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Authorised and notified according to Article 10 of the Council Directive of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products (89/106/EEC)

Deutsches Institut für Bautechnik

DIBt

Mitglied der EOTA
Member of EOTA

European Technical Approval ETA-13/0521

English translation prepared by DIBt - Original version in German language

Handelsbezeichnung *Trade name*	Filigran-Durchstanzbewehrung FDB II *Filigran punching reinforcement FDB II*
Zulassungsinhaber *Holder of approval*	Filigran Trägersysteme GmbH & Co. KG Zappenberg 6 31633 Leese DEUTSCHLAND
Zulassungsgegenstand und Verwendungszweck *Generic type and use of construction product*	Filigran Gitterträger als Durchstanzbewehrung *Filigran lattice girders as punching reinforcement*
Geltungsdauer: *Validity:* vom *from* / bis *to*	13 June 2013 13 June 2018
Herstellwerke *Manufacturing plants*	Filigran Trägersysteme GmbH & Co. KG Zappenberg 6 31633 Leese Deutschland Filigran Trägersysteme GmbH & Co. KG Gewerbegebiet Haide-Feld 06869 Klieken Deutschland

Diese Zulassung umfasst *This Approval contains*	21 Seiten einschließlich 8 Anhänge *21 pages including 8 annexes*

I LEGAL BASES AND GENERAL CONDITIONS

1 This European technical approval is issued by Deutsches Institut für Bautechnik in accordance with:

- Council Directive 89/106/EEC of 21 December 1988 on the approximation of laws, regulations and administrative provisions of Member States relating to construction products[1], modified by Council Directive 93/68/EEC[2] and Regulation (EC) N° 1882/2003 of the European Parliament and of the Council[3];
- *Gesetz über das In-Verkehr-Bringen von und den freien Warenverkehr mit Bauprodukten zur Umsetzung der Richtlinie 89/106/EWG des Rates vom 21. Dezember 1988 zur Angleichung der Rechts- und Verwaltungsvorschriften der Mitgliedstaaten über Bauprodukte und anderer Rechtsakte der Europäischen Gemeinschaften (Bauproduktengesetz - BauPG) vom 28. April 1998[4], as amended by Article 2 of the law of 8 November 2011[5];*
- Common Procedural Rules for Requesting, Preparing and the Granting of European technical approvals set out in the Annex to Commission Decision 94/23/EC[6].

2 Deutsches Institut für Bautechnik is authorized to check whether the provisions of this European technical approval are met. Checking may take place in the manufacturing plant. Nevertheless, the responsibility for the conformity of the products to the European technical approval and for their fitness for the intended use remains with the holder of the European technical approval.

3 This European technical approval is not to be transferred to manufacturers or agents of manufacturers other than those indicated on page 1, or manufacturing plants other than those indicated on page 1 of this European technical approval.

4 This European technical approval may be withdrawn by Deutsches Institut für Bautechnik, in particular pursuant to information by the Commission according to Article 5(1) of Council Directive 89/106/EEC.

5 Reproduction of this European technical approval including transmission by electronic means shall be in full. However, partial reproduction can be made with the written consent of Deutsches Institut für Bautechnik. In this case partial reproduction has to be designated as such. Texts and drawings of advertising brochures shall not contradict or misuse the European technical approval.

6 The European technical approval is issued by the approval body in its official language. This version corresponds fully to the version circulated within EOTA. Translations into other languages have to be designated as such.

1 Official Journal of the European Communities L 40, 11 February 1989, p. 12
2 Official Journal of the European Communities L 220, 30 August 1993, p. 1
3 Official Journal of the European Union L 284, 31 October 2003, p. 25
4 *Bundesgesetzblatt Teil I 1998*, p. 812
5 *Bundesgesetzblatt Teil I 2011*, p. 2178
6 Official Journal of the European Communities L 17, 20 January 1994, p. 34

II SPECIFIC CONDITIONS OF THE EUROPEAN TECHNICAL APPROVAL

1 Definition of the FILIGRAN punching reinforcement FDB II and intended use

1.1 Definition of the construction product

The lattice-girders FDB II 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 (fig. 1). 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 ≤ 320 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.

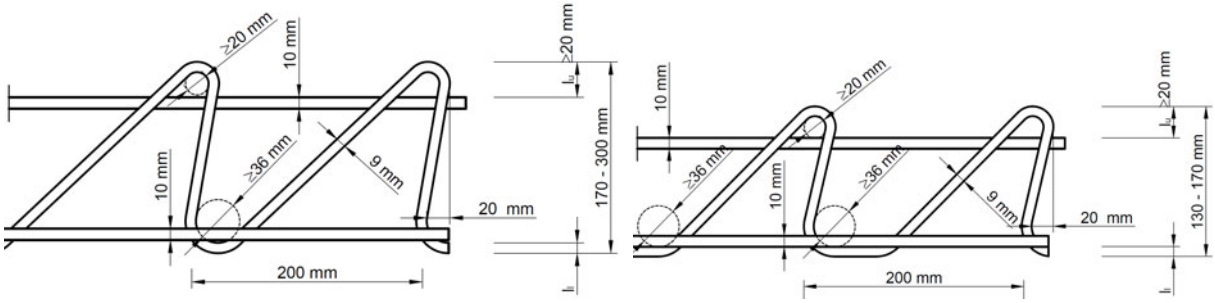


Figure 1: Filigran FDB II high and low punching reinforcement

1.2 Intended use

The lattice-girders FDB II are installed as shear reinforcement in reinforced concrete flat slabs on columns in order to increase the punching shear resistance of the slabs. They may also be used for the increase of the load bearing capacity of the slabs subjected to high concentrated loads.

The lattice girders may be used for predominantly static loading.

Lattice-girders can also be used for prefabricated slabs with partially precast elements and together with other lattice-girders when the respective ETAs or national guidelines are observed. The lattice-girders installed as shear reinforcement are also effective as interface reinforcement.

The concrete strength class shall not be less than C20/25 and shall not exceed C50/60 according to EN 206-1:2000. The use of self compacting concrete is not covered by this ETA.

The slabs shall have a minimum height of h = 18 cm.

The arrangement pattern given in Annexes 2 and 3 shows the maximum distances between diagonals of the lattice-girders as arranged around a column or area of concentrated load.

Where no National Regulation for the design of slabs reinforced with lattice-girders with the geometry as specified in the ETA exists, Annex 7 and 8 should be used.

Lattice-girders are not intended for use in footings.

The provisions made in this European technical approval are based on an assumed working life of the lattice girders of 50 to 100 years, provided that the conditions laid down in sections 4.2, 4.3 and 5.1 for the design, installation and transport are met. 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.

2 Characteristics of the lattice girders FDB II and methods of verification

2.1 Characteristics of product

2.1.1. Geometry

The essential geometrical properties of the product are given in the ETA in Annex 1.

2.1.2 Mechanical strength

The lattice girders comply with the specifications and drawings given in Annex 1.

The following conditions concerning the yield strength and the tensile strength of the rebar coils used for Filigran lattice girders FDB II are considered proven and comply with the requirements as defined in EN 1992-1-1, Annex C:

- $f_{yk} \geq 500$ MPa
- ratio $(f_t/f_y)_k \geq 1.05$
- $\varepsilon_{uk} \geq 2.5$ %

The material characteristics, dimensions and tolerances of the Filigran punching reinforcement FDB II not indicated in Annex 1 are given in the technical documentation[7] of the ETA.

2.1.3 Enhanced ductility of the loops

The enhanced ductility of the loops of the lattice girders with a bending diameter of the diagonal $\leq 4\ d_s$ is considered proven.

2.1.4 Robustness and Durability (shear strength of the -welded point)

The shear strength of the welded connections of upper chord – diagonal and lower chord - diagonal is considered proven so that the robustness and durability of the lattice girders for the intended use is assumed to be verified.

2.1.7 Reaction to fire

The Filigran punching reinforcement FDB II are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of EC Decision 96/603/EC (as amended) without the need for testing on the basis of its listing in that decision.

2.1.8 Resistance to fire

Fire resistance performance cannot be claimed for individual products (non-installed), but for the installed Filigran Punching reinforcement FDB II cast-in slabs.

[7] The technical documentation of the ETA is deposited with DIBt and, as far as relevant fort he tasks of the approved bodies involved in the attestation of conformity procedure, is handed over to the approved bodies.

2.1.9 Durability

Supporting evidence that corrosion will not occur is not required if the steel parts are protected against corrosion, as set out below:

For the verification of durability to environmental exposure, no separate verifications are necessary, if the chords and diagonals of the lattice-girders are protected by a nominal concrete cover according to the national provisions of the Member States.

2.2 Methods of verification

2.2.1 General

The ETA is issued for the Filigran punching reinforcement FDB II on the basis of agreed information, deposited with Deutsches Institut für Bautechnik (DIBt), which identifies the lattice girders that has been assessed and evaluated. Changes to the production process, the dimensions, materials or the elements which could result in this deposited information being incorrect, shall be notified to DIBt before the changes are introduced. DIBt will decide whether or not such changes affect the ETA and consequently the validity of the CE marking on the basis of the ETA, and, if so, whether further assessment and/or alterations to the ETA shall be necessary.

2.2.2 Mechanical resistance and stability of the lattice girders FDB II

The assessment of the fitness of the lattice girders for the intended use with regard to the requirements of mechanical resistance and stability as well as safety in use in the sense of the Essential Requirements 1 and 4 was performed based on the following verifications:

1. Verification for tensile loads
   - yield strength f_{yk}
   - elongation at maximum load ε_{uk}
   - ratio k $(f_t/f_y)_k$
2. Verification of robustness and durability (Shear Test)
   - Tests which ensures sufficient strength of the spot-welded connections.
3. Verification of enhanced ductility (loop of the bent diagonal)
   - Test which ensures that the tensile strength of the bent diagonals with a bending diameter $< 4\ d_s$ is not less than the nominal yield strength.

2.2.3 Punching shear resistance of slabs with lattice girders FDB II

The assessment of the fitness of the lattice girders for the intended use with regard to the punching shear resistance of slabs in the sense of Essential Requirements 1 and 4 was performed based on the following verifications:

1. Punching shear resistance at interior columns

Full scale tests were carried out to determine the maximum punching shear resistance $v_{Rd,max}$. The punching shear resistance for centric loading is calculated by means of the method described in the Annexes 7 and 8.

2. Punching shear resistance at edge- and corner columns

For all edge and corner columns and asymmetrical systems, the load eccentricity is taken into account by means of a load-increase factor β on the design value of the applied load in accordance with the rules and regulations in EN 1992-1-1. The method using a reduced basic control perimeter according to EN 1992-1-1, 6.4.3 (4) and (5) is not applicable.

3. Punching shear resistance near openings

Openings near to columns in the punching area may decrease the punching shear resistance of the slab. Design shall be carried out according to EN 1992-1-1 6.4.2 (3).

2.2.4 Safety in case of fire

2.2.4.1 Reaction to fire

The lattice girders FDB II are considered to satisfy the requirements for performance class A1 of the characteristic reaction to fire, in accordance with the provisions of EC Decision 96/603/EC (as amended) without the need for testing on the basis of its listing in that decision.

2.2.4.2 Resistance to fire

The assessment of slabs reinforced with the lattice girders FDB II that is required to provide a specific fire resistance class, may be determined for concrete failure by reference to EN 1992-1-2, as it may be assumed that the temperature distribution within the slab is comparable or at least no more unfavourable than in a slab or footing reinforced with stirrups as shear or punching shear reinforcement.

The concrete cover required by EN 1992-1-2 for verifying the resistance shall be measured from the surface of the slab to the outer face of the loops of the diagonals.

3 Evaluation and attestation of conformity and CE marking

3.1 System of attestation of conformity

According to the communication of the European Commission[8] system 1+ of the attestation of conformity applies.

This system of attestation of conformity is defined as follows:

System 1+: Certification of the conformity of the product by an approved certification body on the basis of:

(a) Tasks for the manufacturer:
- (1) factory production control;
- (2) further testing of samples taken at the factory by the manufacturer in accordance with a prescribed test plan;

(b) Tasks for the approved body:
- (3) initial type-testing of the product;
- (4) initial inspection of factory and of factory production control;
- (5) continuous surveillance, assessment and approval of factory production control;
- (6) audit-testing of samples taken at the factory.

Note: Approved bodies are also referred to as "notified bodies".

3.2 Responsibilities

3.2.1 Tasks for the manufacturer

3.2.1.1 Factory production control

The manufacturer shall exercise permanent internal control of production. All the elements, requirements and provisions adopted by the manufacturer shall be documented in a systematic manner in the form of written policies and procedures, including records of results performed. This production control system shall ensure that the product is in conformity with this European technical approval.

The manufacturer may only use initial materials stated in the technical documentation of this European technical approval.

[8] Letter of the European Commission of 4 October 1999 to EOTA

The factory production control shall be in accordance with the control plan which is part of the technical documentation of this European technical approval. The control plan is laid down in the context of the factory production control system operated by the manufacturer and deposited with Deutsches Institut für Bautechnik.[9]

The results of factory production control shall be recorded and evaluated in accordance with the provisions of the control plan.

3.2.1.2 Other tasks for the manufacturer

The manufacturer shall, on the basis of a contract, involve a body which is approved for the tasks referred to in section 3.1 in the field of lattice girders in order to undertake the actions laid down in section 3.2.2. For this purpose, the control plan referred to in sections 3.2.1.1 and 3.2.2 shall be handed over by the manufacturer to the approved body involved.

3.2.2 Tasks for the approved bodies

The approved body shall perform the

- initial type-testing of the product,
- initial inspection of factory and of factory production control,
- continuous surveillance, assessment and approval of factory production control
- audit-testing of samples taken at the factory

in accordance with the provisions laid down in the control plan.

The approved body shall retain the essential points of its actions referred to above and state the results obtained and conclusions drawn in a written report.

The approved certification body involved by the manufacturer shall issue an EC certificate of conformity of the product stating the conformity with the provisions of this European technical approval.

In cases where the provisions of the European technical approval and its control plan are no longer fulfilled the certification body shall withdraw the certificate of conformity and inform Deutsches Institut für Bautechnik without delay.

3.3 CE marking

The CE marking shall be affixed on a small label which is fixed at each reinforcement element (lattice girder) or on the accompanying commercial document. The letters ”CE” shall be followed by the identification number of the approved certification body, where relevant, and be accompanied by the following additional information:

- the name and address of the producer (legal entity responsible for the manufacture),
- the last two digits of the year in which the CE marking was affixed,
- the number of the EC certificate of conformity for the product,
- the number of the European Technical Approval,
- trade name of the lattice-girder
- diameters of the chords
- characteristic value or the yield strength of the chords and diagonals

[9] The control plan is a confidential part of the European technical approval and only handed over to the approved body involved in the procedure of attestation of conformity. See section 3.2.2.

4 Assumptions under which the fitness of the product for the intended use was favourably assessed

4.1 Manufacturing

The European technical approval is issued for the product on the basis of agreed data/information, deposited with Deutsches Institut für Bautechnik, which identifies the product that has been assessed and judged. Changes to the product or production process, which could result in this deposited data/information being incorrect, should be notified to Deutsches Institut für Bautechnik before the changes are introduced. Deutsches Institut für Bautechnik will decide whether or not such changes affect the approval and consequently the validity of the CE marking on the basis of the approval and if so whether further assessment or alterations to the approval shall be necessary.

4.2 Design requirements

The fitness of the lattice girders for the intended use is given under the following condition:

Where no National Regulation for the design of slabs reinforced with lattice girders exists, the design of the lattice girders is based on EN 1992-1-1 and on Annexes 7 and 8 of this ETA for predominantly static load.

The concrete strength class shall not be less than C20/25 and shall not exceed C50/60 according to EN 206-1:2000. The use of self compacting concrete is not covered by this ETA.

The slabs shall have a minimum height of h = 180 mm.

It is assumed that

- The lower reinforcement of the slab is laid over the column according to the indication in EN 1992-1-1.
- The upper reinforcement of the slab is placed continuously over the loaded area.
- 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 bending resistance of the entire slab is verified in accordance with the relevant national provisions. The chords of the lattice-girders FDB II are not taken as effective longitudinal reinforcement (i.e. bending reinforcement).
- 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, the lower two chords of the lattice-girder reinforcement shall be arranged in the prefabricated slab.
- The flexural reinforcement over the column has to be anchored outside the outer control perimeter u_{out}.
- The roughness of surface of the precast concrete element is classified as "smooth" according to EN 1992-1-1, 6.2.5, or rougher
- The concrete cover according to national regulations shall be ensured.

The favourable effect of normal compressive stresses on the maximum punching shear resistance shall not be taken into account for slabs with lattice girders as punching shear reinforcement. If inclined pre-stressed tendons cross the punching zone, a negative influence shall be considered, while a positive influence may be considered.

If the precast elements need to be joined in the punching area, the distance between the prefabricated elements should be at least 40 mm wide and has to be filled with cast in-situ concrete thoroughly to allow for a reliable transmission of compression forces active in the punching area.

The distance between the prefabricated elements and the surface of the column should be in the range of -10 mm up to 40 mm wide and has to be filled in the same manner as stated above. Therefore, the following must be observed for the on-site installation of joints:

- The complete grouting of the compression joint between precast slab and column face must be ensured with an appropriate mortar of the same strength.
- Basically, the centre of gravity of the vertical bars must be located in front of the column face.
- The punching verification of the slab must be made applying the smaller concrete compressive strength of the in-situ concrete or precast slab.
- If the precast slabs are supported by the column, the interface between slab and column must be completely filled with mortar so that the load transfer from the upper floors through the interface is ensured.
- The concrete structure of the precast slab may not be damaged by subsequent chiselling (compensation of building tolerances).
- The concrete must be well compacted in the area of the interface.

The position, the type, the size and the length of the lattice girders shall be indicated on the design drawings. The material of the lattice girders is given additionally on the drawings.

<u>The lattice girders shall be positioned in the following way:</u>

The reinforcement elements shall be positioned such that the chords of the lower end of the lattice-girder are positioned on a parallel line to the surface of the slab and at the same level as the lowest bending reinforcement (s. assumptions before and Annex 2)

The lattice-girders shall be arranged in the multiple of 200 mm as defined in Annex 1 of this ETA. The diagonals are arranged in such a way that they point upwards in the direction of the column centre. The first row of diagonals nearest to the column face shall always be almost perpendicular to the lower chord at a distance of ≤ 0,35 d.

The area up to a distance of 1,125·*d* from the face of the column is called area C (Fig. 2).

The tangential distance of the lattice-girders with effective diagonals shall not exceed 1,7 *d* in a distance of 1,00 *d* from the column face. The maximum distance between the axis of the lattice-girders shall be not greater than 0,75 *d.*

Outside the area C the maximum tangential distance is 3,5·*d*. The number of punching reinforcement elements in the area D (Fig. 2) may be increased compared to the area C to fulfil this requirement. Arrangement of the lattice-girders shall be in accordance with Annexes 2 and 3. Only the bars marked as "effective bars" (s. Annex 6) may be taken into account as contributing to the punching shear reinforcement.

For lattice-girders next to free slab edges and recesses a transverse reinforcement shall be provided to control the transverse tensile forces.

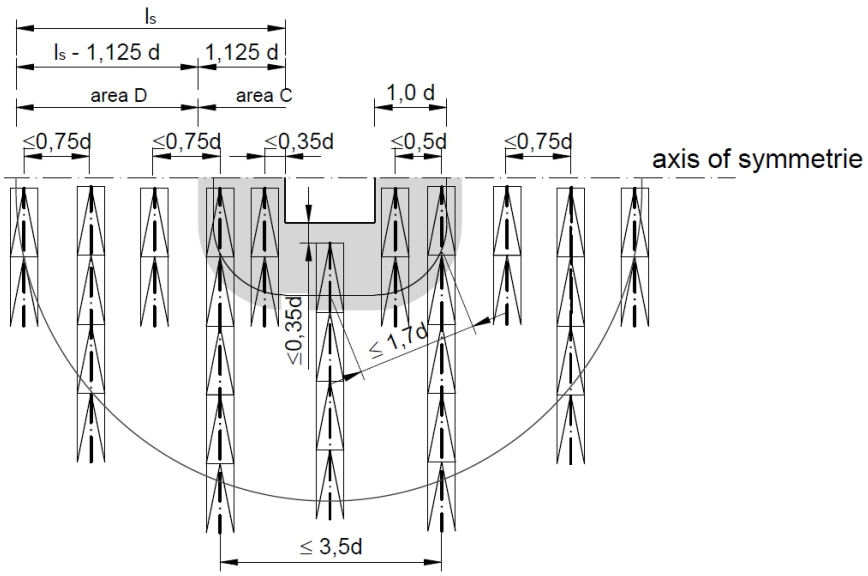


Figure 2: Arrangement and maximum spacings of the lattice-girders FDB II in area C and D for central columns in flat slabs

4.3 Installation

The fitness for use of the lattice girders can only be assumed if the following installation conditions are observed:

The reinforcement elements shall be positioned in such a way that the filigran lattice girders are distributed evenly in the critical punching area.

For the arrangement of the longitudinal reinforcement, the instructions given in clause 4.2 shall be considered. The concrete cover according to national regulations shall be ensured. In a punching area around any column or area of concentrated load, only punching reinforcement lattice-girders FDB II considered within this ETA may be used

The flexural tensile reinforcement (longitudinal reinforcement) may be placed in several layers where the maximum height of all layers shall not exceed 6 cm (s. Annex 2).

The maximum diameter for longitudinal reinforcement bars shall be ∅ = 25 mm.

The overlap of the loop shall be larger than or equal to the sum of the reinforcement diameters of all layers of the longitudinal reinforcement.

The surface of the precast elements (interface between in-situ concrete and precast element) may be untreated and the roughness shall be classified as "smooth" according to EN 1992-1-1, 6.2.5 (2), or rougher.

If precast elements 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 meticulously filled with concrete on-site. The recess between prefabricated element and the surface of the column shall be in the range of -1cm to + 4cm.

5 Indications to the manufacturer

5.1 Packaging, transport and storage

Special considerations shall be given to the transportation of the prefabricated elements to avoid any damage to the lattice girders and the anchorage in the precast concrete slab.

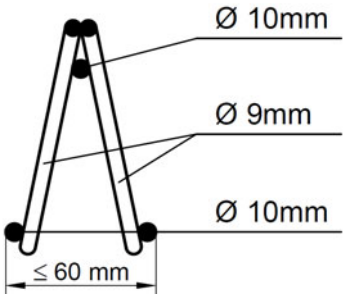
Andreas Kummerow
p. p. Head of Department

beglaubigt:
Rosenbusch

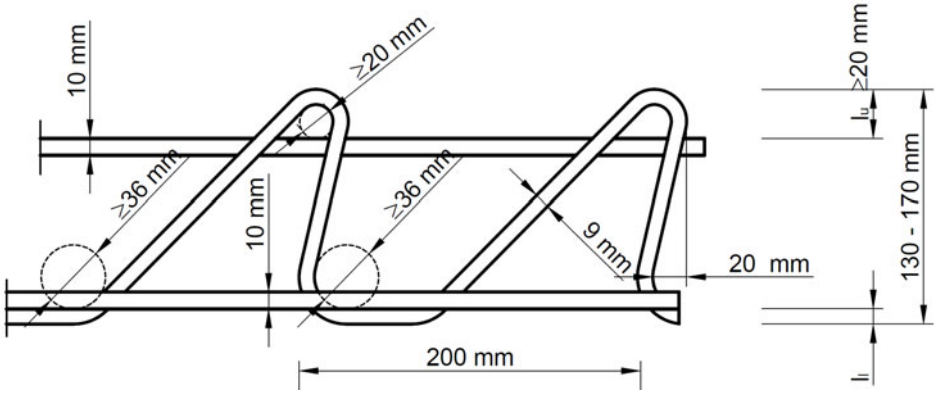
Deutsches Institut für Bautechnik

DIBt

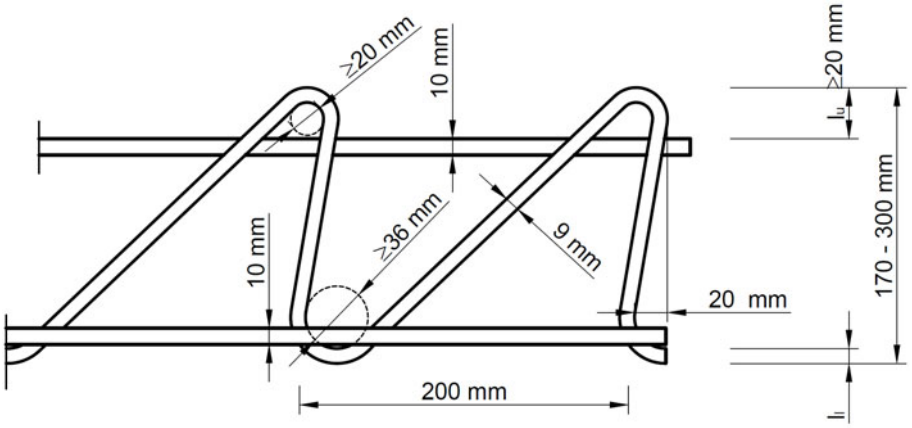
Section of punching shear reinforcement



View of lower punching shear reinforcement



View of higher punching shear reinforcement



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

Filigran punching reinforcement FDB II	Annex 1
Geometry	

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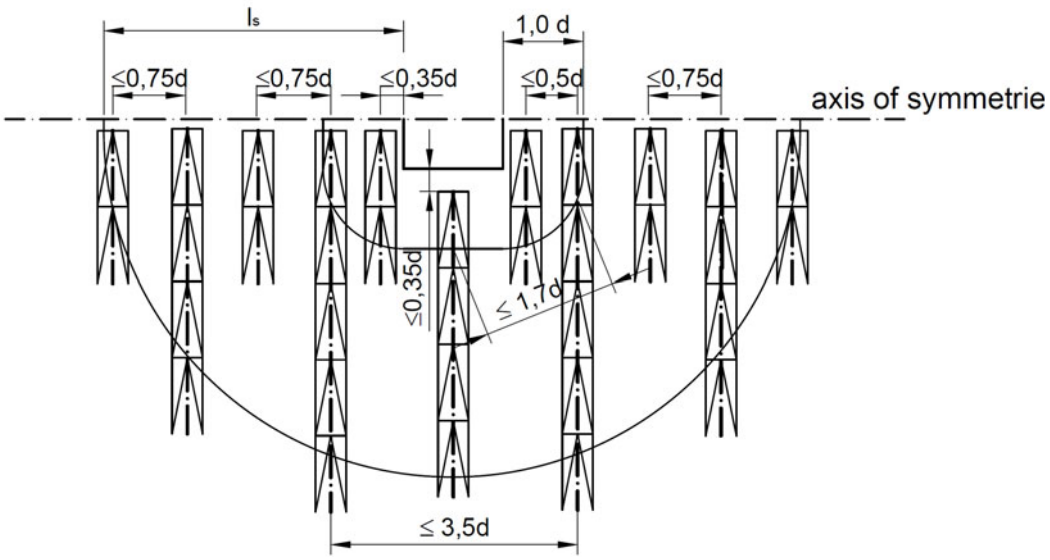
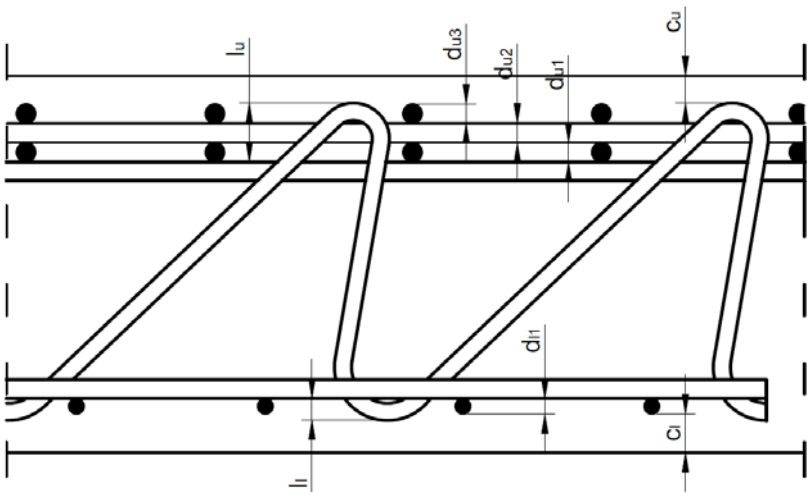
Arrangement and maximum spacing of punching shear reinforcement for inner columns



Arrangement of bending reinforcement

$$l_u \geq \Sigma\, d_{u,i} \leq 60\ \text{mm}$$



$$l_l \geq \Sigma\, d_{l,i}$$

Filigran punching reinforcement FDB II	Annex 2
Arrangement of punching shear reinforcement and bending reinforcement	

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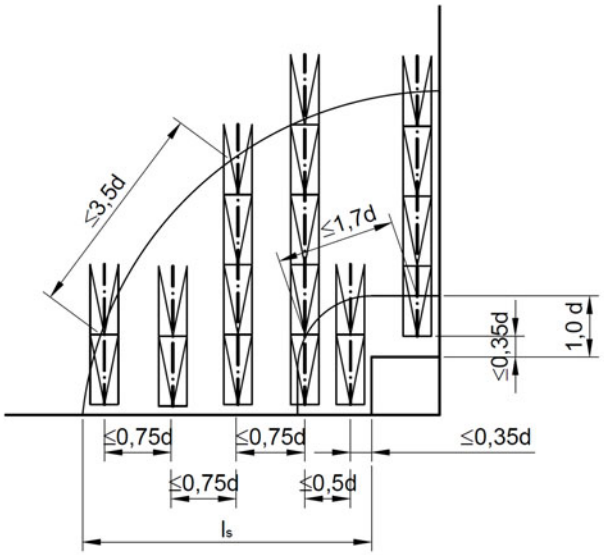
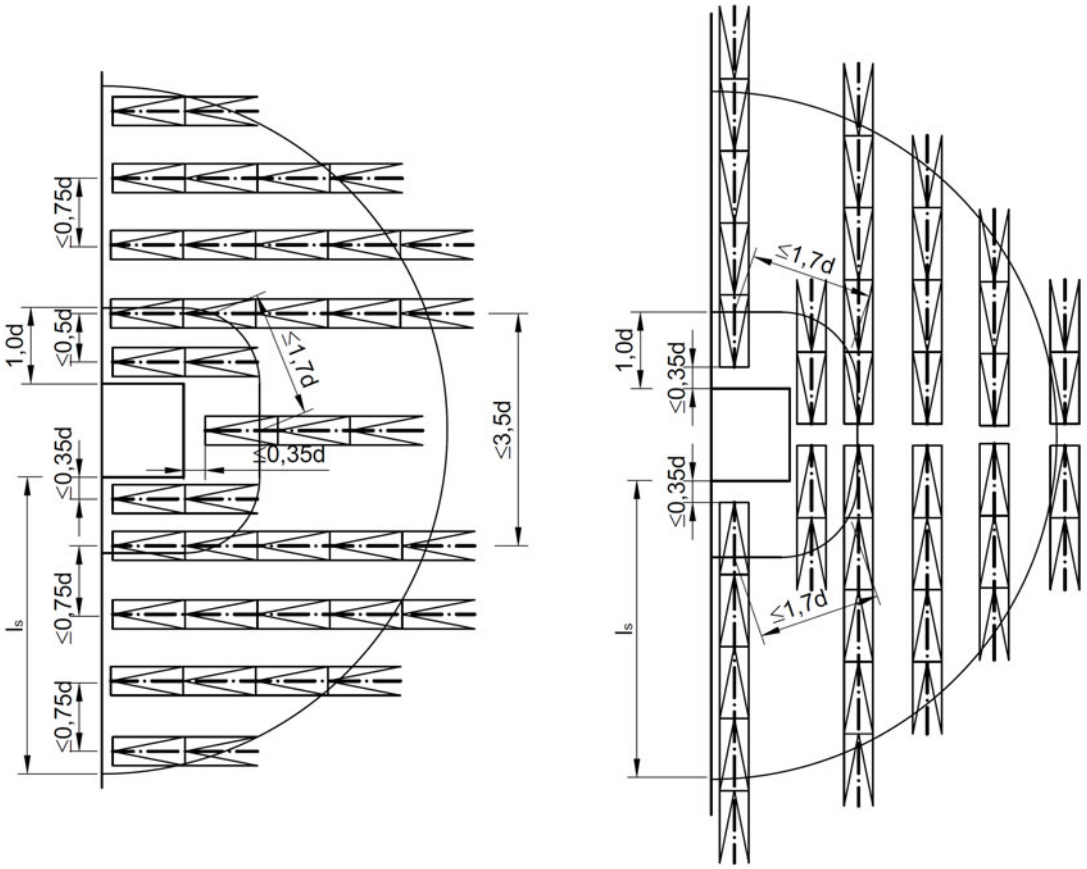
Arrangement and maximum spacing of punching shear reinforcement for corner columns



Arrangement and maximum spacing of punching shear reinforcement for edge columns



Filigran punching reinforcement FDB II	Annex 3
Arrangement of punching shear reinforcement	

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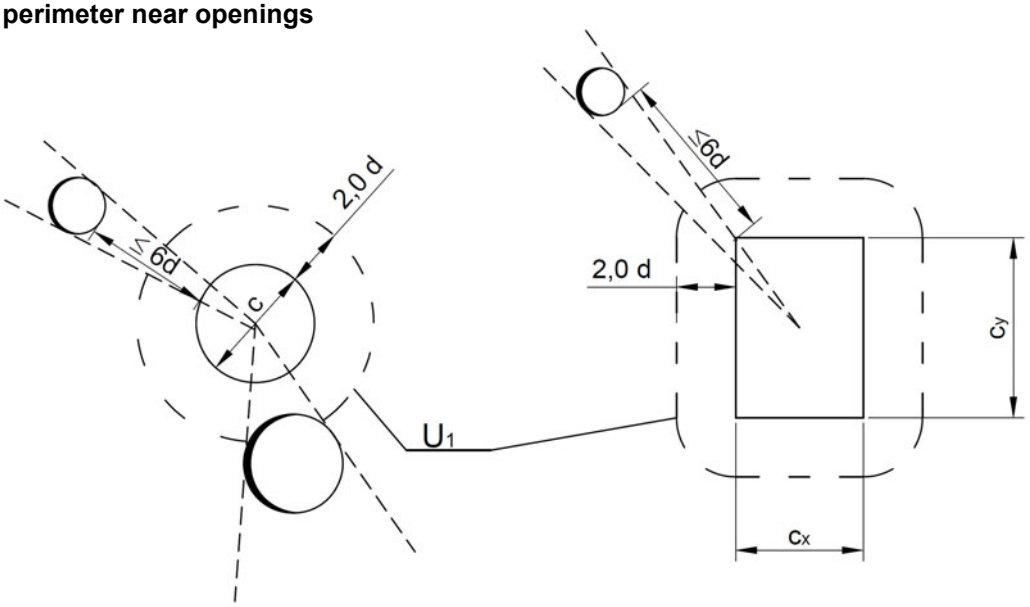
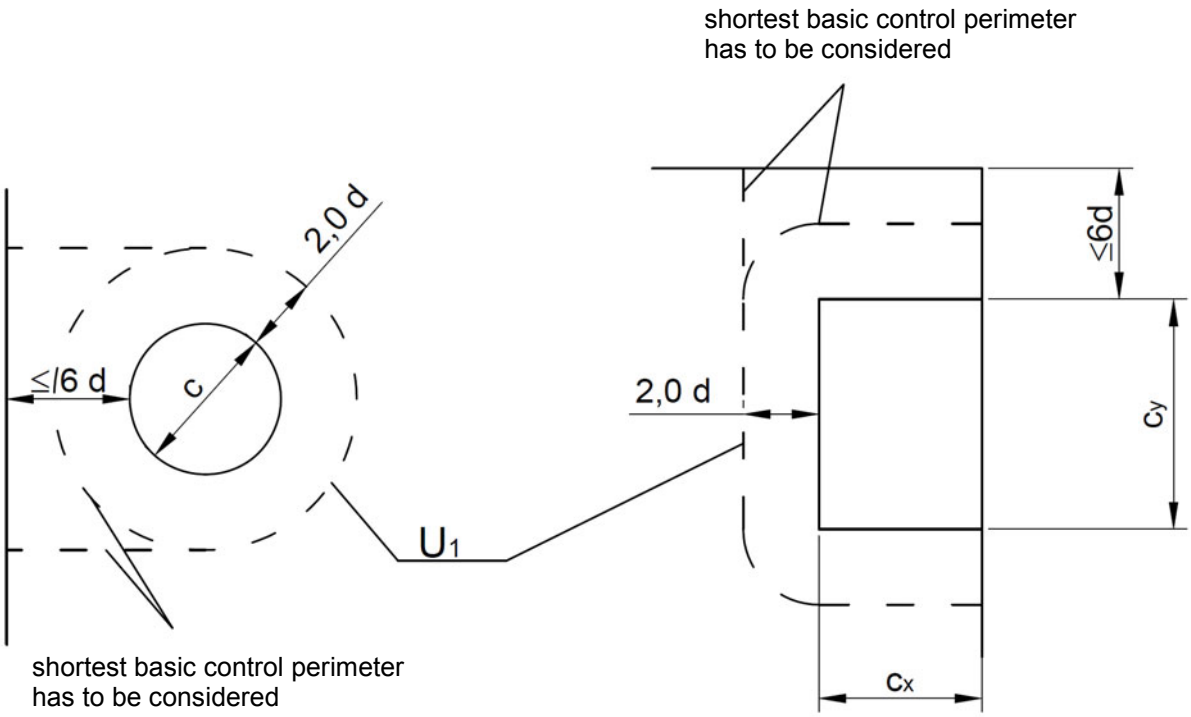
Basic control perimeter near openings

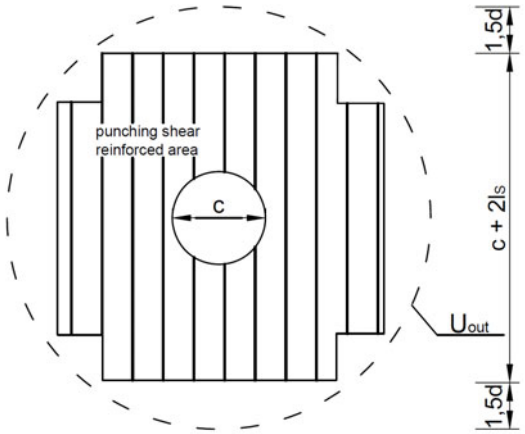


Basic control perimeters for loaded areas close to or at edge or corner



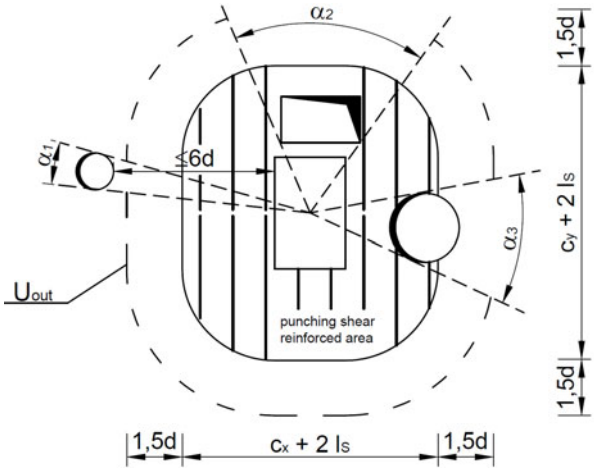
Filigran punching reinforcement FDB II	Annex 4
Control perimeter near edges and openings	

Deutsches Institut für Bautechnik DIBt

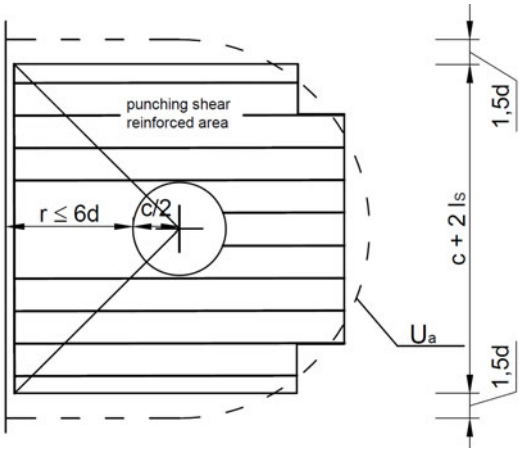


Outer control perimeter

$U_{out} = (c + 2 \bullet l_s + 3{,}0 \bullet d) \bullet \pi$



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 reinforcement FDB II	Annex 5
outer control perimeter near edges and openings	

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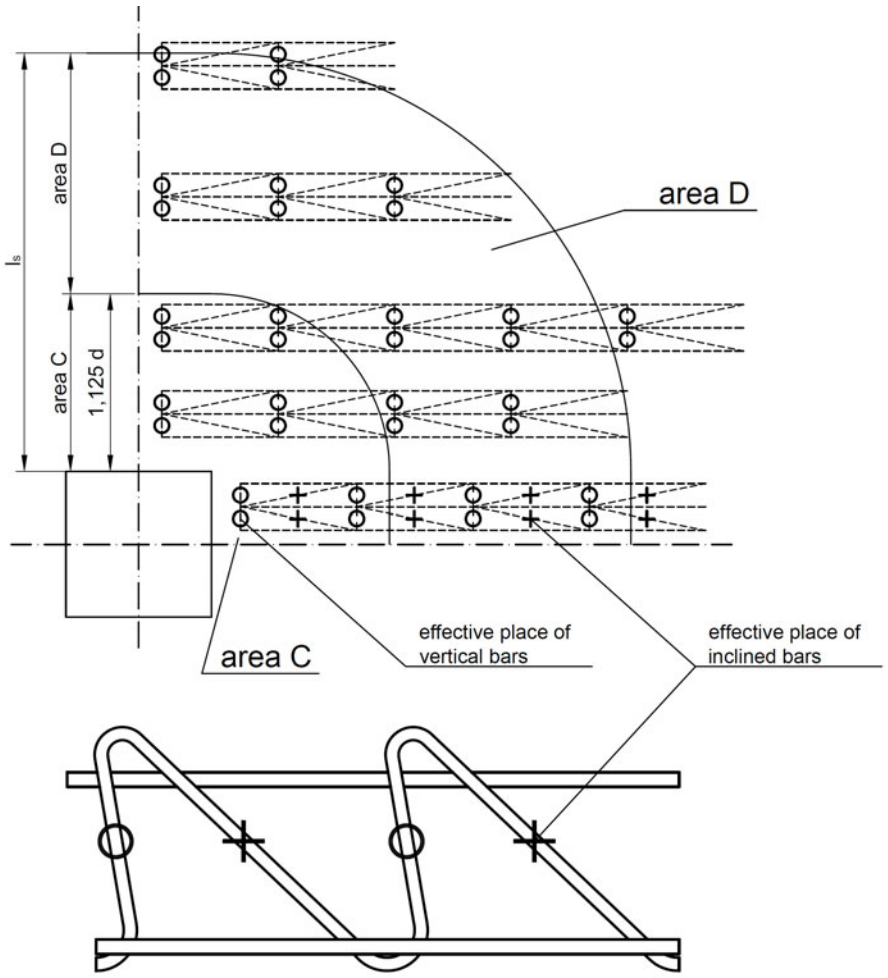
Effective bars and place



Filigran punching reinforcement FDB II	Annex 6
effective bars and place	

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DETERMINATION OF PUNCHING SHEAR RESISTANCE

The verification of the punching shear resistance at ultimate limit state is performed as follows:

The ultimate limit state of punching shear shall be assessed in 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.

To determine the punching shear resistance, an inner critical perimeter u_1 perpendicular to the flat slab surface at a distance 2.0 d (d = effective depth of the slab) around the column and an outer control perimeter u_{out} at a distance of 1.5 d from the outermost row of the punching shear reinforcement are considered.

The critical perimeter may be determined as stated above for columns with a perimeter u_0 less than 12 d and a ratio of the longer column side to the shorter column side not greater than 2.0. 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.

For irregular shaped columns the perimeter u_0 is the shortest length around the loaded area. The critical perimeters u_1 shall be determined according to EN 1992-1-1, 6.4.2.

In a first step, the design value of the shear stress v_{Ed} along the critical control perimeter u_1 is calculated:

$$v_{Ed} = \frac{\beta \cdot V_{Ed}}{u_1 \cdot d} \qquad \text{(A1)}$$

v_{Ed} shear stress calculated along the critical perimeter

β coefficient taking into account the effects of load eccentricity.

V_{Ed} design value of the applied shear force

u_1 perimeter of the critical section with a distance of 2.0 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 %, approximate values for β may be used:

interior columns	β = 1.10	
edge columns	β = 1.40	
corner columns	β = 1.50	(A2)
corner of wall	β = 1.20	
end of wall	β = 1.35	

Alternatively, the more detailed calculation according to EN 1992-1-1 (6.39) can be used to determine the factor β, but the method with the reduced basic control perimeter is not applicable.

In flat slabs, where the total shear force is greater than the resistance of the slab without punching reinforcement according to equation (A3) punching shear reinforcement is necessary:

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} \geq (v_{min}) \qquad \text{(A3)}$$

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

γ_C partial safety factor for concrete ($\gamma_C = 1.5$)

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

$$k = 1 + \sqrt{\frac{200}{d}} \leq 2.0$$

ρ_l mean reinforcement ratio of the y- and z-directions

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

f_{cd} design value of cylinder concrete strength

f_{yd} design value of yield stress of the reinforcing steel

v_{min} $(0.0525/\gamma_C) \cdot k^{3/2} \cdot f_{ck}^{1/2}$

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

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

The effect of normal compressive stresses on the punching shear resistance of the slab may not be included. If inclined pre-stressed tendons influence the punching shear resistance negatively, the effect shall be included with the maximum value of the negative influence when dimensioning the lattice girders.

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

$$u_{out} = \frac{\beta_{red} \cdot V_{Ed}}{v_{Rd,c} \cdot d} \qquad \text{(A4)}$$

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 reinforcement according to expression (A3),

$C_{Rd,c}$ can be taken from the national guidelines for members not requiring design shear reinforcement (EN 1992-1-1, 6.2.2(1)), the recommended value is $0.15/\gamma_C$

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For the calculation of the shear resistance along the outer perimeter (u_{out}) of edge and corner columns, a reduced factor β_{red} in combination with $C_{Rd,c} = 0.15/\gamma_C$ for the verification in the outer perimeter can be used (s. also equation (A4)):

$\beta_{red} = \kappa_\beta \cdot \beta \geq 1.10$ (A5)

edge columns	$\kappa_\beta = \frac{1}{1.2 + \beta/20 \cdot l_s/d}$
corner columns	$\kappa_\beta = \frac{1}{1.2 + \beta/15 \cdot l_s/d}$
corner of wall	$\kappa_\beta = 1.0$
end of wall	$\kappa_\beta = 1.0$

l_s: distance between the face of the column and the outermost effective bar

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PUNCHING DESIGN OF FLAT SLABS

It has to be distinguished between area C (adjacent to the column) and the area D (further than 1.125·*d* from the column face). The lattice girders in the area C shall be dimensioned according to the following equation:

$$\beta \cdot V_{Ed} \le V_{Rd,sy} = \frac{f_{yk}}{\gamma_s \cdot \eta} \cdot \Sigma(A_{sy} \cdot \sin\alpha_i) \qquad \text{(A7)}$$

with $\eta = 1{,}0$ for $V_{ED} / V_{Rd,c} = 1{,}8$

$\eta = 1{,}5$ for $V_{ED} / V_{Rd,c} = 2{,}09$

intermediate values η may be interpolated

A_{sy}: cross section of each effective bars as defined in Annex 6 of this ETA

α_i respective angle of deviation from the horizontal direction (direction of the chord) of each effective diagonal related to A_{sy}

f_{yk}: characteristic value of yield stress of the lattice-girder diagonals

γ_s: safety factor for steel (recommended value is $\gamma_s = 1{,}15$)

In area D, the required cross-section of the lattice girders per circular ring is dimensioned as follows:

$$0.5 \cdot \beta \cdot V_{Ed} \cdot (s/(0.75 \cdot d)) \le V_{Rd,sy}$$

Here, $s \le 0.75 \cdot d$ is the width of the virtual circular ring around area C.

The maximum punching shear resistance in the critical perimeter u_1 is defined as a multiple value of the resistance of the slab without shear reinforcement according to expression (A8):

$$v_{Rd,max} = 2.09 \cdot v_{Rd,c} \qquad \text{(A8)}$$

$v_{Rd,c}$ is the calculated design value of the punching shear resistance according to (A3), taking into account the relevant partial safety factors for material properties.

Filigran punching reinforcement FDB II	Annex 8
Punching design of flat slabs	