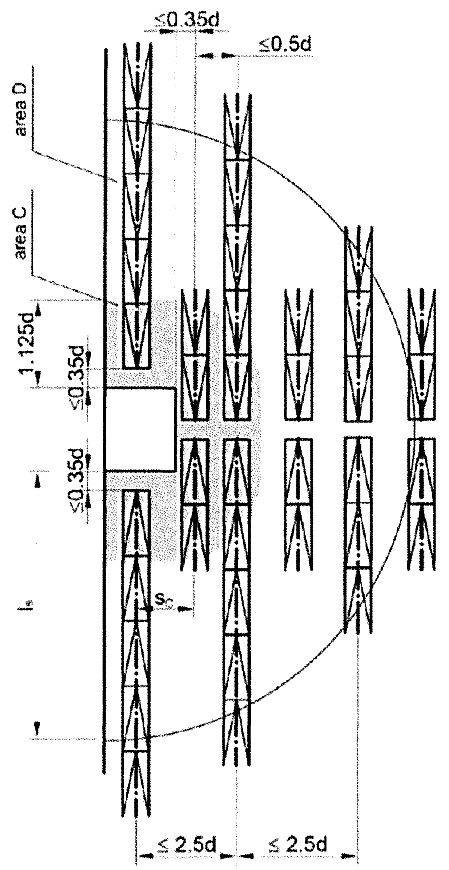


$s_c \leq 1.25\,d\ (\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c})$
$\leq 0.75\,d\ (\beta \cdot v_{Ed} = k_{pu,sl} \cdot v_{Rd,c})$

Arrangement and maximum spacing of punching shear reinforcement for edge columns

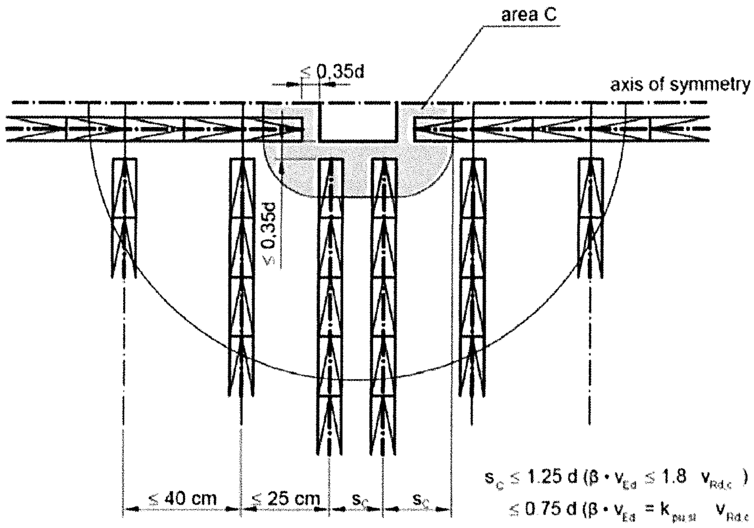


$s_c \leq 1.25\,d\ (\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c})$
$\leq 0.75\,d\ (\beta \cdot v_{Ed} = k_{pu,sl} \cdot v_{Rd,c})$



Filigran® Punching Shear Reinforcement FDB	**Annex B2**
Intended Use **Arrangement of punching shear reinforcement**	

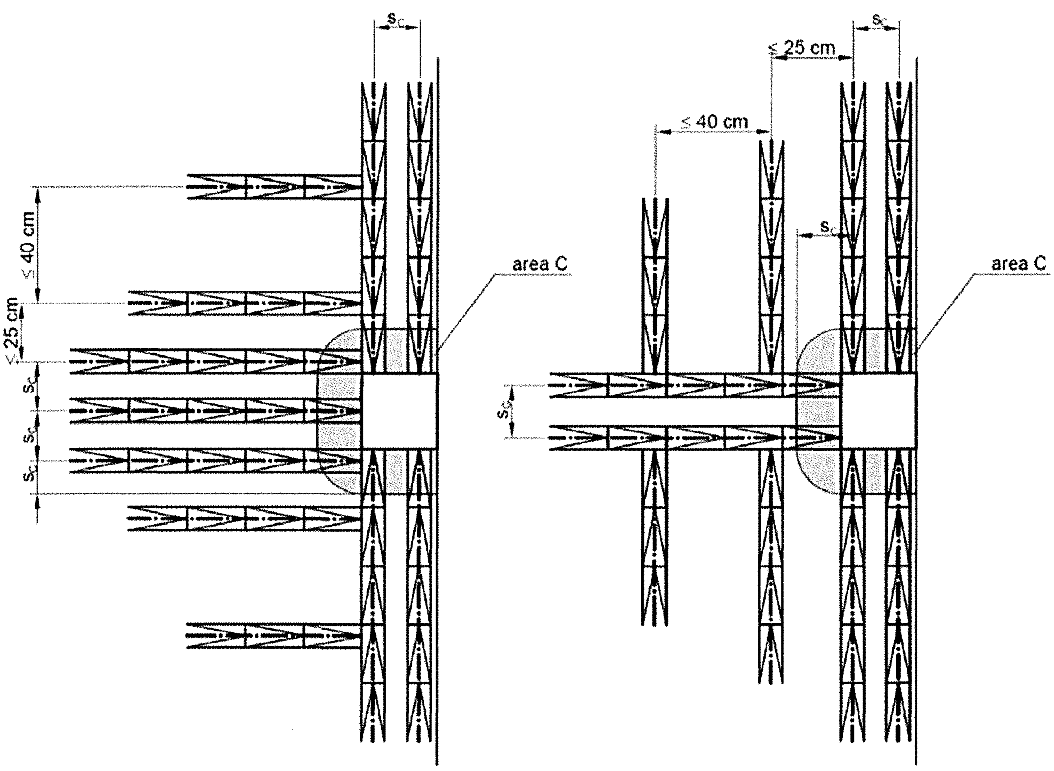
Alternativ arrangement and maximum spacing of punching shear reinforcement for inner columns



$s_C \leq 1.25\,d\ (\beta \cdot v_{Ed} \leq 1.8\ \ v_{Rd,c}\ )$

$\leq 0.75\,d\ (\beta \cdot v_{Ed} = k_{pu,sl}\ \ v_{Rd,c}\ )$

Alternativ arrangement and maximum spacing of punching shear reinforcement for edge columns

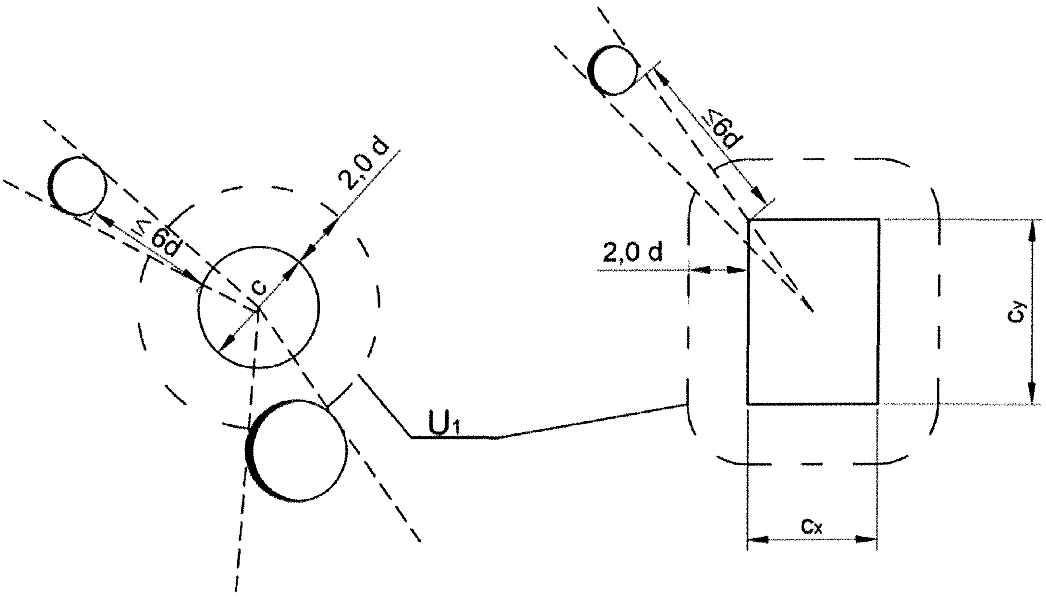


$s_C \leq 1.25\,d\ (\beta \cdot v_{Ed} \leq 1.8\ \ v_{Rd,c}\ )$

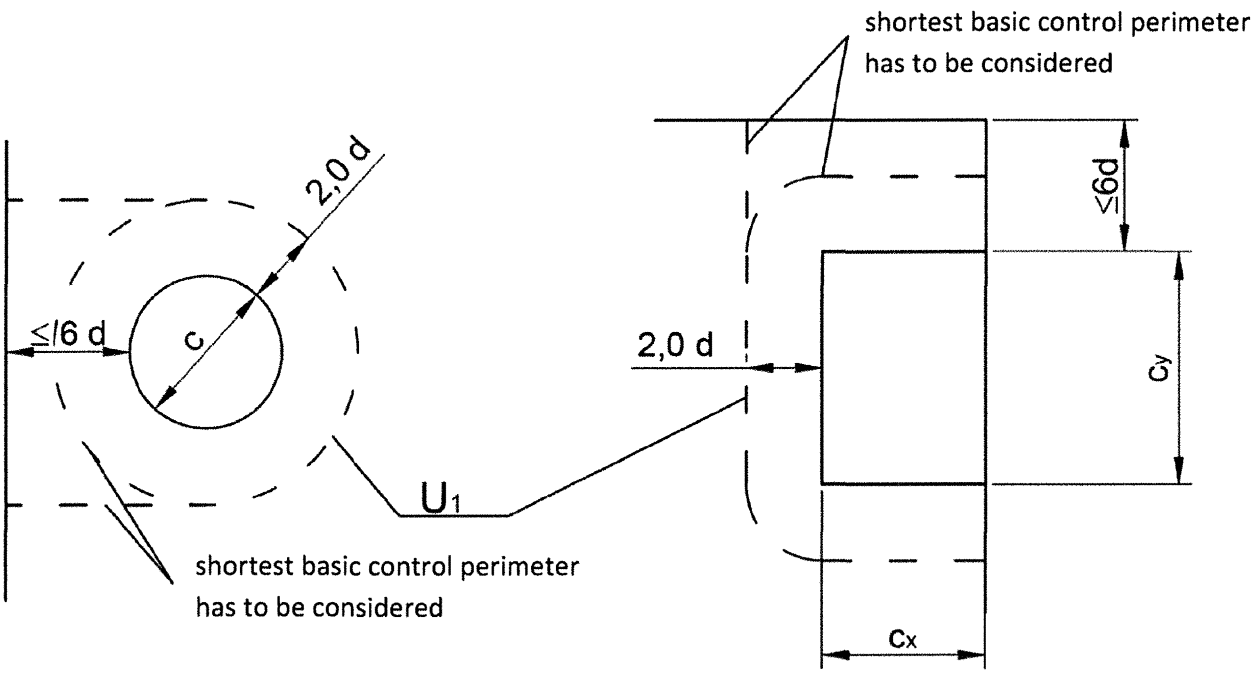
$\leq 0.75\,d\ (\beta \cdot v_{Ed} = k_{pu,sl}\ \ v_{Rd,c}\ )$

Filigran® Punching Shear Reinforcement FDB	**Annex B3**
Intended Use **Alternative Arrangement of Punching Shear Reinforcement**	

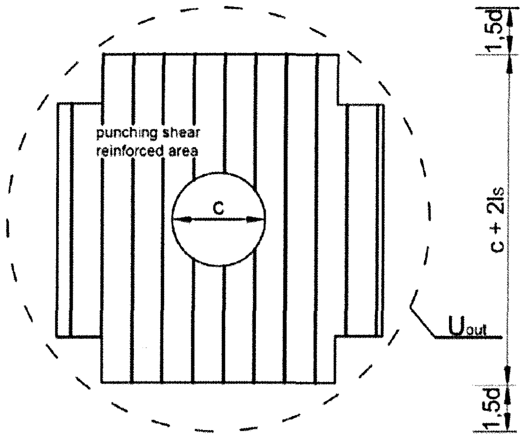
Basic control perimeter near openings



Basic control perimeter for columns close to an edge

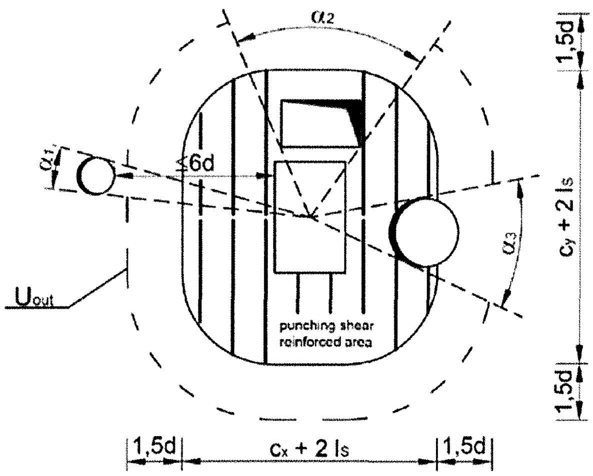


Filigran® Punching Shear Reinforcement FDB	**Annex B4**
Intended Use **Control Perimeter near Edges and Openings**	

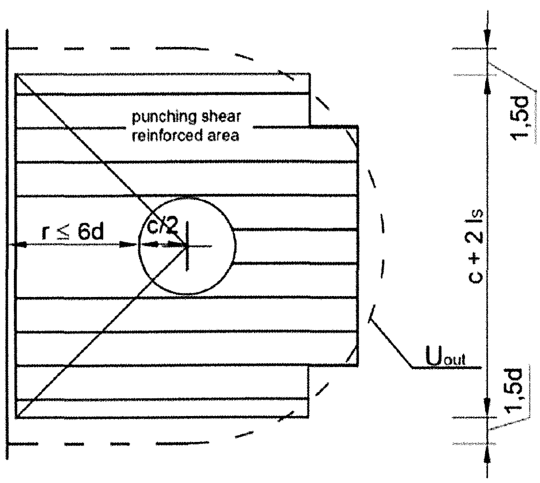


Outer control perimeter

$U_{out} = (c + 2 \bullet l_s + 3.0 \bullet d) \bullet \pi$



Outer control perimeter near openings



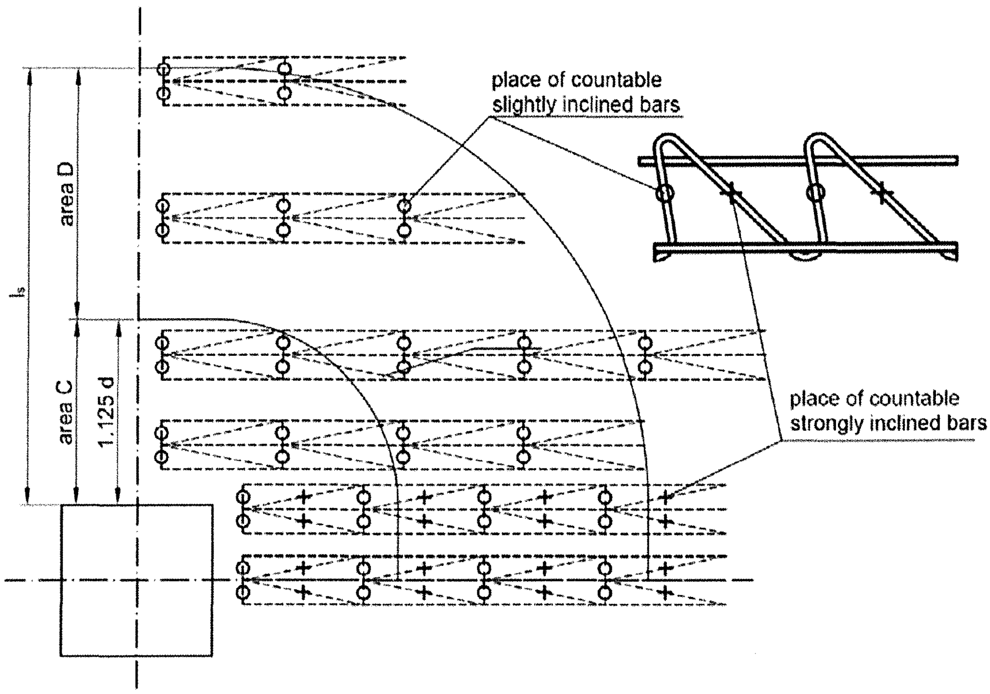
Outer control perimeter near free edge of slab

$U_{out} = 2 \bullet r + c + (c + 2 \bullet l_s + 3.0 \bullet d) \bullet \pi / 2$

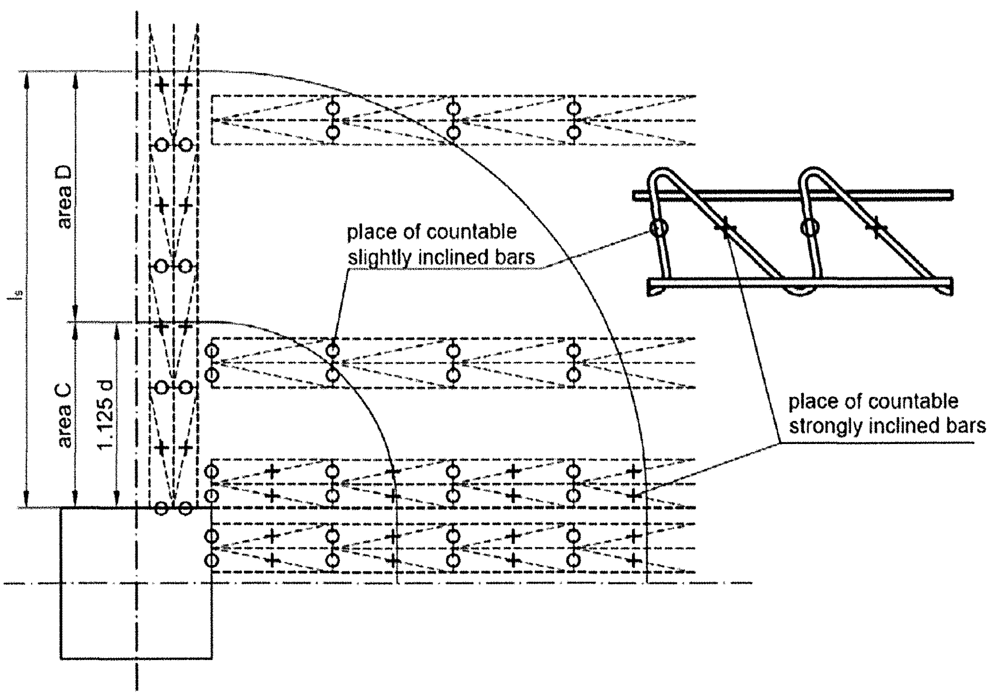
$\leq (c + 2 \bullet l_s + 3.0 \bullet d) \bullet \pi$

Filigran® Punching Shear Reinforcement FDB	**Annex B5**
Intended Use **Outer Control Perimeter U_{out}**	

Effective bars and place



Effective bars and place alternative arrangement



Filigran® Punching Shear Reinforcement FDB	**Annex B6**
Intended Use **Effective Bars and Place**	

EOTA®

TECHNICAL REPORT

Increase of punching shear resistance of flat slabs or footings and ground slabs -lattice girders-

Calculation methods

TR 058
June 2017

EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT
WWW.EOTA.EU

Contents

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 in form of specified lattice girders are used for the increase of the punching shear resistance. In case of composite slabs the reinforcement elements can be used as shear interface reinforcement too.

This TR covers lattice-girders with an ETA issued on basis of EAD 160055-00-0301.

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
- flat slabs or footings and ground slabs with a minimum height of h = 180 mm
- reinforcement elements placed in the punching area around a column or high concentrated load
- reinforcement elements arranged in general parallel to each other
- reinforcement elements positioned such that the upper part of the lattice girder reaches at least to the outside of the uppermost layer of the flexural reinforcement
- reinforcement elements positioned such that the lower part of the lattice girders reaches at least to the outside of the lowest layer of the flexural reinforcement
- reinforcement elements positioned such that the concrete cover complies with the provisions according to EN 1992-1-1

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 composite slabs made of prefabricated thin elements and additional cast in-situ concrete the lattice girders are arranged in the prefabricated slab.
- The flexural reinforcement over the column has to be anchored outside the outer perimeter u_{out}.
- The lower reinforcement according to EN 1992-1-1, 9.4.1 (3) of the slab is laid over the column.
- The upper reinforcement of the slab is placed continuously over the loaded area.
- In case of composite slabs the requirements in chapter 2.4.2 are fulfilled.
- The position and the length of the reinforcement elements are indicated on the design drawings.
- The material of the lattice girders is given in the EAD.

1.3 Specific terms used in this TR

1.3.1 Abbreviations

1.3.2 Indices

E	action effects
R	resistance
V	shear force
P	punching shear reinforcement
C	area C adjacent to the column
D	area D around area C
c	concrete
d	design value
db	diagonal bar
fo	footing or ground slab
k	characteristic value
max	maximum
min	minimum
pu	punching shear
re	reinforcement
s	steel
sl	flat slab
msl	monolithic slab
csl	composite 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 reinforcement
σ_{cp}	normal stresses in concrete in critical section
f_{ywd}	design value of the yield strength of the load bearing bars of the lattice girders

1.3.4 Concrete, reinforcement and lattice girders

d	effective depth of the slab
ρ	ratio of flexural reinforcement
a	distance from column face to control perimeter
u_0	column perimeter
κ	coefficient to take into account size effects
$\varnothing$	diameter of a bar
γ_s	product dependent partial safety factor = 1.15

$A_{sw,0.8d}$	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 contraflexure for the bending moment in radial direction in a continuous ground slab)
s	distance
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
u_1	perimeter of the critical section at a distance of 2.0·d from the column face
u_{out}	outer control perimeter u_{out} at a distance of 1.5·d from the outermost row of the punching shear reinforcement
l_s	distance between column face and outermost punching shear reinforcement

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 the basic control perimeter u_1

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

- Maximum resistance of the slabs at basic control perimeter u_1

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

- Amount of punching shear reinforcement

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

- 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 at inner critical perimeter u_1 perpendicular to the flat slab surface at the distance $2.0 \cdot d$ 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 ($u_1 \cdot d$) along the basic control perimeter u_1 is calculated:

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

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:	$\beta = 1.10$
edge columns:	$\beta = 1.40$
corner columns:	$\beta = 1.50$

corners of walls β = 1.20
ends of walls: β = 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 National Amendment.

2.2.2 Flat slabs

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

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} \tag{2.6}$$

and

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

where

β	is defined as in section 2.2.1 of this TR
$V_{Rd,sy}$	is determined as in section 2.4.1of this TR
$v_{Rd,max}$	is determined as in section 2.4.1or 2.4.2 respectively 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:

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} \tag{2.8}$$

and

$$\beta \cdot V_{Ed,red} \leq v_{Rd,max} \cdot u \cdot d \tag{2.9}$$

where

$V_{Rd,sy}$	is determined as in section 2.4.3 of this TR
$v_{Rd,max}$	is determined as in section 2.4.3 of this TR
u	is the control perimeter determined by iterative calculation as in section 2.3.2 of this TR

in general: $$\beta \cdot V_{Ed,red} = \beta \cdot (V_{Ed} - \Delta V_{Ed}) = \beta \cdot (V_{Ed} - \sigma_{gd} \cdot A_{crit}) \tag{2.10}$$

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

for a uniform soil pressure distribution: $$\beta \cdot V_{Ed,red} = \beta \cdot V_{Ed}(1 - \frac{A_{crit}}{A}) \tag{2.11}$$

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 flat plate)

If outside of $0.8 \cdot d$ further punching shear reinforcement is necessary, the required cross-sectional area of each additional annulus 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 (2.12) or according to NA to EN1992-1-1:

$$v_{Rd,c} = C_{Rd,c} \cdot \kappa \cdot \sqrt[3]{100 \cdot \rho_l \cdot f_{ck}} + k_1 \cdot \sigma_{cp} \geq (v_{min} + k_1 \cdot \sigma_{cp}) \tag{2.12}$$

$C_{Rd,c}$ empirical factor, the recommended value is $C_{Rd,c} = 0.18 / \gamma_c$

γ_c partial safety factor for concrete (recommended value is $\gamma_c = 1.5$)

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

$$\kappa = 1 + \sqrt{\frac{200}{d}} \leq 2.0 \tag{2.13}$$

ρ_l mean reinforcement ratio of y- and z-directions

$$\rho_l = \sqrt{\rho_{lx} \cdot \rho_{ly}} \leq \begin{cases} 2.0\% \\ 0.5 \cdot f_{cd} / f_{yd} \end{cases} \tag{2.14}$$

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

$$v_{min} = \frac{0.0525}{\gamma_c} \cdot \kappa^{1.5} \cdot \sqrt{f_{ck}} \quad \text{for} \quad d \leq 600 \text{ mm} \tag{2.15}$$

$$v_{min} = \frac{0.0375}{\gamma_c} \cdot \kappa^{1.5} \cdot \sqrt{f_{ck}} \quad \text{for} \quad d > 800 \text{ mm} \tag{2.16}$$

(intermediate values are linearly interpolated)

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

$$u_0/d < 4.0: \qquad C_{Rd,c} = \frac{0.18}{\gamma_c} \cdot \left(0.1 \cdot \frac{u_0}{d} + 0.6\right) \geq \frac{0.15}{\gamma_c} \tag{2.17}$$

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 (2.18) or according to NA to EN1992-1-1:

$$v_{Rd,c} = C_{Rd,c} \cdot \kappa \cdot \sqrt[3]{100 \cdot \rho_l \cdot f_{ck}} \cdot \frac{2 \cdot d}{a} \geq v_{min} \cdot \frac{2 \cdot d}{a} \tag{2.18}$$

$C_{Rd,c}$ $0.15/\gamma_c$ 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 ($\leq 2\,d$) 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 Monolithic flat slabs

The maximum punching shear resistance flat slabs along the critical perimeter u_1 is defined as the resistance of the slab without shear reinforcement multiplied with the factor $k_{pu,msl(asl)}$ according to equation (2.19):

$$v_{Rd,max} = k_{pu,msl(asl)} \cdot v_{Rd,c} \tag{2.19}$$

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

The value $k_{pu,msl(asl)}$ 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 (2.12) 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 amount of punching shear reinforcement 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 amount of shear reinforcement, 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 shear reinforcement in the area C shall be dimensioned according to the following equation:

$$\beta \cdot V_{Ed} \leq V_{Rd,sy} = \frac{f_{yk}}{\gamma_S} \cdot \sum A_{sy} \cdot \sin \alpha_i \tag{2.20}$$

A_{sy} cross section of each effective bar as defined in fig. 1 of this TR

α_i inclination of the countable diagonal bar referred to the slab plane of the slab

f_{yk} characteristic value of yield stress of the countable diagonal bar (see Table A1)

γ_s product dependent safety factor for punching shear reinforcement
= 1.15 (if not otherwise stated in the ETA)

In the area D, the dimensioning of the shear reinforcement has to be according to equation (2.21).

$$0.5 \cdot \beta \cdot V_{Ed} \cdot \frac{s_D}{0.75d} \leq V_{Rd,sy} \tag{2.21}$$

s_D width of the virtual annulus in area D
$s_D \leq 0.75d$

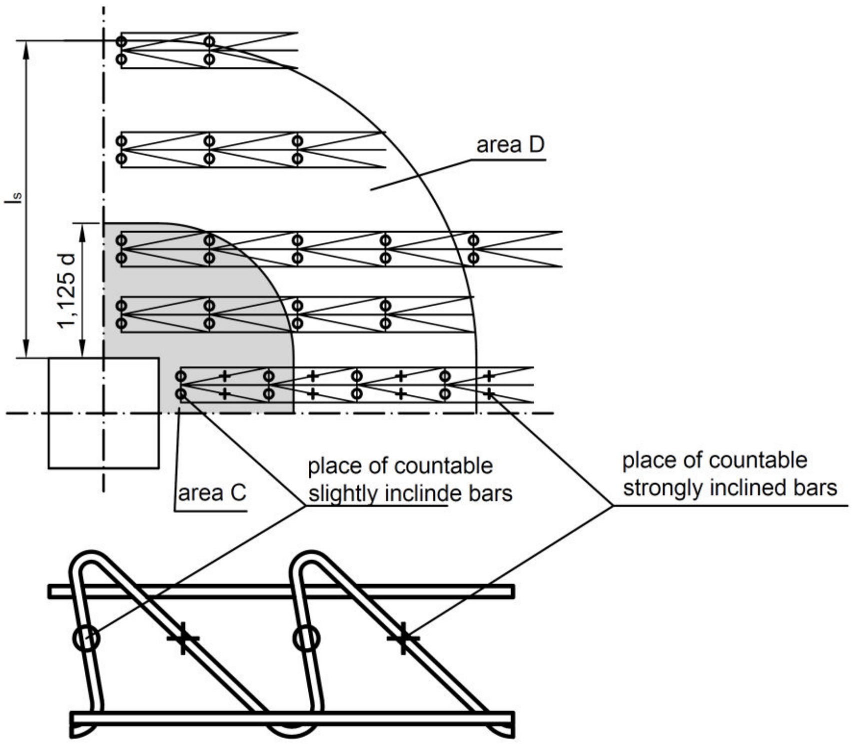


Figure 1: Countable inclined bars of the lattice girder as punching shear reinforcement

2.4.2 Composite flat slabs

If the punching shear reinforcement is used in composite slabs made of thin precast elements with in situ topping equation (2.19) has to be taken into account with $k_{pu,msl} = k_{pu,csl}$.

The value $k_{pu,csl}$ is product dependent and given in the ETA.

The design concept according chapter 2.4.1 is also valid in the case of composite slabs.

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 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.

The interface shear resistance has to be proved according to chapter 5 of this TR.

2.4.3 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:

$$v_{Rd,max} = k_{pu,fo} \cdot v_{Rd,c} \qquad \text{footings and ground slabs} \qquad (2.22)$$

The verification acc. to Eq. (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 (2.22) is the calculated punching shear resistance according to Equation (2.18) 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 shear reinforcement shall be dimensioned according to the following equation:

$$V_{Rd,s} = \frac{f_{yk}}{\gamma_S} \cdot \sum A_{sy,0.8d} \cdot \sin \alpha_i \tag{2.23}$$

$A_{sy,0.8d}$ cross section of each effective bar in a distance between 0.3d and 0.8d

If outside of $0.8 \cdot d$ further shear reinforcement is necessary, the required cross-sectional area of each additional annulus 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 perimeter of the outermost effective bars of the shear reinforcement.

2.4.4 Outer control perimeter

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

$$u_{out} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c} \cdot d} \tag{2.24}$$

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 (2.12)

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} in combination with $C_{Rd,c}$ according to NA for the verification along the outer perimeter can be used.

Edge columns:

$$\beta_{red} = \frac{\beta}{1.2 + {}^{\beta}/_{20} \cdot {}^{l_s}/_{d}} \geq 1.1 \tag{2.25}$$

Corner columns:

$$\beta_{red} = \frac{\beta}{1.2 + {}^{\beta}/_{15} \cdot {}^{l_s}/_{d}} \geq 1.1 \tag{2.26}$$

Other columns, corners of walls and ends of walls:

$$\beta_{red} = \frac{\beta}{1.2 + {}^{\beta}/_{40} \cdot {}^{l_s}/_{d}} \geq \beta_{int,col} \tag{2.27}$$

l_s distance between the face of the column and the outermost countable bar

$\beta_{int,col}$ increasing factor for inner columns according to EN1992-1-1, 6.4.3 (6) and NA

If inclined pre-stressed tendons increase the punching shear capacity, they have to be effective in both areas C and D.

3 POSITIONING OF THE PUNCHING SHEAR REINFORCEMENT ELEMENTS

3.1 Flat slabs

The positioning of the shear reinforcement elements is given by maximum distances of the elements to the column and to each other. It is distinguished between elements which run in the direction of the column (radial placed) and parallel to the column face (tangential placed) and it is distinguished between area C and area D.

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.

The maximum distance of the adjacent element to the column is 0.35d. In case of radial arranged elements this distances is measured from the countable place of the adjacent bar to the column face. In case of tangential arranged elements this distance is measured from the axis of the lattice girder to the column face (compare fig. 2).

The maximum distance between the axis of the reinforcement elements is shown in fig. 2.

Maximum axis distance for tangential placed elements in area C: 0.5d

Maximum axis distance for tangential placed elements in area D in the axis of the column perpendicular to the direction of the parallel reinforcement elements: 0.75d

Maximum axis distance in area C:

$\beta \cdot v_{Ed} = k_{pu,sl} \cdot v_{Rd,c}$: 0.75d

$\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c}$: 1.25d

Linear interpolation between the maximum distance for $1.8 \cdot v_{Rd,c}$ and for $k_{pu,sl} \cdot v_{Rd,c}$ is possible.

Maximum axis distance in area D: 2.5d

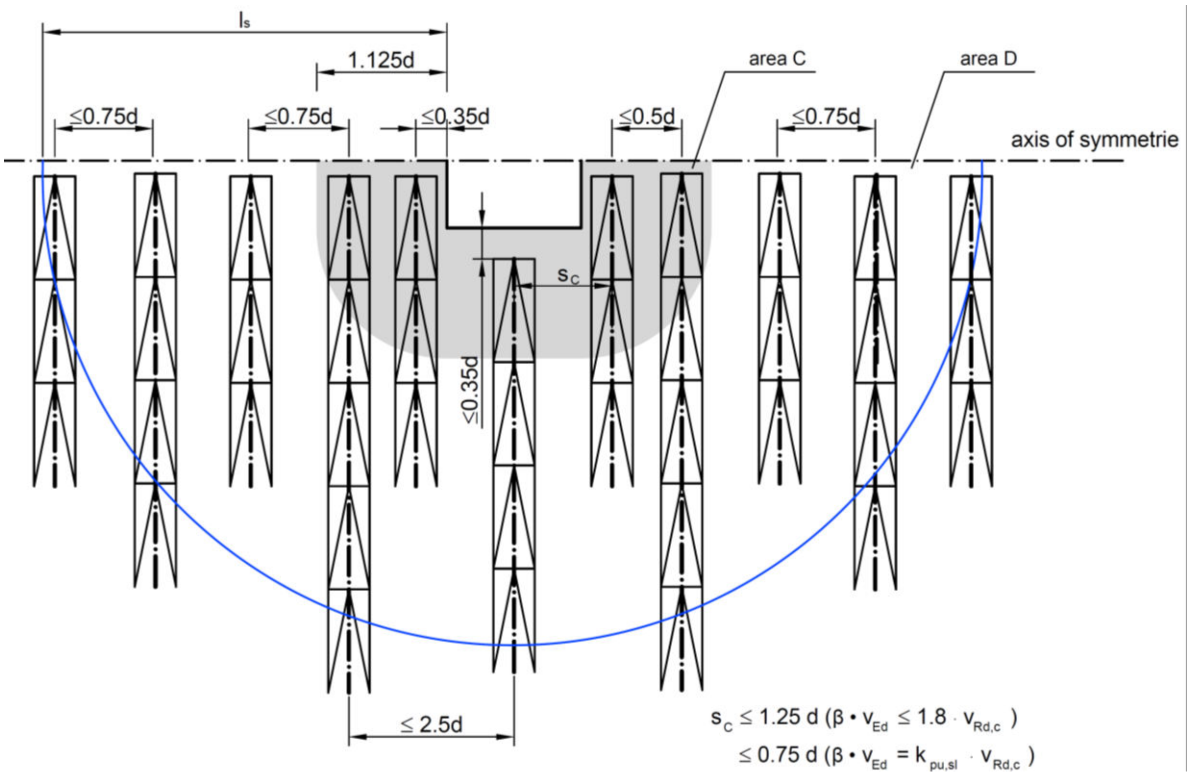


Figure 2: Maximum distances of the shear reinforcement elements in a flat slab

In addition to the arrangement according to fig. 2 an alternative arrangement according to fig. 3 can be given in an EAD.

The maximum distance between the axis of the reinforcement elements for the alternative arrangement is shown in fig. 3.

Maximum axis distance to the direction of the parallel reinforcement elements:

$\beta \cdot v_{Ed} = k_{pu,asl} \cdot v_{Rd,c}$: 0.75d

$\beta \cdot v_{Ed} \leq 1.8 \cdot v_{Rd,c}$: 1.25d

Linear interpolation between the maximum distance for $1.8 \cdot v_{Rd,c}$ and for $k_{pu,asl} \cdot v_{Rd,c}$ is possible.

Maximum axis distance in area D: 40 cm

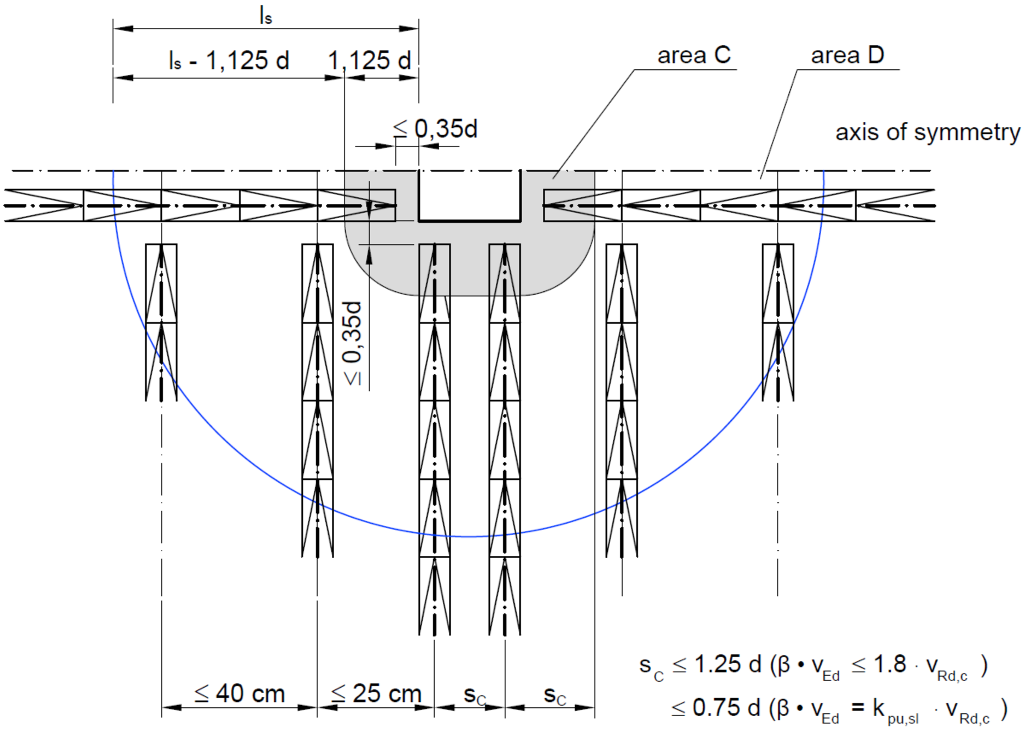


Figure 3: Alternative arrangement of the shear reinforcement elements in a flat slab

3.2 Footings and ground slabs

The area with a radial distance from the face of the column of ≤ 0.8d is called area C.
The area with a radial distance from the face of the column of > 0.8d is called area D.

The countable bars of the lattice shear reinforcement in area C must be placed between 0.3d and 0.8d.
The maximum axis distances of the shear reinforcement elements in area C is 0.5d.
The maximum axis distances of the shear reinforcement elements in area D is 0.75d.

Other arrangements of the shear reinforcement elements with different maximum distances can be given in the ETA.

4 FATIGUE DESIGN

4.1 General

In case of gravity fatigue load two design method can be used:

Method I: complete method

Method II: simplified method

In both cases the fatigue of the punching shear reinforcement (steel failure) and the punching shear failure of the compression strut (concrete failure) must be proved separately.

4.2 Method I

Method I is used when the upper limit of load cycles during working life and an allocation of the lower cyclic load is known.

The concrete fatigue resistance has to be proved according to eq. (4.1) (compare fig.4).

$$\frac{\beta \cdot max\ v_{Ed,fat}}{v_{Rd,max}} = k_{fat,c} + 0.45 \cdot \frac{\beta \cdot min\ v_{Ed,fat}}{v_{Rd,max}} \leq 0.9 \tag{4.1}$$

max $v_{ED,fat}$	maximum applied load with a partial safety factor γ_{fat} with γ_{fat} according to national requirement (recommended value γ_{fat} = 1.0)
min $v_{Ed,fat}$	minimum applied load with a partial safety factor γ_{fat} with γ_{fat} according to national requirement (recommended value γ_{fat} = 1.0)
$k_{fat,C}$	factor for the fatigue strength of the concrete cone failure according to eq. (4.2)

$$k_{fat,c} = 1 - \frac{log\ n}{14} \tag{4.2}$$

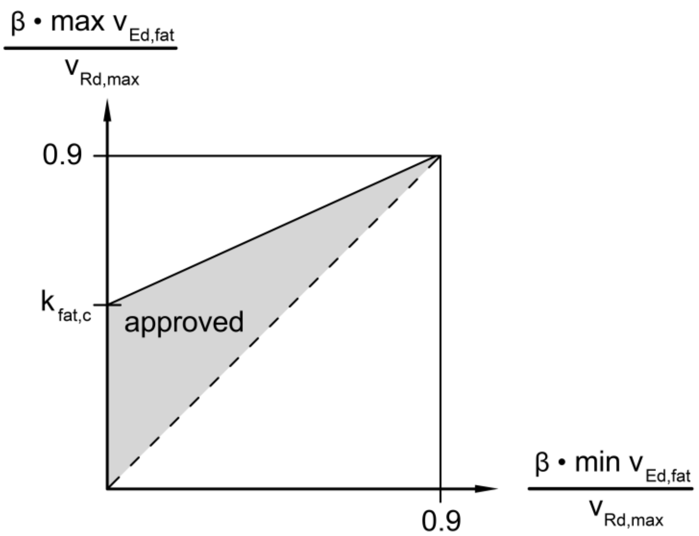


Figure 4: Goodman diagram to prove the punching shear failure (concrete failure) according to eq. (4.1)

To prove the fatigue resistance of the shear reinforcement two cases are possible:

Case 1:

There is a collective load or actions on several levels and the maximum value of actions Δv_{max} is assumed for the design. Equation (4.3) has to be fulfilled.

$$\Delta\sigma_{max} = \sigma_{fat,Rsk}(n) \tag{4.3}$$

n	number of cycles for the fatigue proof
$\Delta\sigma_{max}$	maximum stress in the shear reinforcement during cycle 1 to n due to fatigue loads calculated with γ_{fat} (recommended γ_{fat} = 1.0)
$\sigma_{fat,Rsk}(n)$	fatigue strength of the shear reinforcement for n cycles = $\Delta\sigma_{Rsk,n}$ acc. to ETA

Case 2:
There is given a collective load or one which was is converted using the Miner´s Rule.

$$\Delta\sigma_{max}^{col} = \sigma_{fat,Rsk}(n) \tag{4.4}$$

n	number of cycles for the fatigue proof
$\Delta\sigma^{col}_{max}$	maximum stress in the shear reinforcement during cycle 1 to n due to a collective of fatigue loads calculated with γ_{fat} (recommended γ_{fat} = 1.2)
$\sigma_{fat,Rsk}(n)$	fatigue strength of the shear reinforcement for n cycles = $\Delta\sigma_{Rsk,n}$ acc. to ETA

4.3 Method II

Method II is used when the upper limit of load cycles during working life and the maximum of the lower cyclic load is given. This method is used up to $2\cdot10^6$ load cycles.
The concrete fatigue resistance has to be proved according to eq. (4.1) taking into account the $k_{fat,c}$ – factor according to eq. (4.5)

$$k_{fat,C} = 0.5 \tag{4.5}$$

The fatigue resistance of the shear reinforcement has to be proved according to eq. (4.6).

$$\Delta\sigma_{max} = \sigma_{fat,Rsk}(2\cdot10^6) \tag{4.6}$$

$\Delta\sigma_{max}$	maximum stress in the shear reinforcement due to fatigue loads up to $2\cdot10^6$ calculated with γ_{fat} (recommended γ_{fat} = 1.0)
$\sigma_{fat,Rsk}(2\cdot10^6)$	fatigue strength of the shear reinforcement for $2\cdot10^6$ load cycles = $\Delta\sigma_{Rsk,n=2\cdot10^6}$ acc. to ETA

5 INTERFACE SHEAR PROOF IN COMPOSITE FLAT SLABS

Lattice girder reinforcement elements can be used as interface reinforcement in composite flat slabs. In case where the punching shear reinforcement is used according to the design rules in chapter 2.4.2 and the requirements of chapter 3.1 are fulfilled a proof of the interface in area C is unnecessary.

The interface must be proved in perimeters around the column. The nearest perimeter to the column is situated in a distance of 1.5d. Additional perimeter further away from the column can be proved with reduced interface shear reinforcement.

The resistance of the interface is given by equation (5.1).

$$v_{Rdi} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho_l \cdot f_{yd} \cdot (k_i \cdot \mu \cdot \sin\alpha + \cos\alpha) \leq k_{max,i} \cdot 0.5 \cdot \nu \cdot f_{cd} \tag{5.1}$$

k_i factor for inclined bars (recommended value is k_i = 1.2)

$k_{max,i}$ increasing factor for the maximum resistance (depending on the reinforcement and given in ETA)

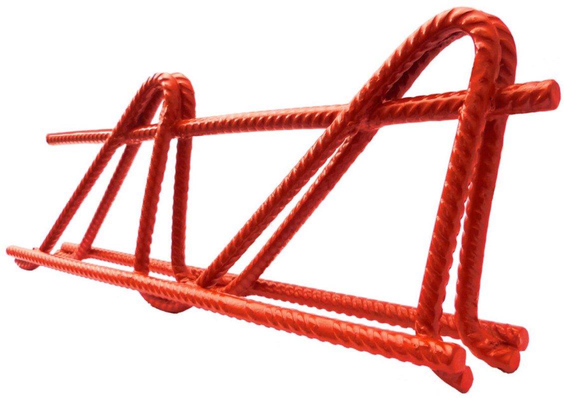
If no figure is proved it is recommended k_{max} = 1.0.

c, μ, ν coefficient depending on the roughness given in NA to EN 1992-1-1

6 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 1992-1-1	Design of concrete structures – Part 1-1: General rules and rules for buildings
NA to EN 1992-1-1	National Annex – Nationally determined parameters – Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings
EN 206	Concrete Part 1: Specification. Performance and conformity
EAD 160055-00-0301	Lattice-girders for the increase of punching shear resistance of flat slabs or footings and ground slabs



FILIGRAN Trägersysteme GmbH & Co. KG
Zappenberg 6 • D-31633 Leese
Telefon: +49 (0)5761 / 9225 – 0
www.filigran.de