European Technical Assessment

ETA-19/0310 of 28 May 2019

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	CLIXS® von BETOMAX®system
Product family to which the construction product belongs	Punching shear reinforcement with L- or Z-shaped metal sheets
Manufacturer	BETOMAX systems GmbH & Co. KG Dyckhofstraße 1 41460 Neuss DEUTSCHLAND
Manufacturing plant	Werk 1 Werk 2 Werk 3
This European Technical Assessment contains	30 pages including 3 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 160057-00-0301

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Specific Part

1 Technical description of the product

The punching shear reinforcement system with metal sheets consists of cut, punched and bent steel sheets according to EN 10025-2:2004, with or without additional stirrups made of reinforcing steel B500A or B500B.

A distinction is made between the punching shear reinforcement system with L-sheets and the punching shear reinforcement system with Z-sheets. The punching shear reinforcement system with L-sheets is two-parted consisting of metal sheets with either one or two specially bent reinforcing steel stirrups, which are suspended in the metal sheets (two-part system). The L-sheets are manufactured in the horizontal slot type (letter "H" in the type designation) and diagonal slot type (letter "S" in the type designation). The punching shear reinforcement system with Z-sheets consists of single-part metal sheets without stirrups made of reinforcing steel (one-part metal sheets).

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	$k_{pu,sl}$ = 2,05 for L-shaped metal sheets $k_{pu,sl}$ = 1,71 for Z-shaped metal sheets $k_{pu,fo}$ = 1,40
Increasing factor for maximum interface shear resistance in composite slabs	$k_{max,i}$ = 0,5

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. 160057-00-0301 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 28 May 2019 by Deutsches Institut für Bautechnik

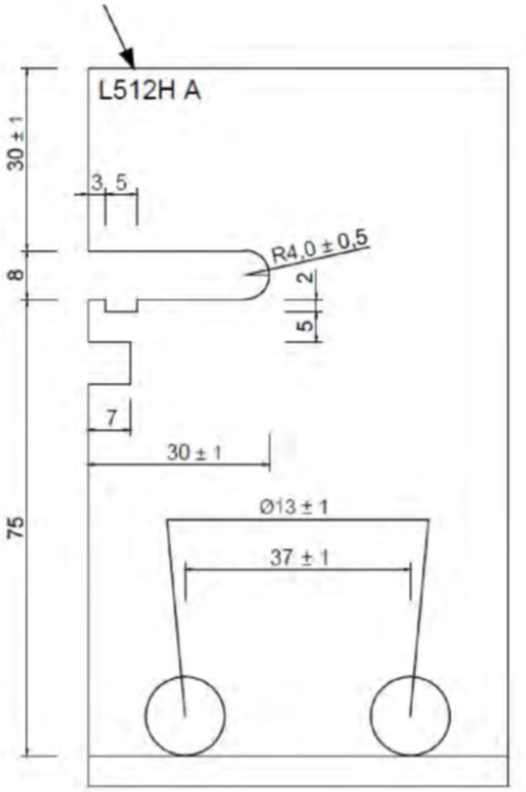
Dr.-Ing. Lars Eckfeldt
p. p. Head of Department

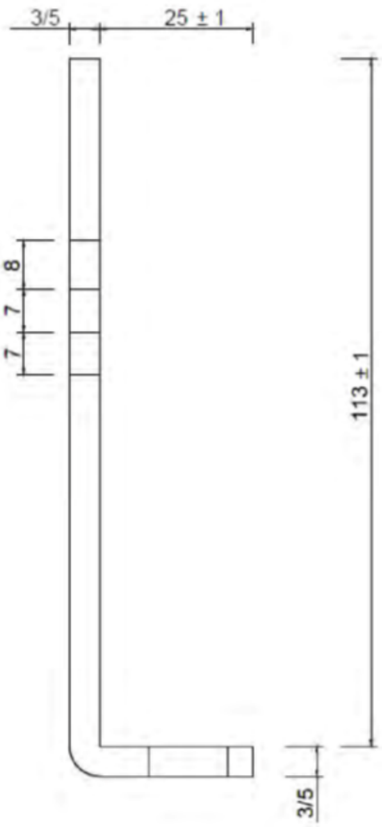
beglaubigt:
Schüler

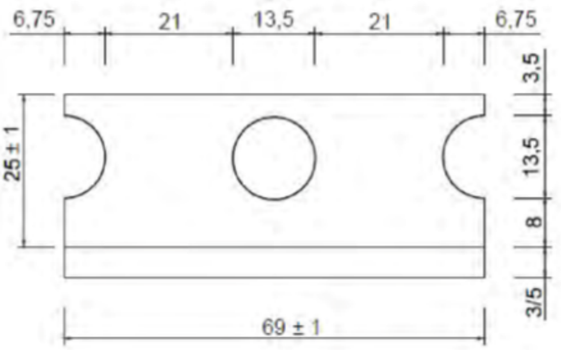
L-SHEET WITH HORIZONTAL SLOT MADE OF STEEL ACCORDING TO DATA SHEET 1)

Dimensions, Clip

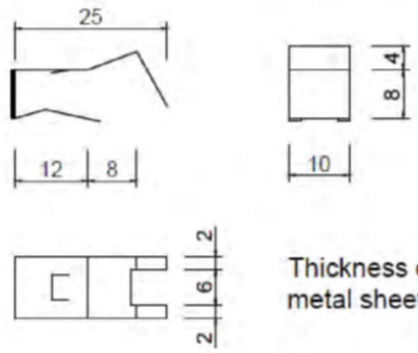
Labeling:
(sheet type – sheet thickness – Ø reinforcement – slot type – manufacturing plant abbreviation)







Steel clip according to data sheet 1)



Thickness of metal sheet t = 0,5mm

Dimensions without tolerances

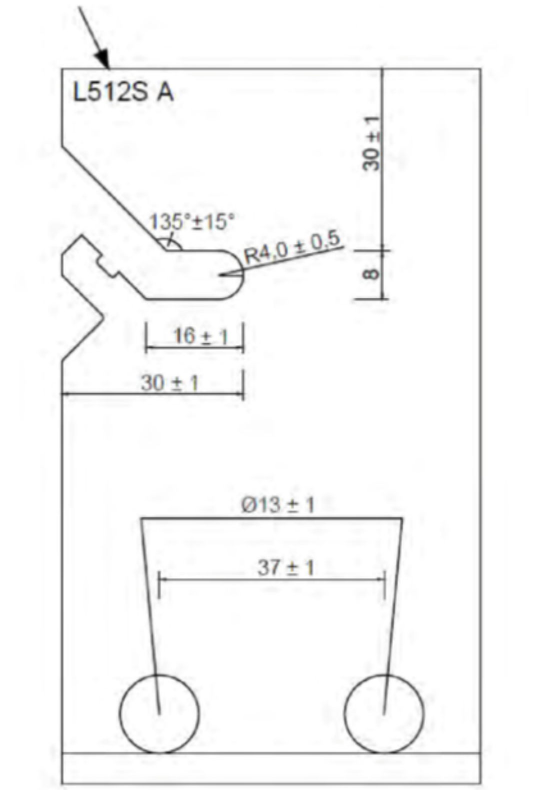
1) The data sheet in stored at Deutsches Institut für Bautechnik (DIBt) and the external monitoring bodies.

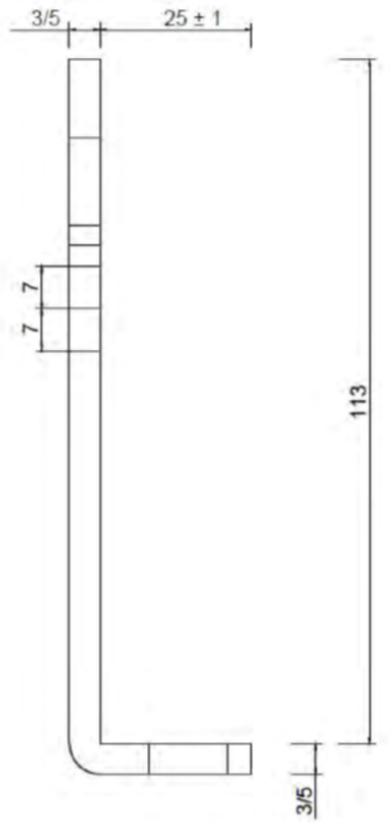
CLIXS® punching shear reinforcement	Annex A1
L-sheet with horizontal slot made of steel	

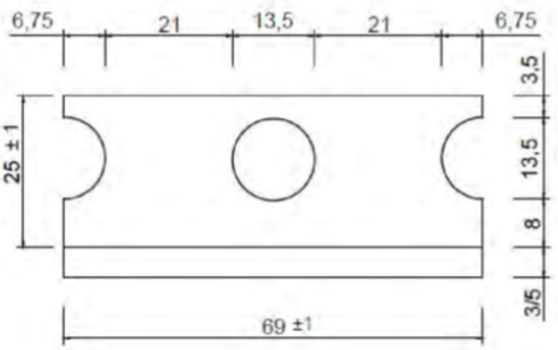
L-SHEET WITH DIAGONAL SLOT MADE OF STEEL ACCORDING TO DATA SHEET [1)]

Dimensions, Clip

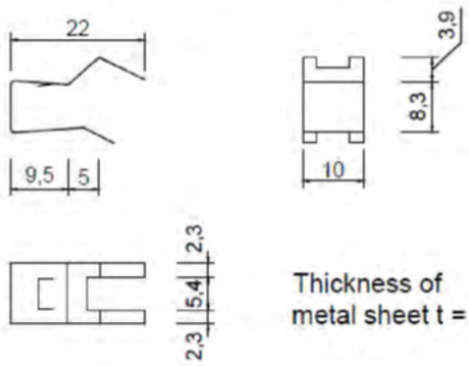
Labeling:
(sheet type – sheet thickness – Ø reinforcement – slot type – manufacturing plant abbreviation)







Steel clip according to data sheet [1)]



Thickness of metal sheet t = 0,5mm

Dimensions without tolerances

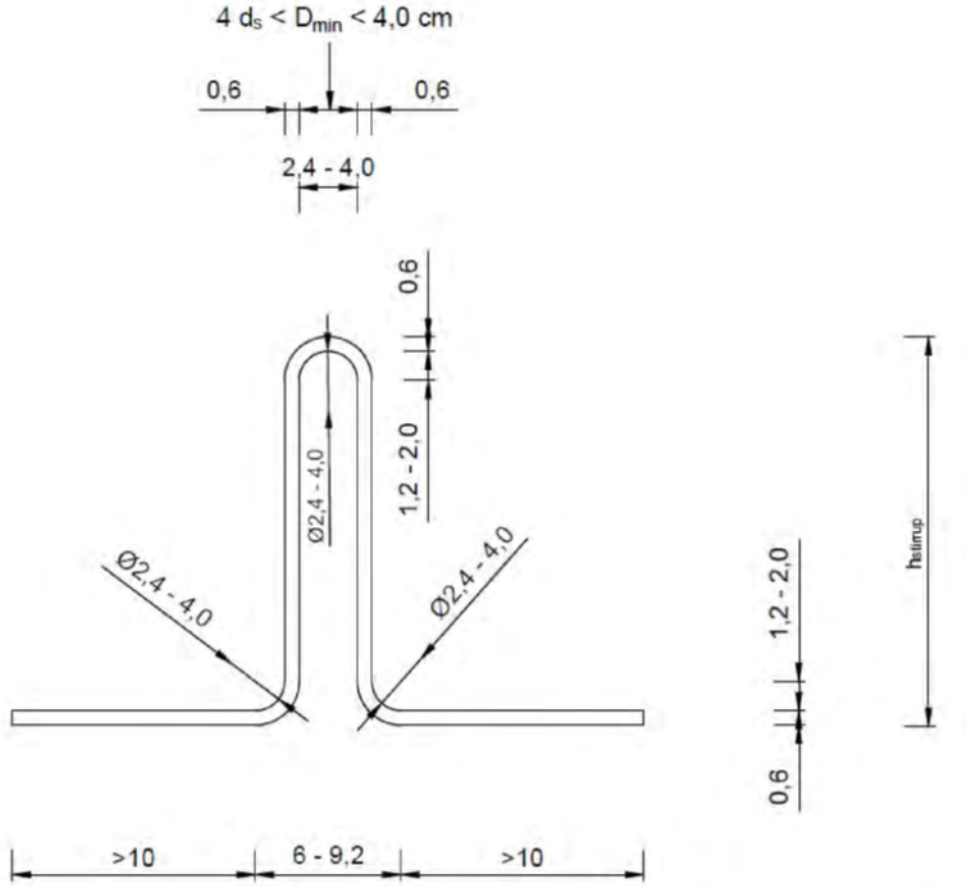
1) The data sheet in stored at Deutsches Institut für Bautechnik (DIBt) and the external monitoring bodies.

CLIXS® punching shear reinforcement	Annex A2
L-sheet with diagonal slot made of steel	

Deutsches Institut für Bautechnik DIBt

STIRRUP Ø 6 mm, OPEN AT THE TOP
B500 A / B500 B / B500 A NR / B500 B NR

Dimensions



All dimensions in [cm]

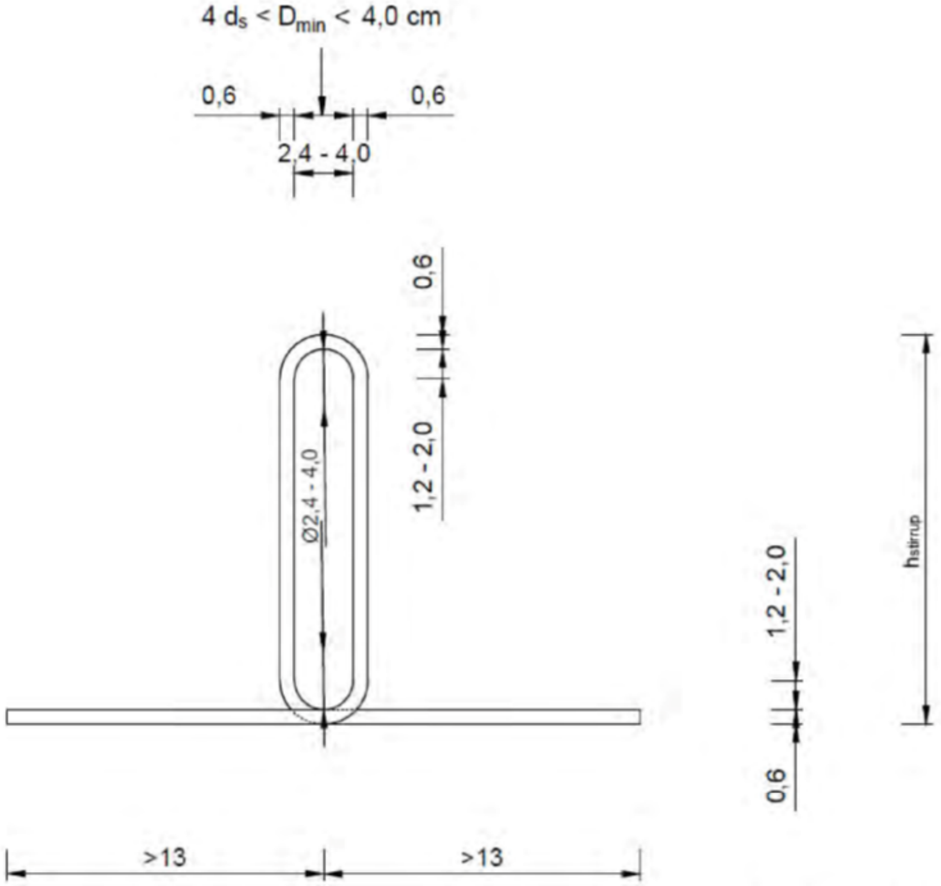
$h_{stirrup}$ depending on the slab thickness h and the concrete cover of the sheet at bottom (c_{bottom}) and the top layer of the flexural tensile reinforcement at top (c_{top}). For c_{bottom} and c_{top} see also Annex B2, B3.

slab thickness $h < 24$ cm: $h_{stirrup} = (h - c_{top} - c_{bottom} - 7{,}5) \cdot 1{,}06$
slab thickness $h \geq 24$ cm: $h_{stirrup} = h - c_{top} - c_{bottom} - 6{,}5$
h and c in [cm]

CLIXS® punching shear reinforcement	Annex A3
Stirrup Ø 6 mm, open at the top	

STIRRUP Ø 6 mm, CLOSED AT THE TOP
B500 A / B500 B / B500 A NR / B500 B NR

Dimensions



All dimensions in [cm]

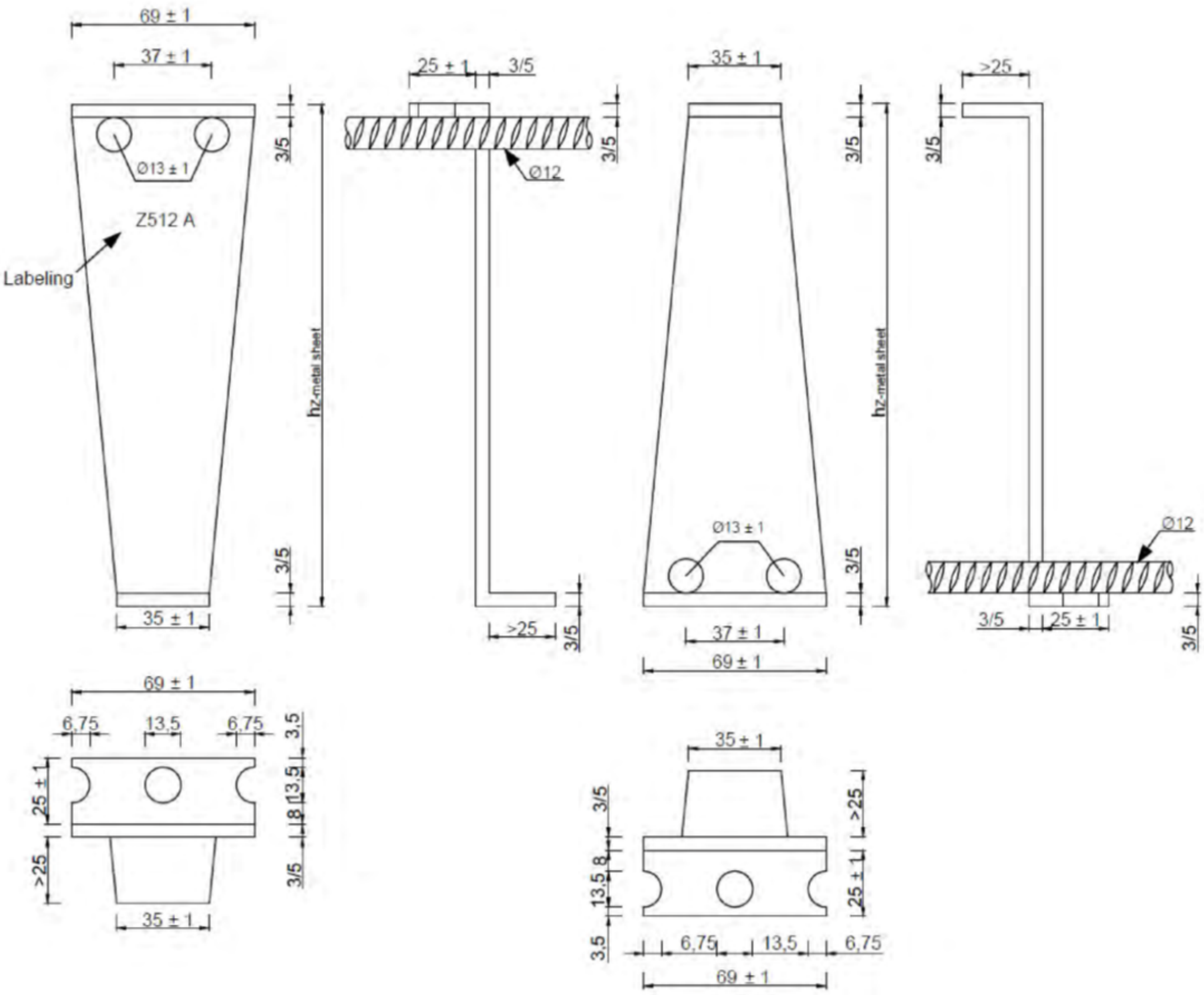
$h_{stirrup}$ depending on the slab thickness h and the concrete cover of the sheet at bottom (c_{bottom}) and the top layer of the flexural tensile reinforcement at top (c_{top}). For c_{bottom} and c_{top} see also Annex B2, B3.

slab thickness h < 24 cm: $h_{stirrup} = (h - c_{top} - c_{bottom} - 7{,}5) \cdot 1{,}06$
slab thickness h ≥ 24 cm: $h_{stirrup} = h - c_{top} - c_{bottom} - 6{,}5$
h and c in [cm]

CLIXS® punching shear reinforcement	Annex A4
Stirrup Ø 6 mm, closed at the top	

Z-SHEET MADE OF STEEL ACCORDING TO DATA SHEET [1)]

Dimensions, installation



top-installation

bottom-installation

$h_{Z\text{-metal sheet}}$ depending on slab thickness

1) The data sheet in stored at Deutsches Institut für Bautechnik (DIBt) and the external monitoring bodies.

CLIXS® punching shear reinforcement	Annex A5
Z-sheet made of steel	

SPECIFICATION OF THE INTENDED USE

General

- use for increase of punching shear resistance of flat slabs or footings and ground slabs under static and quasi-static loading
- design according to EN 1992-1-1:2004/A1:2014, section 6.4 and Annex C.1 and Annex C.2
- The reinforcement required for bending must comply with EN 1992-1-1, 9.3.1
- The free edges shall be enclosed in accordance with EN 1992-1-1, 9.3.1.4
- flat slabs or footings and ground slabs made of reinforced normal weight concrete of strength class C20/25 to C50/60 according to EN 206:2013+A1:2016
- flat slabs or footings and ground slabs with a height h of
  L-shaped metal sheets with one specially bent stirrup — 18 cm ≤ h ≤ 40 cm
  L-shaped metal sheets with two specially bent stirrups — 18 cm ≤ h ≤ 110 cm
  Z-shaped metal sheets — 18 cm ≤ h ≤ 110 cm
- to ensure anchoring and to secure the metal sheets during assembly reinforcing steel bars of diameter 12 mm and the following characteristics are guided through holes provided in the metal sheets:
  yield strength: $f_{yk} \geq 500$ MPa
  ratio of tensile strength over yield strength: $(f_t/f_y)_k \geq 1{,}05$
  elongation: $\varepsilon_{uk} \geq 2{,}5\%$
- the reinforcing steel extends at least 20 cm beyond the metal sheets or covers the adjacent reinforcing steel of the flexural tensile reinforcement
- reinforcement elements are distributed uniformly, circularly or orthogonally in the punching area around the column or high concentrated load
- metal sheets of the same type, the same dimensions and the same number of stirrups are arranged in the punching area - when using linear elements in prefabricated slabs, metal sheets with a smaller thickness and one stirrup are also used at distances > 2,0 d
- the Z-shaped metal sheets and the two-part L-shaped metal sheets with mounted stirrups enclose or extend to the outermost upper and outermost lower reinforcement layer
- reinforcement elements positioned such that the concrete cover complies with the provisions according to EN 1992-1-1
- reinforcement elements positioned such that the minimum and maximum distances between the metal sheets around a column or area of high concentrated load comply with the provisions according to Annex B5

Arrangement and distances of the punching shear reinforcement elements

- The reinforcement elements are distributed uniformly (circular or orthogonal) within the punching area.
- The distances of the elements in the direction of the radii a (radial direction) from the loaded area (column) do not exceed the following values:

  The distance of a reinforcement element to the previous or next perimeter shall not exceed 0,75 d. The distance of the first row of the reinforcement elements from the column face should be approximately 0,375 d and must not exceed 0,5 d.
- The reinforcement elements can be assigned to the respective perimeter in the distance 0,375 d inwards and outwards.
- The distances a_t of the reinforcement elements one beside the other in the direction of the course of the perimeters (tangential direction) must not exceed the following values:

  $a_t \leq \max(140\text{ mm}; 0{,}6 \cdot d \cdot i)$; i = 1

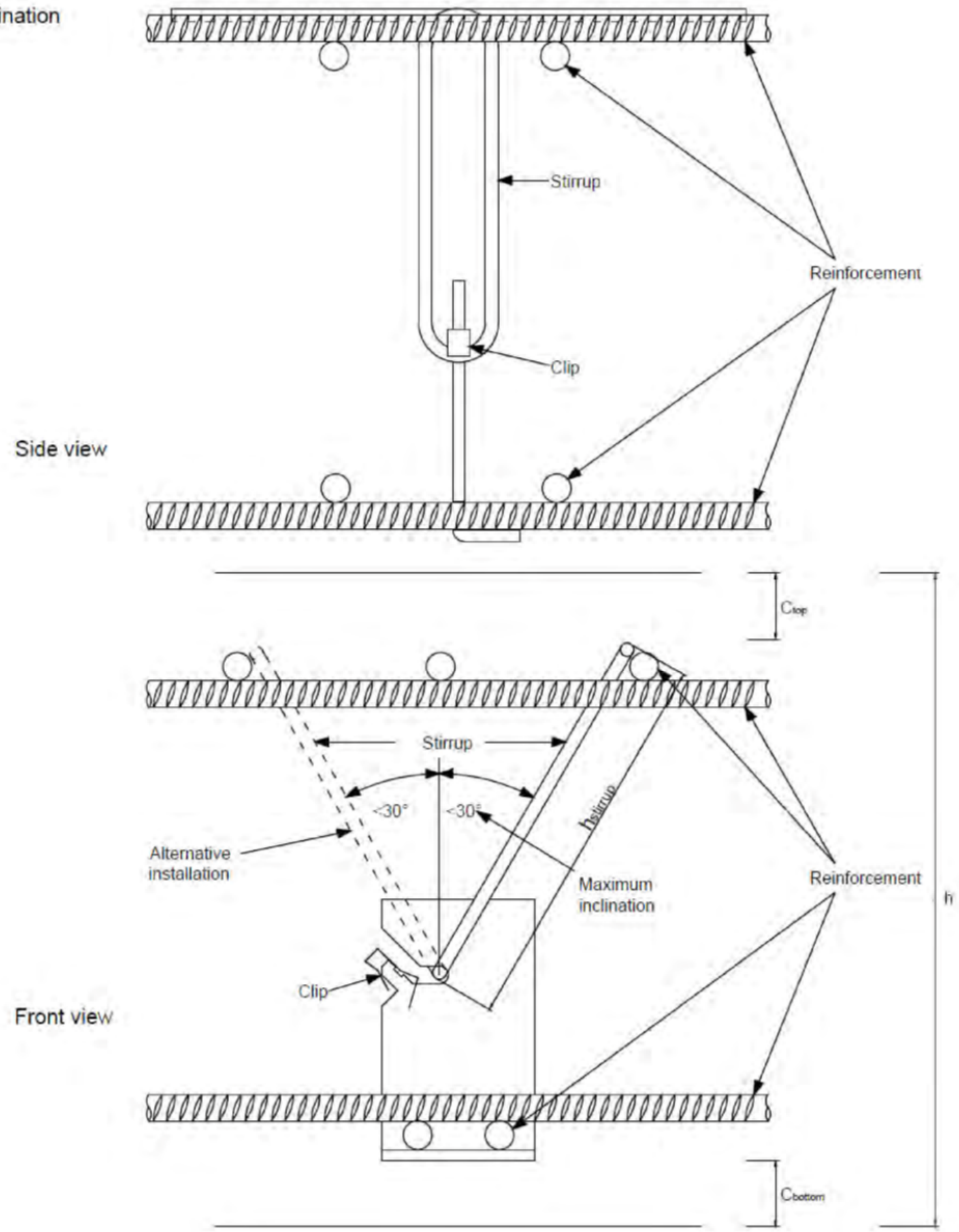
  $a_t \leq 0{,}6 \cdot d \cdot i$; $i \geq 2$

  with i = number of perimeter
- If the required punching shear reinforcement elements cannot be arranged side by side on a perimeter, they must be installed at regular intervals within the area between the perimeter considered and the next perimeter which is located with respect to the spacing rules.

L-SHEET WITH DIAGONAL SLOT, WITH A CLOSED STIRRUP

Arrangement of the stirrup shank parallel to the top layer of the upper reinforcement

Installation, inclination



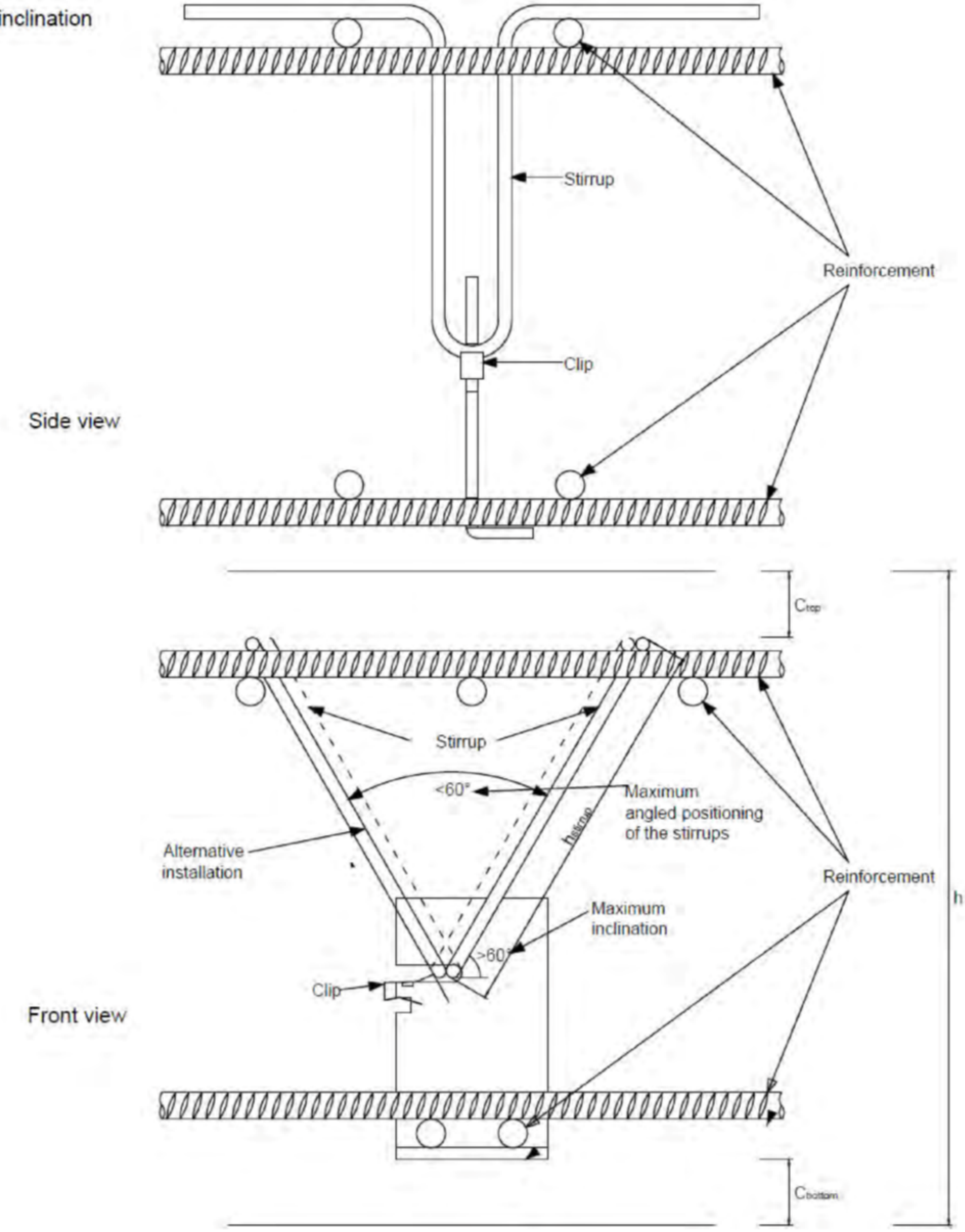
$h_{stirrup}$ depending on the slab thickness and the concrete cover, see Annex A3/A4.

CLIXS® punching shear reinforcement	Annex B2
L-sheet with diagonal slot, with a closed stirrup	

L-SHEET WITH HORIZONTAL SLOT, WITH TWO STIRRUPS OPEN AT THE TOP

Arrangement of the stirrup shank perpendicular to the top layer of the upper reinforcement

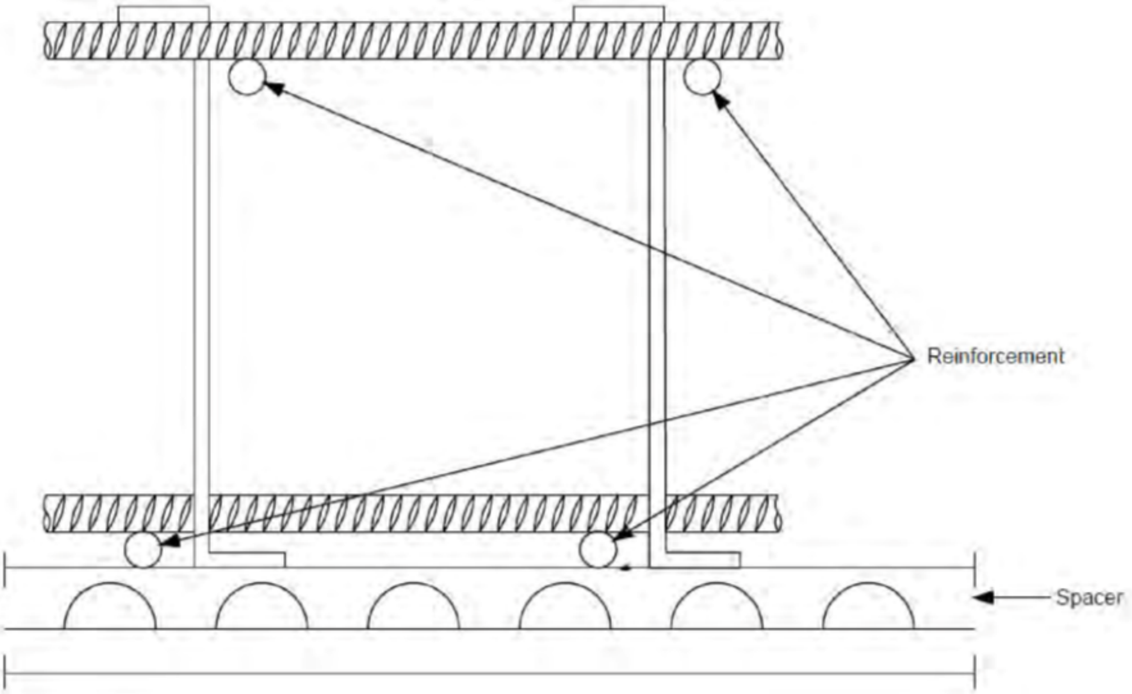
Installation, inclination



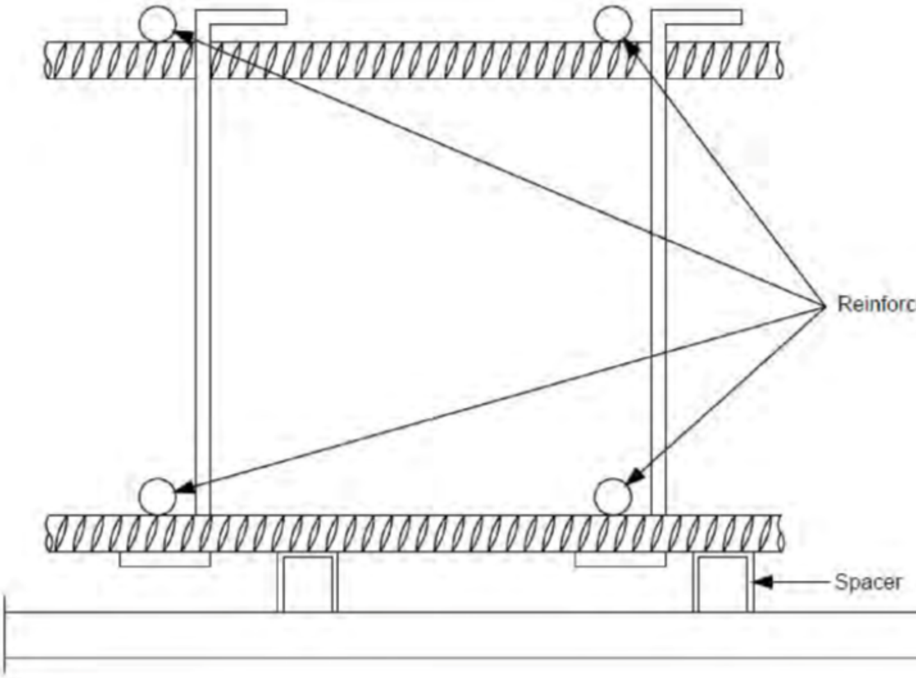
$h_{stirrup}$ depending on the slab thickness and the concrete cover, see Annex A3/A4.

CLIXS® punching shear reinforcement	Annex B3
L-sheet with horizontal slot, with two stirrups open at the top	

Z-SHEET – INSTALLATION



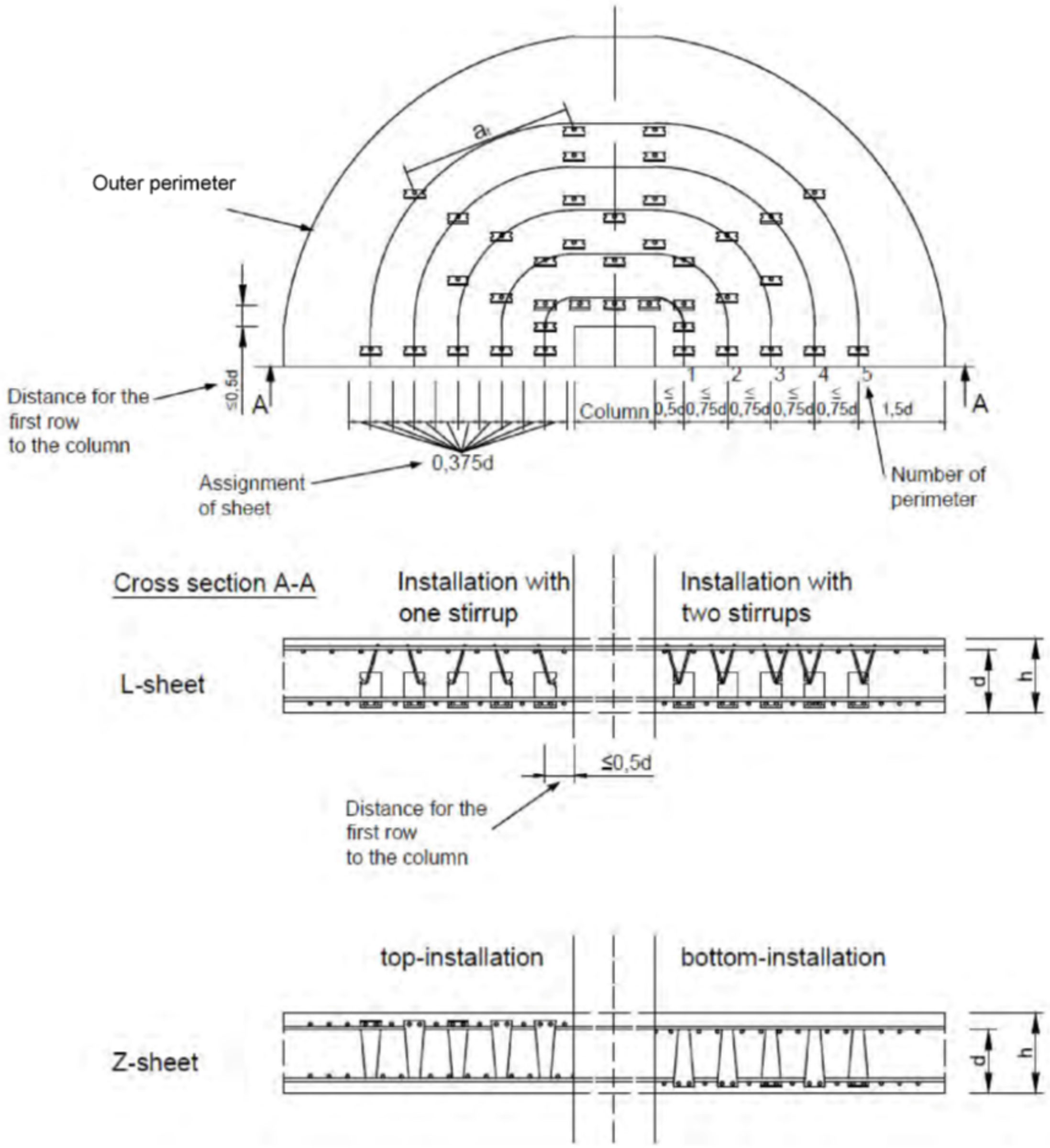
top-installation



bottom-installation

CLIXS® punching shear reinforcement	Annex B4
Z-sheet – Installation	

PRINCIPLE ARRANGEMENT OF PUNCHING SHEAR REINFORCEMENT WITH L- OR Z-SHEETS



Tangential distances:

$a_t \leq \max(140\text{ mm}; 0{,}6\cdot d\cdot i)$; i = 1

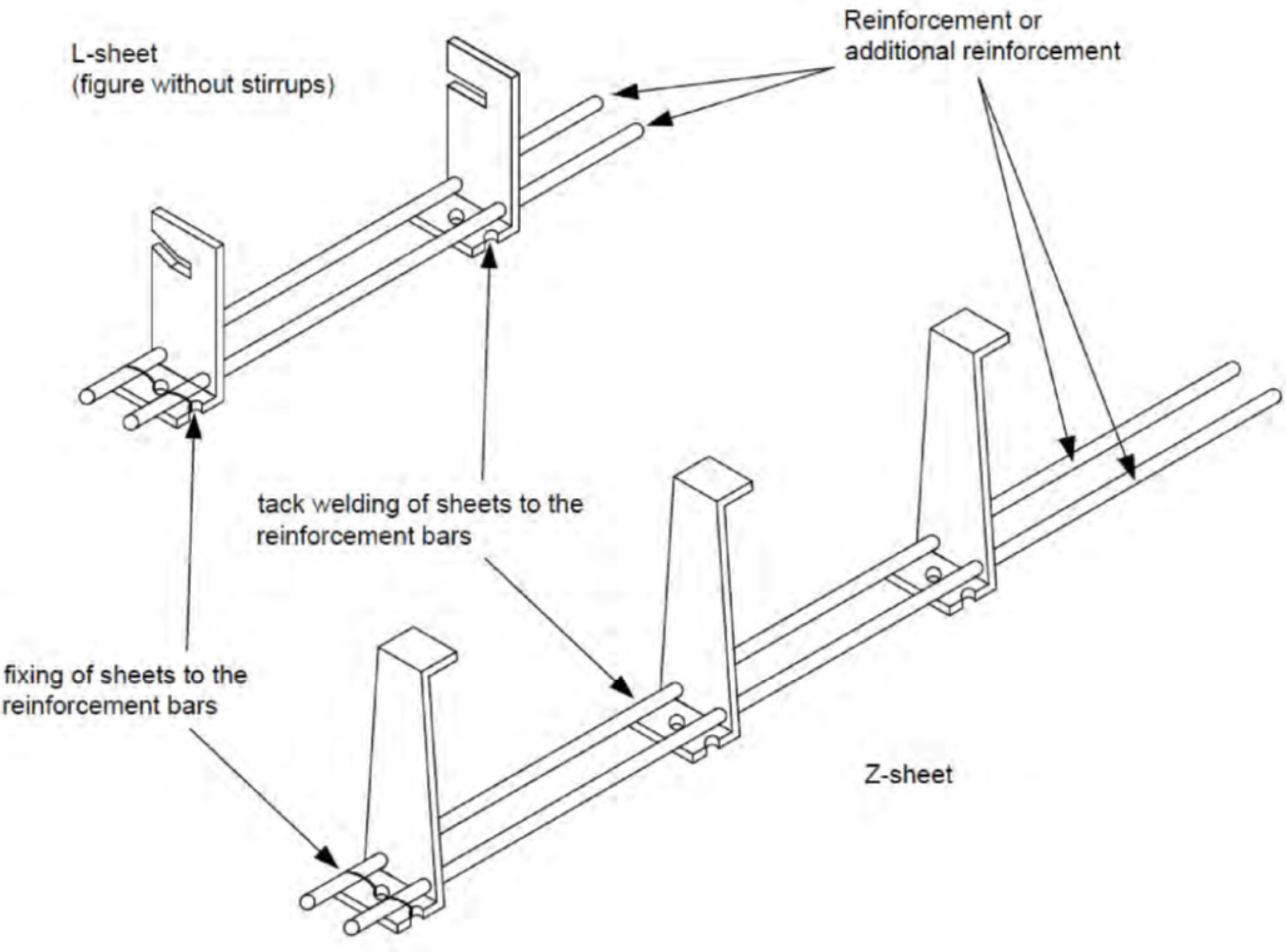
$a_t \leq 0{,}6\cdot d\cdot i$; i ≥ 2

i = number of perimeter

Arrangement of the sheets:
Each perimeter contains the sheets with spacing of 0,375 d inside and a spacing of 0,375 d outside.

CLIXS® punching shear reinforcement	Annex B5
Principal arrangement of punching shear reinforcement with L- or Z-sheets	

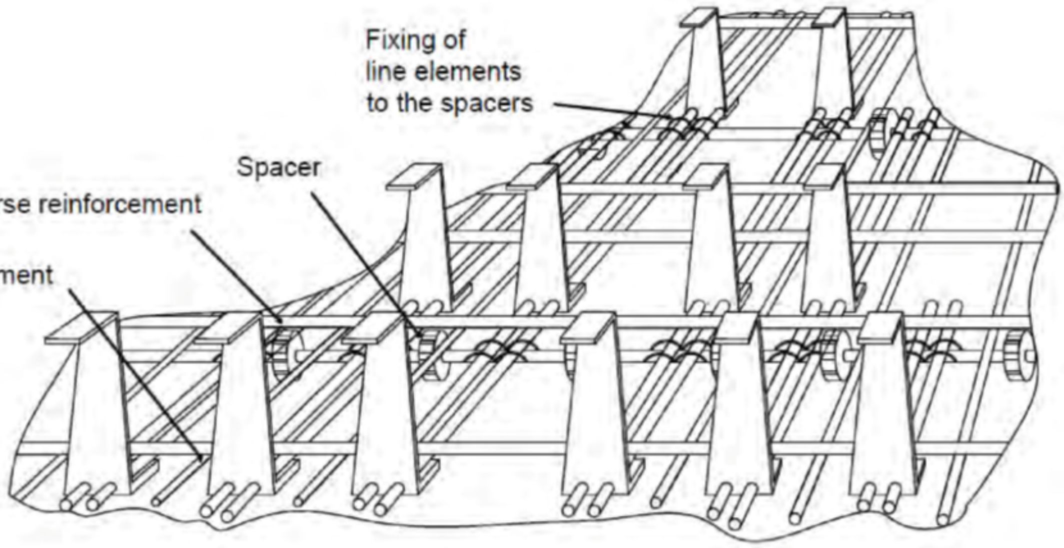
LINE ELEMENTS



CLIXS® punching shear reinforcement	Annex B6
Line elements	

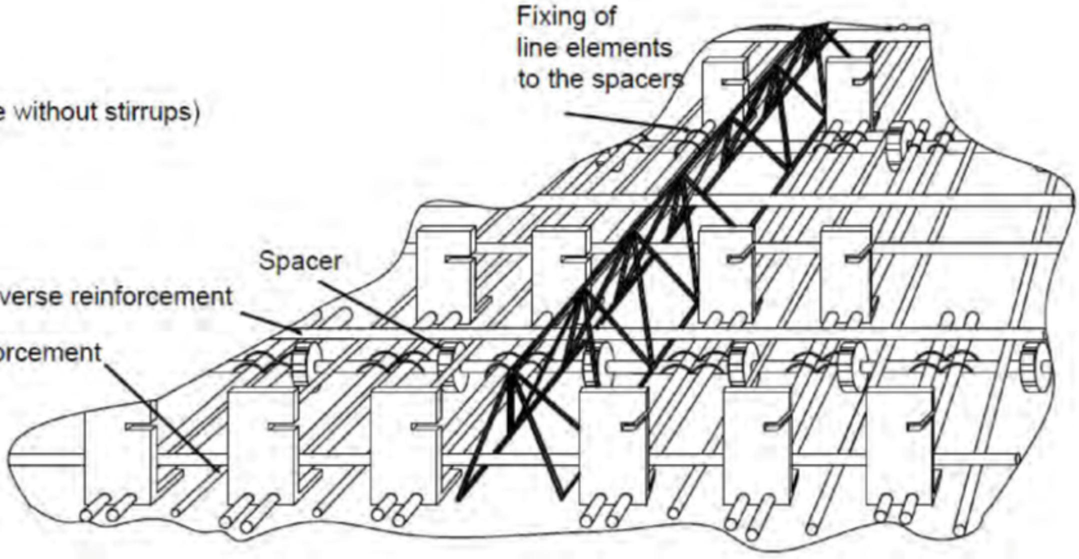
INSTALLATION OF LINE ELEMENTS USING Z-SHEETS

Example: cast-in-situ concrete slab



INSTALLATION OF LINE ELEMENTS USING L-SHEETS

Example: Prefabricated slab



CLIXS® punching shear reinforcement	Annex B7
Installation of line elements	

ASSEMBLY INSTRUCTIONS

Assembly of the punching shear reinforcement system for semi-precast slabs

The Z-shaped steel sheets and the two-part L-shaped steel sheets with mounted stirrups can be used in both in-situ concrete and in precast elements. They enclose or extend to the outermost upper and outermost lower reinforcement layer. The stirrup shanks can be installed parallel or perpendicular to the uppermost layer of the upper reinforcement.

The element arrangement prescribed by the design is divided into individual positions, so-called line elements, parallel to the reinforcement direction. By threading the sheets on the two reinforcing bars at the predetermined distances, the line elements are produced on site.

When reinforcing the ceiling slabs, the line elements are placed like additional reinforcement elements in the direction of the reinforcement on the lower spacers.

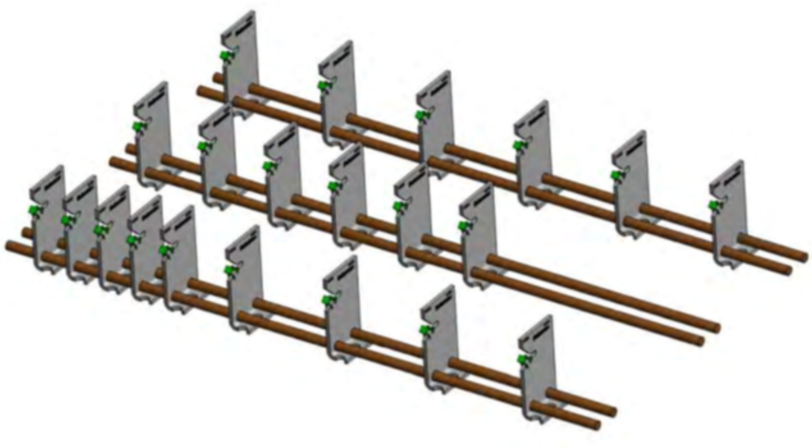
In the case of semi-precast slabs, the concreted L-sheet does not protrude beyond the lattice girders and the semi-precast slabs can be stacked without additional spacers.

After placing the upper reinforcement layer on the construction site, the stirrups are clipped into the slot of the L-plates from above and are laid down on the upper reinforcement layer. The stirrups do not have to be tied and may have a maximum inclination angle of 30°.

1. Production of line elements

The delivery of the Z- or L-sheets with pre-assembled clip takes place in packaging units.

The line elements are produced according to the specifications from the static calculation. The fixing of the sheets delivered to the consumer on the reinforcement bars with diameter d_s = 12 mm is carried out by tying or tacking.

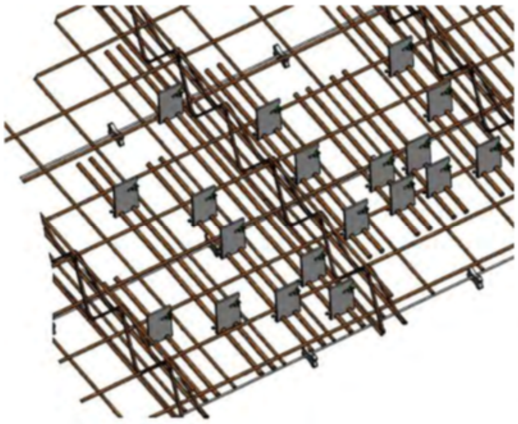


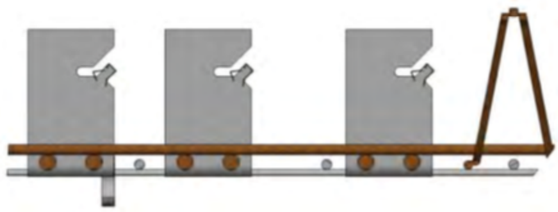
Optionally, prefabricated line elements can be installed.

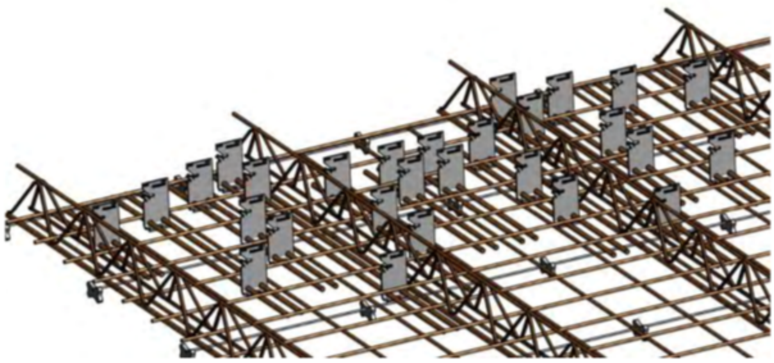
CLIXS® punching shear reinforcement	Annex B8 Page 1/5
Assembly instructions	

2. Installation of the lower transverse reinforcement with corresponding spacers on the formwork table

3. Assembly of the line elements by simply laying parallel to the direction of reinforcement and the lattice girders



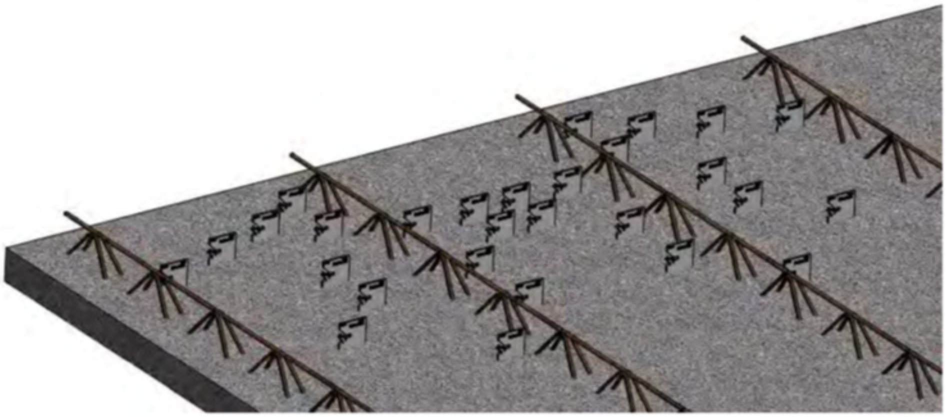




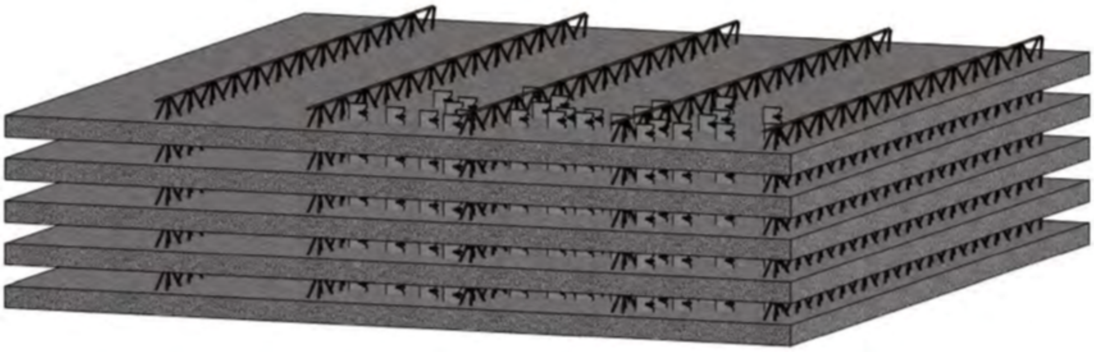
The keeping in place can be realized by means of spring clips or binding wire.

CLIXS® punching shear reinforcement	Annex B8 Page 2/5
Assembly instructions	

4. Concreting of the semi-precast slab

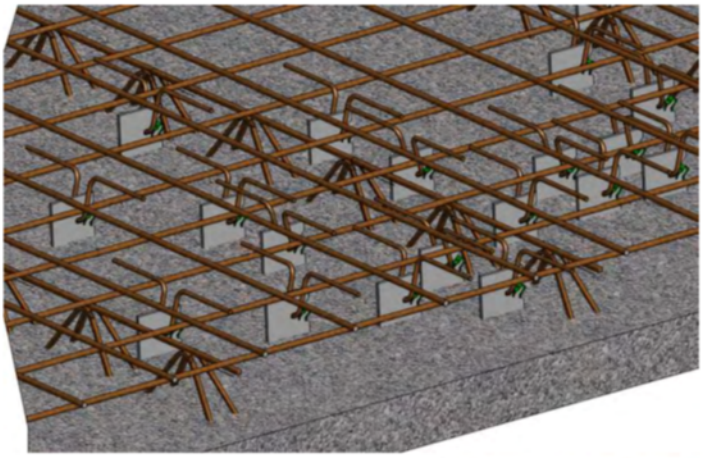


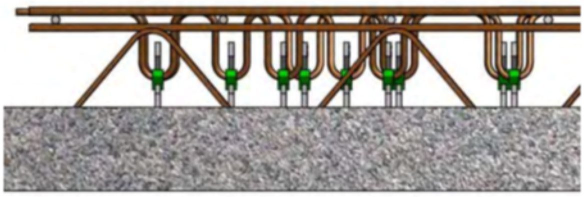
5. Removing the semi-precast slabs from the formwork and stacking



CLIXS® punching shear reinforcement	Annex B8 Page 3/5
Assembly instructions	

6. Completion of the punching shear reinforcement elements by clipping the corresponding stirrups

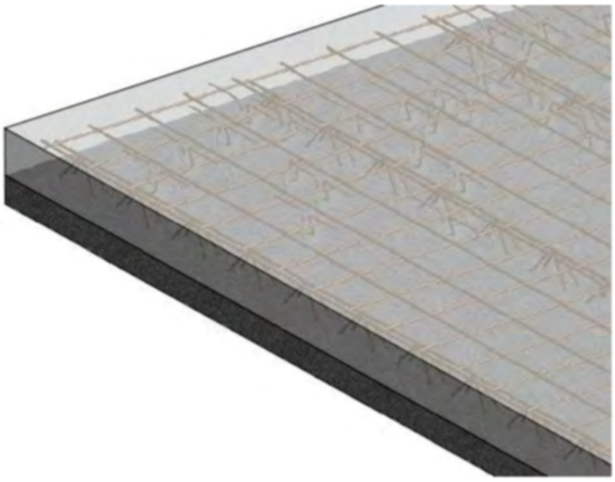




The stirrups can be produced on site according to the specifications from the static calculations or delivered to the construction site by the reinforcing steel supplier.

Optionally, the stirrups can be obtained from the supplier of the L-sheets or from the precast plant in the required amount.

7. Casting of the required concrete topping on the construction site



Further provisions for the design

If CLIXS® punching shear reinforcement systems with metal sheets are used for semi-precast elements and if cross joints of the elements in the punching area cannot be avoided, the cross joints of the elements shall be at least 4 cm wide and have to be filled thoroughly with cast-in-situ concrete to allow for a reliable transmission of compression forces. The distance between the edge of the semi-precast elements and the surface of the column shall be in the range of -1 cm up to 4 cm, provided that the upper edge of the construction joint of the column is located below the bottom side of the semi-precast element. The spacing between the semi-precast element and the edge of the support may be omitted in the case of line-type element slabs, provided that the edge of the element slab is fully supported.

The following must be observed for the on-site installation:

- The complete grouting of the compression joint between precast slab and column face must be ensured with an appropriate mortar of the same strength.
- 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 chiseling (compensation of building tolerances).
- The concrete must be well compacted in the area of the interface.

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 shall be carried out in the ultimate limit state for shear and bending.

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

The critical perimeter may be determined as stated above for circular columns with a perimeter u_0 less than 12 d and for columns with 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 perimeter 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	$\beta = 1{,}10$	
edge columns	$\beta = 1{,}40$	
corner columns	$\beta = 1{,}50$	(A2)
corner of wall	$\beta = 1{,}20$	
end of wall	$\beta = 1{,}35$	

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

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

$$v_{Rd,c} = C_{Rd,c} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} + k_1 \cdot \sigma_{cp} \geq (v_{min} + k_1 \cdot \sigma_{cp}) \qquad \text{(A3)}$$

$C_{Rd,c}$ 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

k_1 empirical factor, the recommended value is $k_1 = 0{,}1$

σ_{cp} normal concrete stresses in the critical section (positive pressure)

v_{min} $(0{,}0525/\gamma_C) \cdot k^{3/2} \cdot f_{ck}^{1/2}$ for $d \leq 600$ mm
$(0{,}0375/\gamma_C) \cdot k^{3/2} \cdot f_{ck}^{1/2}$ for $d > 800$ mm, intermediate depths are linearly interpolated

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

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

If punching shear reinforcement is necessary, an adequate amount of punching shear reinforcement elements has to be placed in the slab. The length of the control perimeter u_{out} at which shear reinforcement is no longer 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 shear reinforcement according to expression (A3),

$C_{Rd,c}$ can be chosen as for members not requiring design shear reinforcement

CLIXS® punching shear reinforcement	Annex C1 Page 2/3
Determination of punching shear resistance	

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 equation (A4) can be used:

$$\beta_{red} = \kappa_\beta \cdot \beta \geq 1{,}10 \qquad \text{(A5)}$$

edge columns $\kappa_\beta = \dfrac{1}{1{,}2 + \beta/20 \cdot l_s/d}$

corner columns $\kappa_\beta = \dfrac{1}{1{,}2 + \beta/15 \cdot l_s/d}$

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 punching shear reinforcement element

The punching shear reinforcement $v_{Rd,c}$ for footings and ground slabs is defined according to the following equation:

$$v_{Rd,c} = \frac{C_{Rk,c}}{\gamma_C} \cdot k \cdot (100 \cdot \rho_l \cdot f_{ck})^{1/3} \cdot \frac{2 \cdot d}{a} \qquad \text{(A6)}$$

DESIGN FOR PUNCHING AND INTERFACE

General

The verification of punching shear resistance of the flat slab is performed according to EN 1992-1-1, unless otherwise stated in the following.

The increase of punching shear resistance through inclined pre-stressed tendons may be considered according to EN 1992-1-1. The punching shear verification may consider the vertical component of only those pre-stressed tendons, which run within a distance of 0,5 d from the column. To determine the maximum punching shear resistance the favourably acting normal stress σ_{cp} must not be considered.

If L-shaped metal sheets are used, a planned or unplanned inclination of the stirrups must not be taken into account in the design.

Verification of punching shear resistance for ceiling slabs

Maximum load-bearing capacity

The maximum load-bearing capacity in the critical perimeter u_1 in a distance of 2,0 d from the column face is limited to:

$$v_{Rd,max} = k_{pu,sl} \cdot v_{Rd,c} \tag{A7}$$

$k_{pu,sl}$ = 2,05 for L-shaped metal sheets (see section 3.1 of the ETA)

$k_{pu,sl}$ = 1,71 for Z-shaped metal sheets (see section 3.1 of the ETA)

$v_{Rd,c}$ design value of the punching shear resistance according to equation (A3) with $C_{Rd,c} = 0{,}18/\gamma_C$

It has to be verified:

$$\frac{\beta \cdot V_{Ed}}{u_1 \cdot d} \leq v_{Rd,max} \tag{A8}$$

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Design of the punching shear reinforcement with L-shaped metal sheets

In addition to the load-bearing capacity of the metal sheets a concrete shear capacity is considered. The concrete shear capacity is calculated in the control perimeter u_1 in a distance of 2,0 d from the column face. The required reinforcement area has to be installed in each of the first three rows up to a distance of 2 d from the column.

The number of punching shear reinforcement elements must be determined so that the following relationship for the design value including the factor β is fulfilled:

$$\beta \cdot V_{Ed} \leq V_{Rd,cs,L\text{-}sheets}$$

β	see Annex C1
$V_{Rd,cs,L\text{-}sheets}$	punching shear resistance of the L-shaped metal sheets

$$V_{Rd,cs,L\text{-}sheets} = k_1 \cdot v_{Rd,c} \cdot u_1 \cdot d + k_{2,L} \cdot n_{stirrups} \cdot 2\,A_{s,stirrup} \cdot f_{ywd,ef} \cdot n_{sheets} \cdot 1{,}5\ d/s_r \qquad \text{(A9)}$$

$v_{Rd,c}$	according to equation (A3)	
k_1	= 0,85	
u_1	control perimeter u_1 in a distance of 2,0 d from the column face	
$n_{stirrups}$	number of stirrups per L-shaped metal sheet (1 or 2)	
$k_{2,L}$	= 0,55	interaction coefficient for interface
$A_{s,stirrup}$	cross-sectional area of a stirrup leg	
$f_{ywd,ef}$	$= 250 + 0{,}25\ d \leq f_{yd}$	effective design value of the yield strength of the stirrups, d [mm]
	f_{yd}	design value of the yield strength of the reinforcing steel, $f_{yd} = 435\ N/mm^2$
n_{sheets}	number of L-shaped metal sheets in the control perimeter	
s_r	radial distance of the punching shear reinforcement (see Annex B5)	

Design of the punching shear reinforcement with Z-shaped metal sheets

In addition to the load-bearing capacity of the metal sheets a concrete shear capacity is considered. The concrete shear capacity is calculated in the control perimeter u_1 in a distance of 2,0 d from the column face. The required reinforcement area has to be installed in each of the first three rows up to a distance of 2 d from the column.

The number of punching shear reinforcement elements must be determined so that the following relationship for the design value including the factor β is fulfilled:

$$\beta \cdot V_{Ed} \leq V_{Rd,cs,Z\text{-}sheets}$$

β	see Annex C1
$V_{Rd,cs,Z\text{-}sheets}$	punching shear resistance of the Z-shaped metal sheets

$$V_{Rd,cs,Z\text{-}sheets} = k_1 \cdot v_{Rd,c} \cdot u_1 \cdot d + (k_{2,Z} \cdot b_{sheet} \cdot t_{sheet} \cdot f_{y,d} \cdot n_{sheets} \cdot 1{,}5\ d/s_r) / k_3 \qquad \text{(A10)}$$

$v_{Rd,c}$	according to equation (A3)
k_1	= 0,85
u_1	control perimeter u_1 in a distance of 2,0 d from the column face
$k_{2,Z}$	= 0,50 interaction coefficient for interface
n_{sheets}	number of Z-shaped metal sheets in the control perimeter
b_{sheet}	smallest web width of the Z-shaped metal sheets
t_{sheet}	thickness of the Z-shaped metal sheets
$f_{y,d}$	$= 235 / \gamma_S$ design value of the yield strength of the Z-shaped metal sheets
s_r	radial distance of the punching shear reinforcement (see Annex B5)
k_3	factor to adjust the load-bearing capacity for larger slab thicknesses (h ≥ 60 cm)
	$k_3 = 1 + 0{,}2 \cdot (h - 60) / 60 \geq 1{,}0$ h [cm]

Design of the punching shear reinforcement in the outer rows

From a distance of the punching shear reinforcement (L- or Z-shaped metal sheets) of 2 d from the column face or from the fourth row of reinforcement the interaction coefficients for interface may be increased to $k_{2,L} = 1{,}0$ and $k_{2,Z} = 1{,}0$, resp.

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Verification of punching shear resistance for footings and ground slabs

Maximum load-bearing capacity

The lower limit of the maximum punching shear resistance $v_{Rd,max}$ in the critical perimeter is defined as a multiple value of the punching shear resistance of the footing or the ground slab without shear reinforcement according to:

$$v_{Rd,max} = k_{pu,fo} \cdot v_{Rd,c} \quad \text{(A11)}$$

$k_{pu,fo}$ = 1,4 (see section 3.1 of the ETA)

$v_{Rd,c}$ design value of the punching shear resistance according to equation (A6)

The required number of punching shear reinforcements in footings and ground slabs has to be determined according to the following equation:

$$\beta \cdot V_{Ed} \leq V_{Rd,s} = \frac{f_{yd} \cdot A_{sw,0,8d}}{1 - A_{crit} / A} \quad \text{(A12)}$$

f_{yd} ≤ 435 N/mm² for stirrups if L-shaped metal sheets are used

f_{yd} ≤ 214 N/mm² for the design value of the yield strength if Z-shaped metal sheets are used

$A_{sw,0,8d}$ cross section of punching shear reinforcement in the rows near to the column (first row in a distance of 0,3 d from the column face; within the distance 0,8 d at least one second row has to be provided)

A_{crit} area within the critical perimeter in the distance a_{crit}, which has to be determined iteratively

A plan area of the single footing (for ground slabs the area within the line of contraflexure for the bending moment in radial direction)

For ground slabs or very large and slender footings, for compliance with the punching shear verification additional rows of punching shear reinforcement may become necessary outside 0,8 d. The required reinforcement cross section in these additional rows may be determined using a simplified method, by “lifting” 33 % of the applied shear force. The soil pressure within the reinforcement row considered may be subtracted here completely from the applied shear force.

Verification of shear force transmission in the joint

The verification of shear force transmission in the joint has to be performed according to EN 1992-1-1 for each control perimeter.

The design value of the applicable shear force is composed additively of the three bearing components (adhesion, friction and reinforcement) and may be determined according to the following equation:

$$v_{Rdi} = c \cdot f_{ctd} + \mu \cdot \sigma_n + \rho \cdot f_{yd} \cdot (1{,}2 \cdot \mu \cdot \sin\alpha + \cos\alpha) \leq k_{max,i} \cdot \nu \cdot f_{cd} \qquad \text{(A13)}$$

$k_{max,i}$ = 0,5 (see section 3.1 of the ETA)

Here c and μ are coefficients which depend on the roughness of the joint, f_{ctd} is the design value of the tensile strength of the concrete, σ_n is the compressive stress (tension negative) perpendicularly to the joint and ρ is the reinforcement ratio of the reinforcement crossing the joint.

The values depending on the roughness of the joint may be taken from the following table.

Surface characteristics	c	μ	ν
Indented	0,50	0,90	0,75
Rough	0,40	0,70	0,50
Smooth	0,20	0,60	0,20
Very smooth	0,00	0,50	0,00

The larger amount of reinforcement determined from joint design and punching design has to be installed. Here, if L-shaped metal sheets are used, the cross section area of the installed stirrups, and, if Z-shaped metal sheets are used, the smallest cross section area of the Z-shaped metal sheet may be considered as interface reinforcement.

The stirrups of the punching shear reinforcement with L-shaped metal sheets may be adopted here with an inclination of 90° relative to the slab plane.

The combined use of metal sheets and lattice girders is possible.