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TECHNICAL REPORT

Design methods for verification of load-bearing capacity of stud connectors for anchoring in reinforced concrete members

TR 081

June 2022

EUROPEAN ORGANISATION FOR TECHNICAL ASSESSMENT
WWW.EOTA.EU

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1 General

1.1 Scope

This Technical Report (TR) provides a design method for verification of load-bearing capacity of stud connectors for transfer of axial tension and/or shear forces to the supporting column made of reinforced normal weight concrete of strength class C20/25 to C70/85 according to EN 206.

This TR covers stud connectors with an ETA issued on the basis of EAD 160202-00-0301.

The design methods apply to stud connectors in the following applications according to the intended use:

– Anchoring of rectangular headed reinforcement bars in reinforced concrete elements, e.g. slabs, beams, walls, corbels or exterior beam-column joints.
  The verification of the immediate local transmission of the stud connector loads into the reinforced concrete element shall be carried out with the design methods described in this document. The transfer of the loads to be anchored into the supports of the concrete member shall be verified by the engineer of the structure.
– Structural connection of steel members and reinforced concrete members e.g. steel corbels or beams and reinforced concrete elements.
  The verification of the immediate transmission of the structural steel member loads into the reinforced concrete element is carried out with the design methods described in this document. The transfer of the loads to be anchored into the supports of the concrete member shall be verified by the engineer of the structure. This TR does not cover the design of the attached steel member. The design of the steel member shall be carried out to comply with the appropriate standards and fulfil the requirements on the fixture as given in this TR.

Examples of applications of the intended use of the stud connectors are given in Annex A.2.

This TR covers reinforced concrete elements of the following specifications:

– Concrete elements that are subjected to static or quasi static actions
– Concrete elements that are subjected to fatigue actions
– Concrete elements that are designed according to EN 1992-1-1 to carry the concentrated loads due to the stud connectors
– Concrete elements that are subjected to fire exposure
– Detailed information on the minimum dimensions of concrete elements and supplementary reinforcement are given in the ETA for the specific stud connector

This TR covers structural steel elements of the following specifications:

– Structural steel elements that are subjected to static or quasi static actions
– Structural steel elements that are subjected to fatigue actions
– Structural steel elements that are designed according to EN 1993-1-1

This TR does not purport to address all of the safety concerns associated with its use. It is the responsibility of the user of this technical report to establish appropriate safety practices and determine the applicability of regulatory limitations prior to use.

1.2 Types of stud connectors

This TR covers a range of stud connectors according to Annex A. The essential characteristics of the respective stud connector are given in the ETA for the specific stud connector.

1.3 Load types and load directions

Loading on the stud connector covered by this TR may be static or quasi-static. The loading on the stud connector resulting from the actions on the fixture or from actions on the concrete element will generally be axial tension and/or shear. A bending moment on the stud connector joint will result in axial tension and compression. Any axial compression on the construction joint shall be transmitted to the concrete directly to the concrete surface.

The stud connectors can also be subjected to axial cyclic tension loading.

1.4 Specific terms used in this Technical Report

1.4.1 Terminology

stud connector

industrially manufactured, assembled part consisting of either integrally forged rectangular anchor heads or/and assembled sockets, which serves to end anchored in concrete as well as to fasten structural steel elements to supporting reinforced concrete element

rectangular anchor head

rectangular anchor head is integrally forged from the reinforcing steel bar with a load bearing area of approximately 8 times of the stress cross-section of the stud connector bar

socket

internal threaded socket for mechanical fastening and providing transfer of axial tension, compression and/or shear

1.4.2 Symbols and abbreviations

Indices	
C	Compression chord
Ed	Design action
G	permanent
L	Longitudinal
N	Normal force
Q	Variable
R	Resistance
Rd	Design resistance
T	Tension chord
V	Shear
a	Anchor
b	Bond
bar	Reinforcing bar
bcj	Bolted connection joint
beam	Beam
c	Concrete, corbel
col	Column
d	Design value
ef	Effective

fr	Friction
i	Interface
ircc	Interface of reinforced concrete corbel
inf	With favourable effect
j	Joint
k	Characteristic value
l	Local
max	Maximum
min	Minimum
perm	Permanent
p0.2	0.2 %-yield stress
rcc	Reinforced concrete corbel
s	Steel
sc	Stud connector
socket	Socket
sp	Splitting
sup	With unfavourable effect
t	Tension
w	Web
y	Yield

Superscripts

h	highest loaded (most stressed) stud connector in a group

Actions, resistances, mechanical characteristics

A_{col}	Cross-section of column
A_{c0}	Loaded concrete area
A_{c1}	Design distribution area with similar shape to A_{c0}
C_s	Axial compression force in column longitudinal reinforcement
D_{Ed}	Design value of compression chord force
F_c	Compression strut load
F_{Ed}	Design value of applied corbel load
$F_{s,beam}$	Steel resistance of the beam top reinforcement
F_t	Tensile splitting load
$F_{t,Rd}$	Design value of tension resistance per screw
$F_{v,Rd}$	Design value of shear resistance per screw
F_{wd}	Design value of web force
H_{Ed}	Design horizontal outward load
M_{Ed}	Design bending moment
N_{Ed}	Design tension force

N_{Ed}^{h}	Design value of tensile load acting on the most stressed stud connector of a connection
$N_{Ed,col}$	Design axial force in column
$N_{Ed,perm,col}$	Design value of quasi-permanent load combination (SLS) for axial column force (compression: negative)
$N_{Gk,j}$	Characteristic value of permanent axial column force
$N_{Qk,i}$	Characteristic value of variable axial column force
$N_{Rd,socket}$	Design tensile resistance from a simultaneous tensile and shear resistance relationship per stud connector socket
$N_{Rd,s,sc}$	Design tensile resistance per stud connector reinforcing bar
$R_{p,0.2}$	Characteristic yield stress of the stud connector socket
T	Axial tensile force in column longitudinal reinforcement
V_{Ed}	Design value of shear force
V_{Ed}^{h}	Design value of shear load acting on the most stressed stud connector of a connection
$V_{Ed,c}$	Design value of shear force acting at the concrete edge
$V_{Ed,col,o}$	Design value of shear force of upper column
$V_{Ed,fr,inf}$	Design value of frictional force with favourable effect
$V_{Ed,fr,sup}$	Design value of frictional force with unfavourable effect
$V_{Ed,j}$	Design value of horizontal joint shear force
$V_{Rd,c,j}$	Design value of basic joint shear strength without stirrup reinforcement
$V_{Rd,c}$	Design shear strength of the member according to EN 1992-1-1, clause 6.2.2.
$V_{Rd,c,bcj}$	Design shear strength of concrete edge failure
$V_{Rd,c,l,bcj}$	Design shear strength of local concrete blow-out failure
$V_{Rd,c,rcc}$	Design value of maximum concrete shear resistance
$V_{Rd,c,ircc}$	Design value of concrete shear resistance at interface
$V_{Rd,socket}$	Design shear resistance from a simultaneous tensile and shear resistance relationship per stud connector socket
$V_{Rd,j}$	Design value of joint shear strength
Z_{Ed}	Design value of anchorage force or tensile chord force
$Z_{Ed,sp1}$	Design value of primary splitting force
$Z_{Ed,sp2,T}$	Design value of secondary splitting force for tension chord
$Z_{Ed,sp2,C}$	Design value of secondary splitting force for compression chord
α	Spread angle for determining part of the anchor length at the edge of support or loading plate
α_{cc}	Coefficient taking account of long-term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied
β	Spread angle for determining part of the anchor length at the centre of support or loading plate
c	Coefficient which depend on the roughness of the interface
f_{bd}	Design bond strength
f_{cd}	Design value of concrete compressive strength

$\overline{f_{cd}}$	Concrete compressive strength in partially loaded areas
f_{ck}	Characteristic value of concrete compressive strength
f_{ctd}	Design value of the concrete tensile strength
$f_{ctk,0.05}$	Characteristic 0.05% value of axial concrete tensile strength
f_{yd}	Design yield strength of reinforcing steel
$f_{yd,i}$	Design yield strength of reinforcing steel crossing the interface
$f_{yd,sc}$	Design yield strength of stud connector steel
f_{yk}	Characteristic yield strength of reinforcing steel
$f_{yk,i}$	Characteristic yield strength of reinforcing steel crossing the interface
$f_{yk,sc}$	Characteristic yield strength of stud connector steel
f_{ywd}	Design yield strength of stirrup reinforcing steel
f_{ywk}	Characteristic yield strength of stirrup reinforcing steel
$\Delta\sigma_{Rsk}$	Characteristic fatigue strength for N* load cycles
$\psi_{2,i}$	Factor defining representative quasi-permanent value for variable actions
μ	Coefficient to account the roughness of the interface
μ_{inf}	Coefficient of friction with favourable effect
μ_{sup}	Coefficient of friction with unfavourable effect
ν	Strength reduction factor for concrete cracked in shear
ν_i	Strength reduction factor for the roughness of the interface
γ_c	Partial safety factor for concrete
$\gamma_{c,t}$	Partial safety factor for concrete in tension
γ_s	Partial safety factor for reinforcement

Stud connectors, reinforcement

A_h	Load bearing area of rectangular stud connector anchor head
$A_{s,sc}$	Cross-sectional area of stud connectors
$A_{s,sc,T}$	Cross-sectional area of stud connectors in the tension chord
$A_{s,link}$	Cross-sectional area of links in corbels
$A_{s,(..),col}$	Cross-sectional area of column longitudinal reinforcement at half column section
$A_{s,i}$	Cross-sectional area of reinforcement crossing the interface
$A_{sj,ef}$	Effective cross-sectional area of column transverse reinforcement which is placed in the tensile zone of joint core
$A_{sw,sp1}$	Cross-sectional area of primary splitting reinforcement
$A_{sw,sp2,T}$	Cross-sectional area of secondary splitting reinforcement for tension chord
$A_{sw,sp2,C}$	Cross-sectional area of secondary splitting reinforcement for compression chord
D	Mandrel diameter
U	Circumference of a column reinforcing bar
a_c	Lever arm of external forces
a_H	Distance from neutral axis of tensile chord reinforcement to horizontal load H_{Ed}
a_L	Support length

$a_{sw,min}$	Minimum shear reinforcement for solid slabs with structurally required shear reinforcement and for beams in the region near to the support
b	Width of beam or slab
b_{beam}	Width of beam
b_c	Width of corbel
b_{col}	Width of column
b_{ef}	Effective joint width
b_i	Width of interface surface
b_{plate}	Width of fixture end-plate
c_{min}	Concrete cover
$c_{sc\text{-}bar}$	Lateral concrete cover of the stud connector bar
c_2	Edge distance from the axis of stud connector to adjacent column edge, measured at right angle to the direction of stud connectors, see Figure 12
d	Effective depth of the cross-section
d_a	Nominal diameter of the stud connector reinforcing steel bar
d_{beam}	Effective depth of beam
$d_{col,L}$	Diameter of column longitudinal reinforcement
$d_{plate,L1}$	Diameter of longitudinal reinforcement placed at each corner of supporting column on near face of connection
$d_{plate,L2}$	Diameter of longitudinal reinforcement placed between the stud connectors in supporting column on near face of connection
d_{socket}	Diameter of a stud connector socket
$d_{w,head}$	Diameter of transverse reinforcement placed at each stud connector layer at the level of stud connector anchor head
$d_{w,plate}$	Diameter of splitting transverse reinforcement placed below each stud connector layer
d_1	Lateral distance between neutral axis of stud connector to nearest component edge
h	Height of beam or slab
h_{beam}	Height of beam
h_c	Height of corbel
h_{col}	Height of column
h_i	Height of interface surface
h_{sc}	Height of stud connector anchor head
h_{sp}	Length in which the secondary splitting reinforcement shall be provided, measured from the stud connector layer
h_{plate}	Height of fixture end-plate
k_1, k_2	Stress exponents for S-N-curve
k_6	Coefficient for accounting the anchorage effect of stud connector
k_7	Coefficient for accounting the effective joint shear reinforcement
k_8	Coefficient for accounting the local concrete shear resistance
k_9	Coefficient for accounting the effective shear resistance on concrete edge

l_{bd}	Anchorage length
l_c	Length of corbel
l_{socket}	Length of stud connector socket
l_{sw}	Length in which a minimal shear reinforcement shall be provided, as shown in Figure 1
l_0	Lap length
n	Total number of reinforcements
n_{sc}	Total number of stud connectors
$n_{sc,T}$	Number of stud connectors of the tensile chord
p_2, $p_{2,i}$	Spacing between adjacent stud connectors
s	Stirrups spacing
ü	Part of the stud connector anchorage length
x_i	Effective height of interface surface under compression
z	Lever arm of internal forces calculated according to the theory of elasticity
z_0	Lever arm of internal forces to determine tensile chord force
γ_{N1}	Factor to account for the impact of axial column force
γ_{N2}	Factor to account for the impact of the shear slenderness
$\rho_{s,(..),col}$	Reinforcement ratio for column longitudinal reinforcement $A_{s,(..),col}$ at half column section
$\rho_{s,1,col}$	Reinforcement ratio for column longitudinal reinforcement $A_{s,1,col}$ at half column section
ϕ	Diameter of reinforcing bar

2 Design Concept

2.1 General

The design shall be in accordance with the same principles and requirements valid for structures given in EN 1990 (including load combinations) and EN 1992-1-1 as well as EN 1993-1-1.

In the ultimate limit state (ULS), verification is required for all appropriate load and all relevant failure modes.

The material of the stud connectors, including the ancillary components, and the corrosion protection shall be selected and demonstrated taking into account the environmental conditions at the place of installation.

2.2 Resistance to static or quasi static loading

2.2.1 Headed stud connectors at end supports of slabs, beams or walls

2.2.1.1 General

Headed stud connectors shall be used for an end anchorage of flexural reinforcement in beams, slabs or walls. Structural analysis of stud connectors provided at end supports of slabs, beams or walls shall be carried out in accordance with EN 1992-1-1 assuming the following specific provisions.

2.2.1.2 Positioning of stud connectors and detailing rules

In ordinary cases the headed stud connectors are placed in a single layer at end supports. In some cases, double or more layers with staggered or non-staggered anchor heads may be necessary. Detailed information on the mandatory supplementary reinforcement and the corresponding configuration of stud connectors at end supports are stated in the ETA for the specific stud connectors.

For the alignment of the anchor head in the concrete element the requirements for the concrete cover according to EN 1992-1-1 shall be apply.

The following detailing rules shall be observed:

a) The minimum limits on cross-section dimensions b and h as shown in Figure 1 complies with the provisions of the ETA for the specific stud connector
b) Lateral concrete cover $c_{sc\text{-}bar}$ of the stud connector reinforcing bar and anchorage length l_{bd} as shown in Figure 1 or Figure 2 according to the ETA for the specific stud connector
c) Placement of a closed transverse stirrup for beams or a transverse U-bar for slabs at the level of the anchor heads per each stud connector layer with minimum link diameter of $\phi d_{w,head}$ according to the ETA for the specific stud connector, as shown in Figure 1
d) Arrangement of a transverse reinforcement in the support region of at least 20% of the flexural tensile reinforcement for slabs

2.2.1.3 Verification of anchorage force at end supports

Verification of anchorage at end supports for a single layer of stud connectors in beams or slabs shall be deemed verified when the detailing rules a) to d) according to section 2.2.1.2 have been observed and when the required anchorage length l_{bd} has been determined according to equation (1).

The required anchorage length of stud connector at end support l_{bd} for a fully loaded stud connector reinforcing steel results from the following equation:

$$l_{bd} = a_L + \ddot{u} \geq 6.7 d_a \quad (1)$$

where, see Figure 2

a_L = Support length

$\ddot{u}$ = Part of the anchorage length

d_a = Diameter of the stud connector reinforcing steel bar

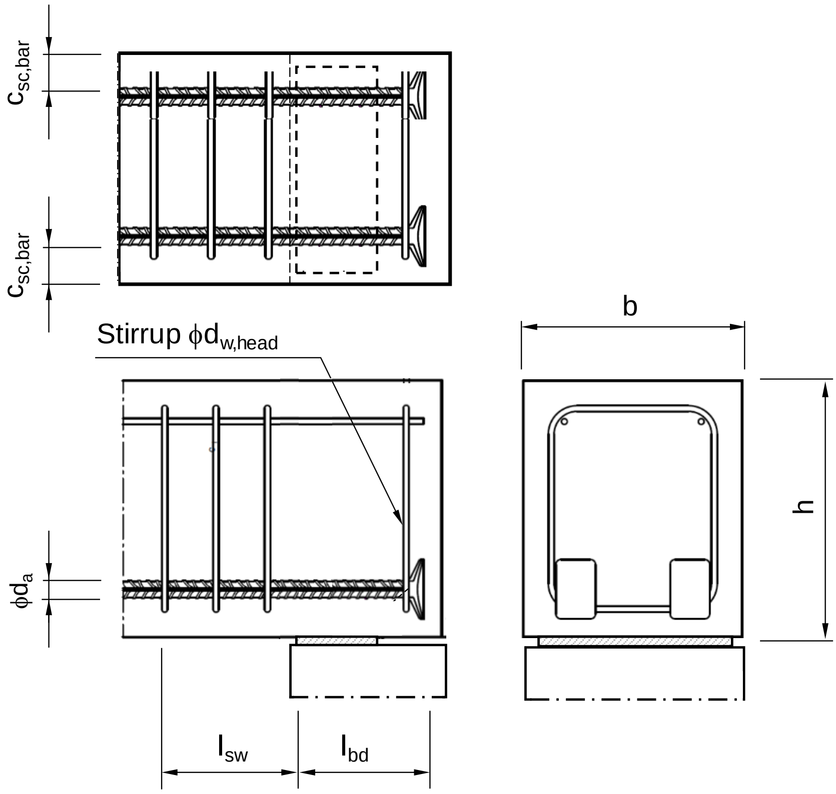
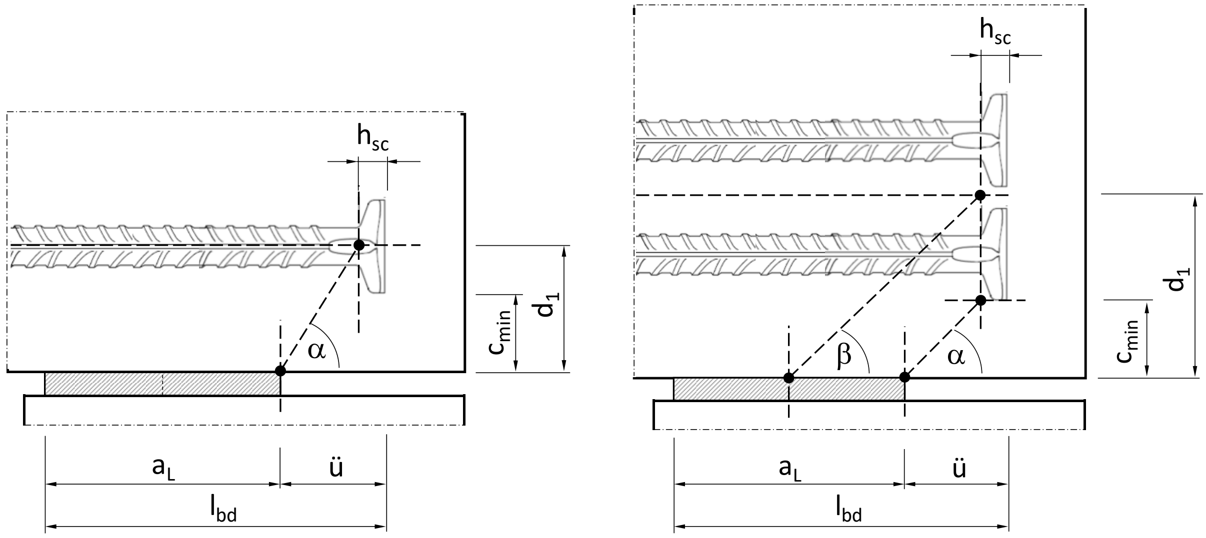


Figure 1: End anchorage of a single layer of stud connectors in a beam



The values of α and β are stated in the ETA for the specific stud connector.

(Transverse stirrup per stud connector layer at the level of the anchor heads not shown.)

Figure 2: Anchorage length of stud connector reinforcement at end support

The anchorage of multi stud connector layers in beams or slabs or if the cross-section dimensions b and h do not complies the provisions of the ETA for the specific stud connector shall be deemed verified when the detailing rules b) to d) according to section 2.2.1.2 have been observed and when the required anchorage length at the end support has been determined according to equation (1). The anchorage verification of Z_{Ed} shall additionally be provided with the following equation:

$$Z_{Ed} \leq n_{sc} \cdot \pi \cdot d_a \cdot l_{bd} \cdot f_{bd} + A_{c0} \cdot \overline{f_{cd}} \quad (2)$$

where, see Figure 1

n_{sc} = Number of stud connectors at end support

d_a = Diameter of the stud connector reinforcing steel bar

l_{bd} = Anchorage length of stud connector

f_{bd} = Design bond strength according to EN 1992-1-1, Clause 8.4.2

$\overline{f_{cd}}$ = Concrete compressive strength in partially loaded areas

$= f_{cd} \cdot \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3.0 \cdot f_{cd}$

f_{cd} = Design value of the concrete compressive strength according to EN 1992-1-1

A_{c0} = Loaded concrete area caused by stud connector anchor heads

$= n_{sc} \cdot A_h$

A_h = Load bearing area of the stud connector anchor head according to the ETA for the specific stud connector

A_{c1} = Design distribution area with a similar shape to A_{c0} in accordance with the provisions in the ETA for the specified stud connector

For a given anchorage length of $l_{bd} \geq 6.7 \cdot d_a$, the anchored tensile force may be determined in accordance with equation (2). For verification of the anchorage of stud connector in beams or slabs the detailing rules b) to d) of section 2.2.1.2 shall be satisfied.

2.2.1.4 Verification of shear resistance at end support

The verification of shear strength at end support results from the following equation:

$$V_{Ed} \leq V_{Rd,c,rcc} = 0.5 \cdot \nu \cdot b \cdot z \cdot \frac{f_{ck}}{\gamma_c} \tag{3}$$

where

V_{Ed} = Shear force at end support

ν $= 0.7 - \frac{f_{ck}}{200\ MPa} \geq 0.5$

b = Width of slab or beam

z = Lever arm of internal forces to determine the shear load capacity, d is the effective depth of the cross-section

$= 0.9 \cdot d$

f_{ck} = Characteristic value of concrete compressive strength according to EN 1992-1-1

γ_c = Partial safety factor for concrete according to EN 1992-1-1

For solid slabs with a structurally required shear reinforcement and for beams, a minimum shear reinforcement of $a_{sw,min}$ shall be provided over a length of $l_{sw} = d$ with $d = h - d_1$ as measured from the front edge of the support as shown in Figure 1.

The minimum shear reinforcement $a_{sw,min}$ results from the following equation:

$$a_{sw,min} \geq 0.7 \cdot \frac{V_{Ed}}{f_{ywd}} \tag{4}$$

where, see Figure 1

V_{Ed} = Shear force at end support

f_{ywd} = Design yield strength of the stirrup reinforcing steel according to EN 1992-1-1

Existing member reinforcements may be taken into account for the cross-sectional area of minimum shear reinforcement.

2.2.2 Headed stud connectors in corbels

2.2.2.1 General

Headed stud connectors shall be used for an end anchorage of flexural reinforcement in corbels. Structural analysis of stud connectors provided in corbels shall be carried out in accordance with EN 1992-1-1 assuming the following specific provisions.

2.2.2.2 Positioning of stud connectors and detailing rules

In ordinary cases headed stud connectors are either placed in a single layer or in double or more layers with staggered or non-staggered anchor heads. Detailed information on the mandatory supplementary reinforcement and the corresponding configuration of stud connectors in corbels are stated in the ETA for the specific stud connectors.

For the alignment of the anchor head the requirements for the concrete cover according to EN 1992-1-1 shall be apply.

The following detailing rules shall be observed:

a) The minimum limits on corbel dimensions of b_c and l_c as shown in Figure 4 complies with the provisions of the ETA for the specific stud connector
b) Lateral concrete cover $c_{sc\text{-}bar}$ of the stud connector reinforcing bar as shown in Figure 4 and anchorage length l_{bd} in the corbel as shown in Figure 5 according to the ETA for the specific stud connector
c) Placement of one closed transverse stirrup per each stud connector layer with a minimum link diameter of $\phi d_{w,head}$ according to the ETA for the specific stud connector at the level of the anchor heads, as shown in Figure 4

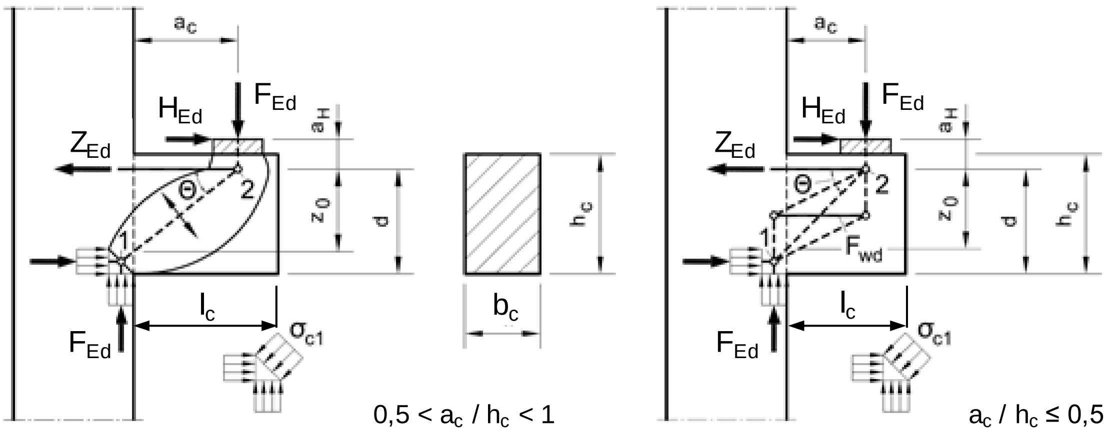


Figure 3: Corbel strut-and-tie model with forces acting on the corbel

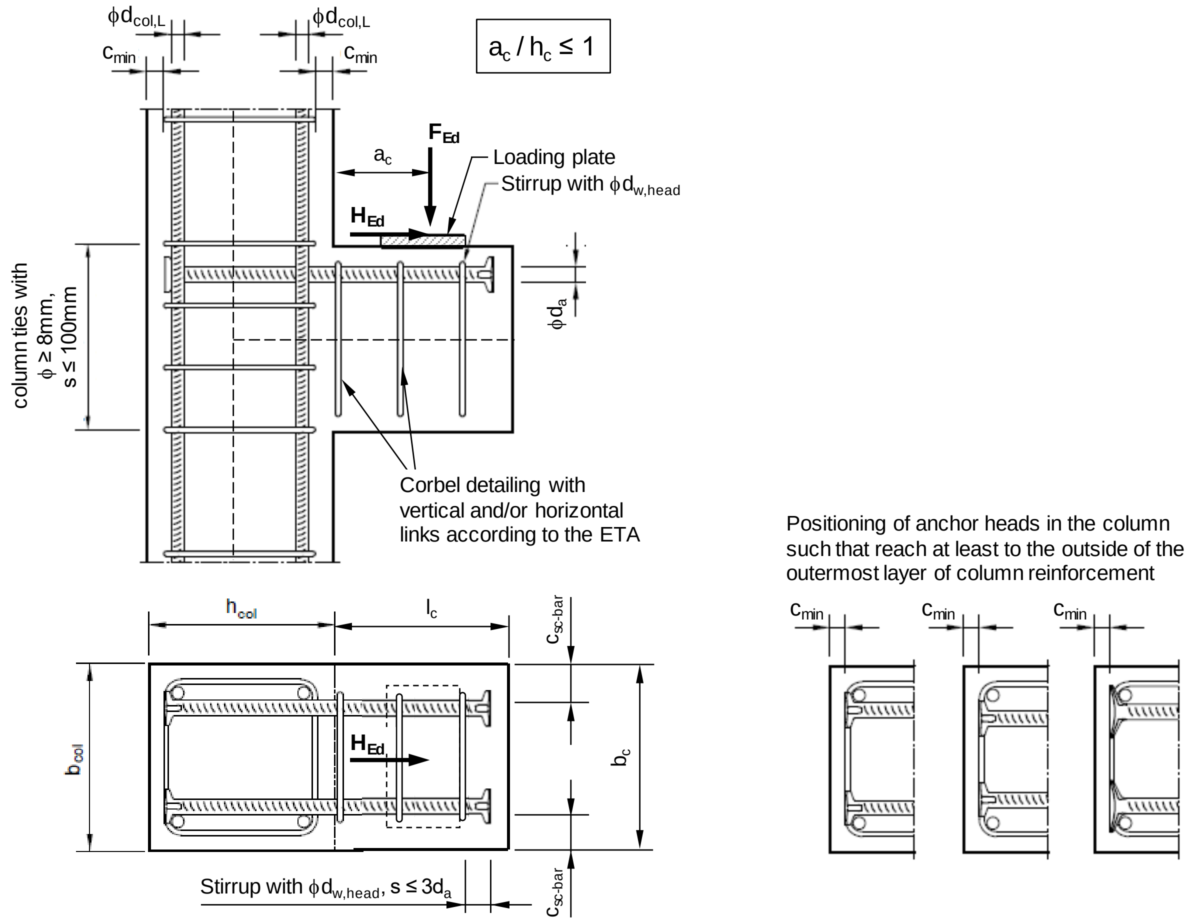
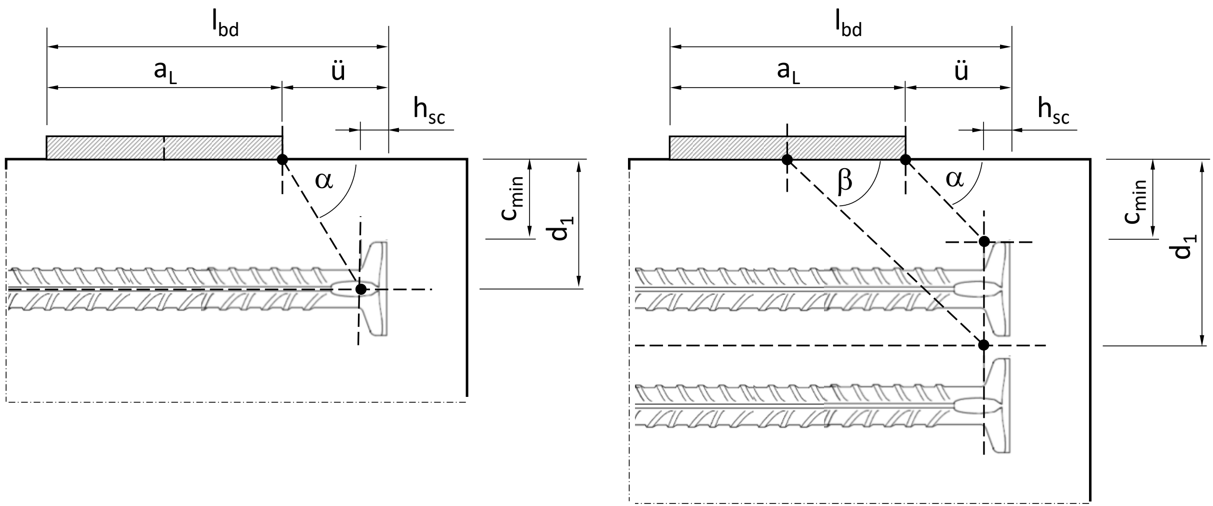


Figure 4: Single layer of stud connectors in a column-corbel joint



The values of α and β are stated in the ETA for the specific stud connector.

(Transverse stirrup per stud connector layer at the level of the anchor heads not shown.)

Figure 5: Anchorage length of stud connector reinforcement in corbels

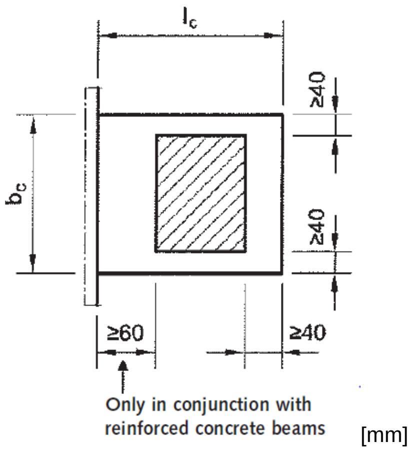


Figure 6: Plan view of bearing with definitions

2.2.2.3 Forces acting on corbel

The design value of acting shear load according Figure 3 results from the following equation:

$$V_{Ed} = F_{Ed} \tag{5}$$

Unbeneficial effects of horizontal restraint at support bearing/loading plate caused by friction shall be considered with a horizontal outward load results from the following equation:

$$H_{Ed} \geq 0.2 \cdot F_{Ed} \tag{6}$$

2.2.2.4 Verification of concrete shear resistance of corbel

The maximum concrete shear capacity of the corbel subjected to shear and horizontal loads shall meet the requirement:

$$V_{Ed} \leq V_{Rd,c,rcc} = 0.5 \cdot \nu \cdot b_c \cdot z \cdot \frac{f_{ck}}{\gamma_c} \tag{7}$$

where, see Figure 5

ν = $0.7 - \frac{f_{ck}}{200\ MPa} \geq 0.5$

b_c = Width of concrete corbel

z = Lever arm of internal forces to determine the shear load capacity, d is the effective depth of the corbel cross-section

= $0.9 \cdot d$

f_{ck} = Characteristic value of concrete compressive strength according to EN 1992-1-1

γ_c = Partial safety factor for concrete according to EN 1992-1-1

2.2.2.5 Determination of tensile chord force and required amount of reinforcement for stud connectors

The strut-and-tie model shown in Figure 3 is limited by $a_c/z_0 \geq 0.4$. The tensile chord force Z_{Ed} results from the following equation:

$$Z_{Ed} = F_{Ed} \cdot \frac{a_c}{z_0} + H_{Ed} \cdot \frac{a_H + z_0}{z_0} \tag{8}$$

where, see Figure 3

a_c = Lever arm of external forces, distance from column edge to vertical force F_{Ed}

a_H = Distance from neutral axis of tensile chord reinforcement to horizontal load H_{Ed}

z_0 = Lever arm of internal forces to determine tensile chord force, $V_{Rd,c,rcc}$ is the maximum concrete shear capacity for corbels according to equation (7)

$= d \cdot \left(1 - 0.4 \cdot \frac{V_{Ed}}{V_{Rd,c,rcc}}\right)$

d = Effective depth

The cross-sectional area $A_{s,sc,T}$ of the required amount of reinforcement for stud connectors in the tension chord results from the following equation:

$$A_{s,sc,T} = \frac{Z_{Ed}}{f_{yd,sc}} \quad (9)$$

where

Z_{Ed} = Tensile chord force according to equation (8)

$f_{yd,sc}$ = Design yield strength of the stud connector according to the ETA for the specified stud connector

2.2.2.6 Verification of concrete compression under the loading plate

Verification of concrete compression under the loading plate shall be carried out in accordance with EN 1992-1-1. The determination of the design distribution area A_{c1} is stated in the ETA for the specific stud connector.

2.2.2.7 Verification of anchorage of stud connectors in the corbel

The anchorage of a single layer of stud connectors in the corbel shall be deemed verified when the detailing rules a) to c) specified in section 2.2.2.2 have been observed.

The anchorage of multi stud connector layers in corbels or if the cross-section dimensions b_c and h_c do not complies the provisions of the ETA for the specific stud connector shall be deemed verified when the detailing rules b) and c) specified in section 2.2.2.2 and the following anchorage verification have been observed:

$$Z_{Ed} \leq n_{sc,T} \cdot \pi \cdot d_a \cdot l_{bd} \cdot f_{bd} + A_{c0} \cdot \overline{f_{cd}} \quad (10)$$

where, see Figure 4 and Figure 5:

$n_{sc,T}$ = Number of stud connectors in the tension chord

d_a = Diameter of the stud connector reinforcing bar

l_{bd} = Anchorage length of stud connector in the corbel

f_{bd} = Design bond strength according to EN 1992-1-1, clause 8.4.2

$\overline{f_{cd}}$ = concrete compressive strength in partially loaded areas

$= f_{cd} \cdot \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3.0 \cdot f_{cd}$

f_{cd} = Design value of the concrete compressive strength according to EN 1992-1-1

A_{c0} = Loaded concrete area caused by stud connector anchor heads in the corbel

$= n_{sc,T} \cdot A_h$

A_h = Load bearing area of the stud connector anchor head according to the ETA for the specific stud connector

A_{c1} = Design distribution area with similar shape to A_{c0} in accordance with the provisions in the ETA for the specific stud connector

2.2.2.8 Verification of anchorage of headed stud connectors in the supporting column

Verification of the anchorage of the stud connectors in the supporting column may be deemed to be satisfied if the following detailing rules have been observed:

a) Minimum cross-section dimensions of column b_{col} and h_{col} as shown in Figure 4 complies the provisions with the ETA for the specific stud connector
b) The number of the column longitudinal reinforcement shall not be less than four bars as shown in Figure 4. At least one longitudinal reinforcement bar shall be placed at each corner with a minimum diameter of $\phi d_{col,L}$ according to the ETA for the specific stud connector
c) Headed stud connector bars shall be anchored at the outside face of the column. Positioning of anchor heads in the column such that reach at least to the outside of the outermost layer of column longitudinal reinforcement as shown in Figure 4
d) Additional column tie reinforcement with a diameter not be less than ϕ8 mm and a spacing not be larger than 10 cm shall be placed in the supporting column along the corbel height, as shown in Figure 4.

2.2.2.9 Verification of anchorage of stud connectors bent downwards in the supporting column

The anchorage of stud connectors bent downwards by 90° in the supporting column and transmission of the tensile force from the stud connector to the column longitudinal reinforcement by a lap according to EN 1992-1-1, Clause 8.7 shall be deemed verified when the following detailing rules have been observed:

a) Minimum mandrel diameter of the stud connector bar of $D \geq 10 \cdot \phi d_a$, cf. illustration in Figure 7
b) The number of the column longitudinal reinforcement shall not be less than four bars as shown in Figure 7. At least one longitudinal reinforcement bar shall be placed at each corner with a minimum diameter of $\phi d_{col,L}$ according to the ETA for the specific stud connector
c) Stud connectors shall be bent to the outside face of the column and lapped with the column longitudinal reinforcement with a lap length of l_0
d) Additional column tie reinforcement with a diameter not be less than ϕ8 mm and a spacing not be larger than 10 cm shall be placed in the supporting column along the corbel height, as shown in Figure 7.

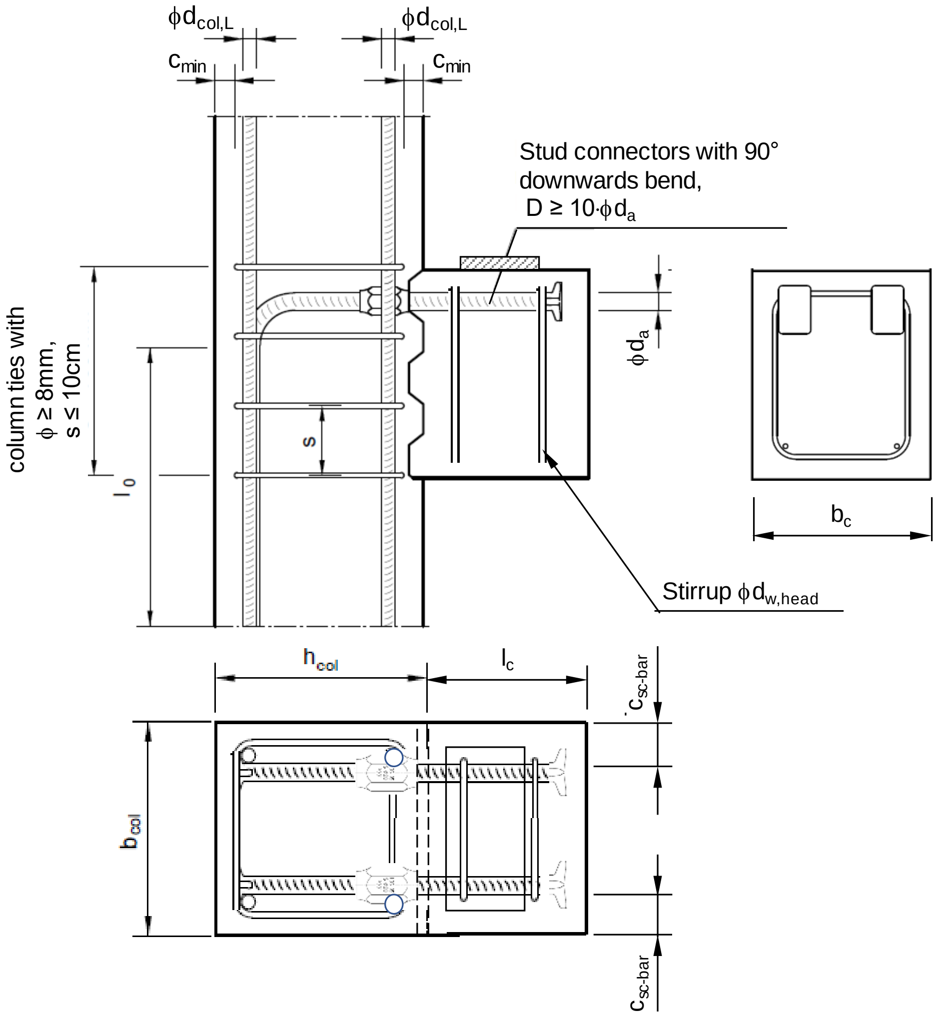


Figure 7: Anchorage of stud connectors bent downwards in the supporting column

2.2.2.10 Arrangement of stirrups in the corbel

To secure the loaded concrete area caused by stud connector anchor heads, at least one closed transverse stirrup with $\phi d_{w,head}$ in accordance with detailing rule c) of section 2.2.2.2 shall be required for each stud connector layer. It shall be arranged at the level of the anchor heads.

Stirrups for taking up splitting forces:

For $a_c / h_c \leq 0.5$ and $V_{Ed} > 0.3 \cdot V_{Rd,c,rcc}$ with $V_{Rd,c,rcc}$ given in equation (7),

either

- closed horizontal links with a total cross-section of $A_{s,link} \geq 0.5 \cdot A_{s,sc,T}$ shall be provided in addition to the stud connectors with the links encompassing both the corbel and the supporting column as shown in Figure 8(a). The cross-sectional area $A_{s,sc,T}$ of the stud connector is determined with equation (9).

or

- closed horizontal links in combination with closed vertical links each with a total cross-section of $A_{s,link} \geq 0.5 \cdot A_{s,sc,T}$ shall be provided in addition to the stud connectors with the corbel and the supporting column being separately reinforced with links as shown in Figure 8(b). The cross-sectional area $A_{s,sc,T}$ of the stud connector is determined with equation (9).

For a_c / h_c > 0.5 and V_{Ed} > $V_{Rd,c}$ with $V_{Rd,c}$ according to EN 1992-1-1, clause 6.2.2

- closed vertical links as shown in Figure 9 with a total cross-section of $A_{s,link} \geq 0.7 \cdot F_{Ed} / f_{ywd}$ with F_{Ed} according to Figure 3 and the design yield strength of stirrup reinforcing steel f_{ywd} shall be provided in addition to the stud connector reinforcement.

If there are special requirements for crack limitation, inclined stirrups at the re-entrant opening will be effective.

2.2.2.11 Verification of construction joint

If supporting column and corbel section be cast at different time the shear at interface shall be verified in accordance with section 2.2.4.

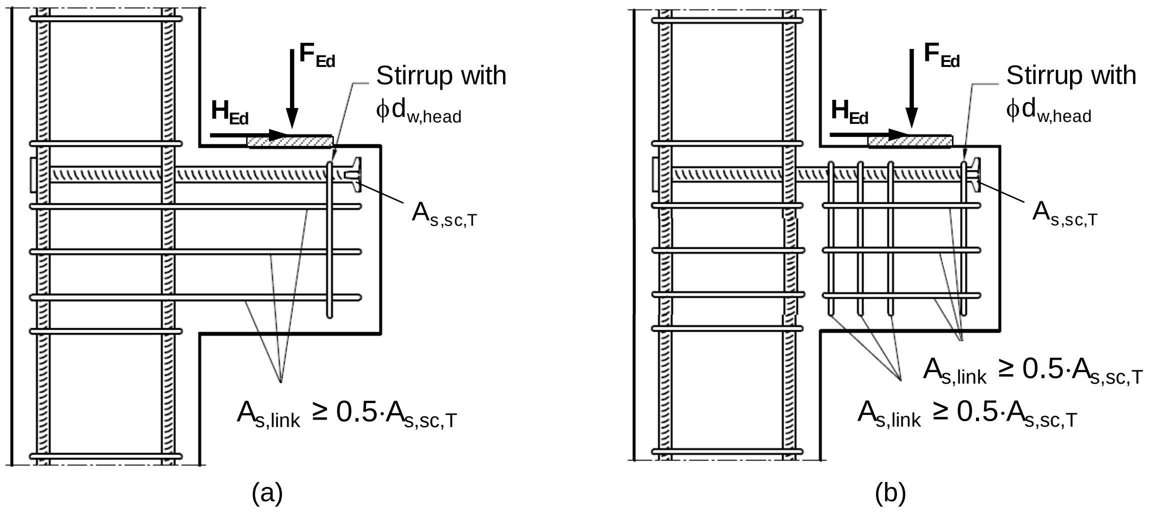


Figure 8: Corbel detailing: link reinforcement for a_c / $h_c \leq 0.5$

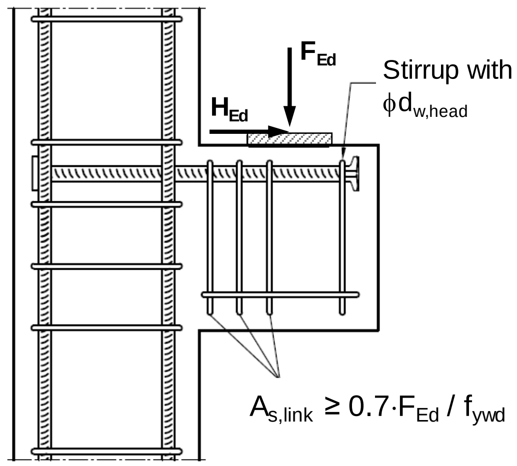


Figure 9: Corbel detailing: link reinforcement for a_c / h_c > 0.5

2.2.3 Headed stud connectors at exterior beam-column joints

2.2.3.1 General

Headed stud connectors shall be used for an end anchorage of beam top reinforcement in exterior beam-column joints. Structural analysis of stud connectors provided for beam top reinforcement in exterior beam-column joints with a sufficient ultimate strength and deformation capacity shall be carried out in accordance with EN 1992-1-1 assuming the following specific provisions.

2.2.3.2 Positioning of stud connectors and detailing rules

In ordinary cases the stud connectors are placed in a single layer. In some cases, double or more stud connector layers may be necessary. Detailed information on the mandatory supplementary reinforcement and the corresponding configuration of headed stud connectors in exterior beam-column joints are stated in the ETA for the specific stud connector.

For the alignment of the anchor heads the requirements for the concrete cover according to EN 1992-1-1 shall be apply.

The following detailing rules shall be observed:

a) The minimum column cross-section dimensions of b_{col} and h_{col} as shown in Figure 11 complies with the provision of the ETA for the specific stud connector
b) Number of column longitudinal reinforcement bars shall not be less than four. At least one bar shall be placed at each corner as shown in Figure 11 with a minimum diameter of $\phi d_{col,L}$ according to the ETA for the specific stud connector
c) Headed stud connectors used as beam top reinforcement shall be anchored at the far face of the column. Positioning of anchor heads in the column such that reach at least to the outside of the outermost layer of column longitudinal reinforcement as shown in Figure 11.
d) Additional U-link or column tie reinforcement as shown in Figure 11 with a diameter not be less than ϕ8 mm and a spacing not be larger than 10 cm shall be placed in the joint core, in the columns sections over a length of h_{col} as measured from the node sections and in the beam section over a length of h_{beam} as measured from the node section.

2.2.3.3 Forces acting on exterior beam-column joints

Figure 10 shows the strut and tie model for the design of exterior beam-column joints. The ratio of the depths of beam and column is limited by $1 \leq h_{beam}/h_{col} \leq 2$. The forces acting at the joint shall be in equilibrium.

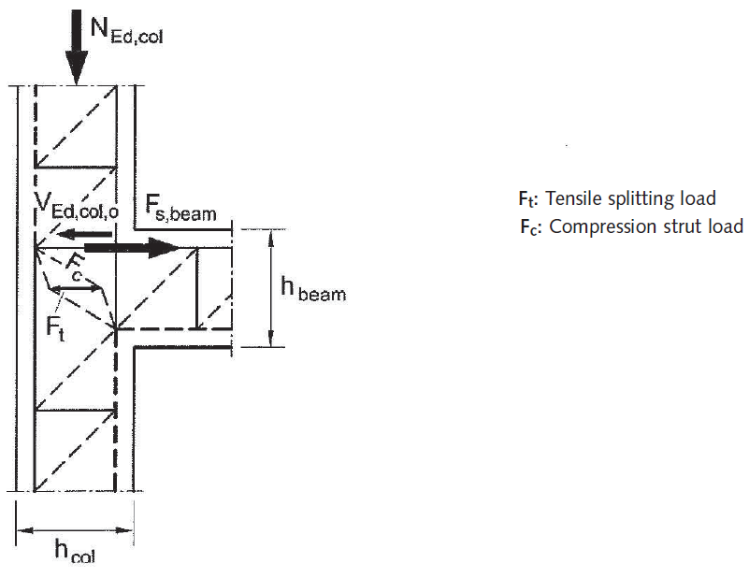


Figure 10: Strut-and-tie model for exterior beam-column joints

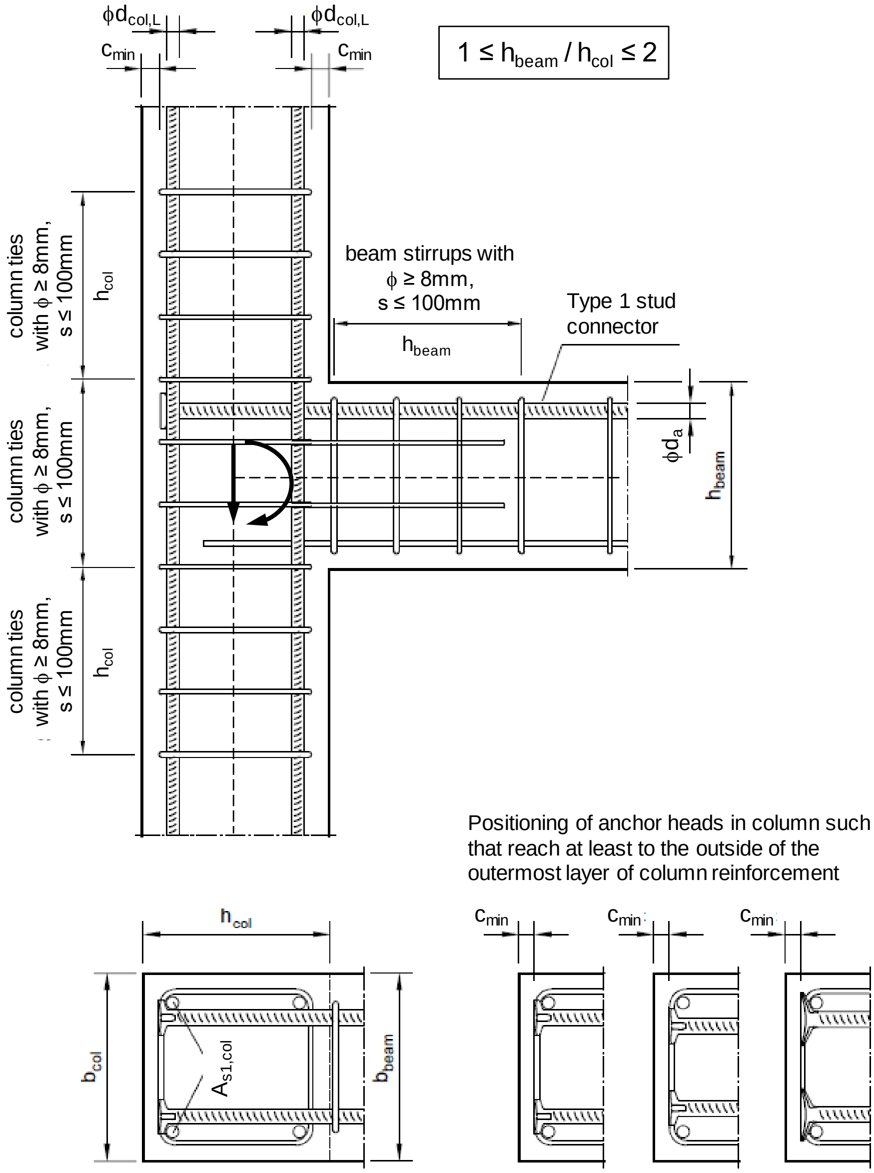


Figure 11: Dimension and reinforcement details for exterior beam-column joints

2.2.3.4 Verification of column longitudinal reinforcement

The column longitudinal reinforcement ratio for each column side $\rho_{s(..),col}$ shall be at least 0.5%:

$$\rho_{s(..),col} = \frac{A_{s(..),col}}{b_{col} \cdot h_{col}} \geq 0.5\% \qquad (11)$$

where, see Figure 11

$A_{s(..),col}$ = Cross-sectional area of column longitudinal reinforcement at half column section [mm²]

b_{col} = Column width [cm]

h_{col} = Column height [cm]

The column longitudinal reinforcement shall run straight through the node.

It shall be verified that the sum of the axial tensile and compression forces in the column longitudinal reinforcement can be anchored within the node length or rather the beam height h_{beam}. The required anchorage length l_{bd} results from the following equation:

$$l_{bd} = \frac{|T| + |C_s|}{f_{bd} \cdot n \cdot U} \leq h_{beam} \qquad (12)$$

where

T = Axial tensile force in column longitudinal reinforcement

C_s = Axial compression force in column longitudinal reinforcement

U = Circumference of a column reinforcing bar

n = Number of bars in the respective column reinforcement

f_{bd} = Design bond strength according to EN 1992-1-1, Clause 8.4.2

The anchorage of column longitudinal reinforcement $A_{s(..),col}$ shall be verified for the least favourable ratio of moment and axial force of possible combinations of actions.

The cross-sectional area of column longitudinal reinforcement obtained from bending analysis shall be increased across-the board to 33% along the node to take into account for non-restraint frame structures. This supplementary column longitudinal reinforcement shall be anchored outside the node.

2.2.3.5 Determination of beam reinforcement

The beam top reinforcement shall be determined for the beam cross-section at a distance of 0.3 · h_{col} from the neutral axis of the column.

A beam compression reinforcement shall not be taken into account in the calculation.

The lower beam reinforcement shall run straight into the node and shall end straight, i.e. unbent, in front of the far column longitudinal reinforcement.

Additionally, the detailing rules a) and d) according to section 2.2.3.2 have been observed.

2.2.3.6 Arrangement of stirrups in the beam-column joint

Beam and Columns shall be supplementary reinforced with stirrups or column ties with a diameter of at least ϕ8 mm and a maximum spacing of s ≤ 10 cm, cf. illustration in Figure 11.

The column ties of the node shear field shall be executed with U-bars or closed stirrups. The U-bars shall be anchored in the beam with an anchor length of $l_{bd} \geq d_{beam}$ with the effective depth of beam d_{beam}.

The structurally required reinforcement ratio of U-links or column ties according to the detailing rule d) in section 2.2.3.2 shall be calculated in accordance with equation (14).

2.2.3.7 Verification of joint shear strength

The magnitude of the horizontal joint shear force $V_{Ed,j}$ results from the tensile strength of the beam top reinforcement $F_{s,beam}$ and the shear force of the upper column section $V_{Ed,col,o}$:

$$V_{Ed,j} = F_{s,beam} - V_{Ed,col,o} \qquad (13)$$

where, see Figure 10

$F_{s,beam}$ = $A_{s,sc} \cdot f_{yd,sc}$

$A_{s,sc}$ = Cross-sectional area of stud connectors at the top of the beam

$f_{yd,sc}$ = Design yield strength of the stud connector according to the ETA for the specified stud connector

Verification of joint shear failure may be deemed to be satisfied if the detailing rules a) and d) according to section 2.2.3.2 have been observed and the joint shear strength has been verified with the following equation:

$$V_{Ed,j} \leq V_{Rd,j} = min \begin{cases} V_{Rd,c,j} + k_7 \cdot A_{sj,ef} \cdot f_{ywd} \\ 2 \cdot V_{Rd,c,j} \\ \gamma_{N1} \cdot \gamma_{N2} \cdot 0.3 \cdot f_{ck}/\gamma_c \cdot b_{ef} \cdot h_{col} \end{cases} \tag{14}$$

where

$V_{Rd,c,j}$ = Basic joint shear strength without stirrups according to equation (15)

k_7 = Coefficient for accounting the effective joint shear reinforcement stated in the ETA for the specific stud connector

$A_{sj,ef}$ = Effective cross-sectional area of column transverse reinforcement which is placed in the tensile zone of joint core

f_{ywd} = Design yield strength of the stirrup reinforcing steel according to EN 1992-1-1

γ_{N1} = Factor to account for the impact of axial column force, quasi-permanent load combination (SLS)

$= 1.5 \cdot \left[1 + 0.8 \cdot \frac{N_{Ed,perm,col}}{A_{col} \cdot f_{ck}}\right] \leq 1.0$

γ_{N2} = Factor to account for the impact of shear slenderness

$= 1.9 - 0.6 \cdot \frac{h_{beam}}{h_{col}} \leq 1.0$

$N_{Ed,perm,col}$ = Design value of quasi-permanent load combination (SLS) for axial column force (compression: negative)

$= \sum_{j \geq 1} N_{Gk,j} + \sum_{i \geq 1} \psi_{2,i} \cdot N_{Qk,i}$

$N_{Gk,j}$ = Characteristic value of permanent axial column force

$N_{Qk,i}$ = Characteristic value of variable axial column force

$\psi_{2,i}$ = Factor defining representative quasi-permanent value for variable actions according to EN 1992-1-1

A_{col} = $h_{col} \cdot b_{col}$

h_{col} = Column height

b_{col} = Column width

b_{ef} = Effective joint width

$= \frac{b_{beam} + b_{col}}{2} \leq b_{col}$

h_{beam} = Beam height

b_{beam} = Beam width

f_{ck} = Characteristic concrete compressive strength according to EN 1992-1-1

γ_c = Partial safety factor for concrete according to EN 1992-1-1

The design value of the basic joint shear strength without stirrup reinforcement $V_{Rd,c,j}$ is limited by $1.0 \leq \frac{h_{beam}}{h_{col}} \leq 2.0$ and given from the following equation:

$$V_{Rd,c,j} = k_6 \cdot \left[1.2 - 0.3 \cdot \frac{h_{beam}}{h_{col}}\right] \cdot \left[1 + \frac{\rho_{s1,col} - 0.5}{7.5}\right] \cdot b_{ef} \cdot h_{col} \cdot (f_{ck}/\gamma_c)^{0.25} \quad [N] \tag{15}$$

where, see Figure 11

k_6 = Coefficient for accounting the anchorage effect of stud connector stated in the ETA for the specific stud connector

h_{beam} = Beam height [mm]

h_{col} = Column height [mm]

b_{ef} = Effective joint width [mm]

$= \frac{b_{beam} + b_{col}}{2} \leq b_{col}$

b_{beam} = Beam width [mm]

b_{col} = Column width [mm]

$\rho_{s1,col}$ = Geometric ratio of the column longitudinal reinforcement cross-sectional area $A_{s1,col}$ at half column section to the area of column concrete section according to equation (11), which is limited by $0.5 \leq \rho_{s1,col} \leq 2.0$ [%]

f_{ck} = Characteristic concrete compressive strength according to EN 1992-1-1 [MPa]

γ_c = Partial safety factor for concrete according to EN 1992-1-1

2.2.3.8 Verification of construction joint

If the beam shall be cast in later times to the column the shear at the interface shall be verified in accordance with section 2.2.4.

2.2.4 Shear at the interface between concrete cast at different times

2.2.4.1 General

Structural analysis for shear at the interface surface between concrete cast at different times shall be carried out in accordance with EN 1992-1-1, Clause 6.2.5 assuming the following specific provisions.

The dimensions of the interface surface definition and indentations complies with the provisions of the ETA for the specific stud connector.

In general, couplers may be used for mechanical splice of individual lengths of stud connectors to make continuous anchor bars across the construction joint. The couplers shall have a strength, elongation and fatigue characteristics sufficient to meet the requirements of the stud connector design. The coupler shall be in accordance with a relevant ETA.

2.2.4.2 Verification of shear resistance at interface between concrete cast at different times

The shear stress at the interface between concrete cast at different times shall satisfy the following:

$$V_{Ed} \leq V_{Rd,ircc} = \min \begin{cases} c \cdot f_{ctd} \cdot b_i \cdot x_i + 1.2 \cdot \mu \cdot A_{s,i} \cdot f_{yd,i} \\ 0.5 \cdot \nu_i \cdot f_{cd} \cdot b_i \cdot h_i \end{cases} \tag{16}$$

where

c, μ = Coefficients which depend on the roughness of the interface surface are stated in the ETA for the specific stud connector

ν_i = Strength reduction factor for the roughness of the interface surface stated in the for the specific stud connector

x_i = Effective height of interface under compression stated in the ETA for the specific stud connector

b_i = Width of the interface surface stated in the ETA for the specific stud connector

h_i = Height of the interface surface stated in the ETA for the specific stud connector

f_{ctd} = Design value of the concrete tensile strength
= $f_{ctk,0.05} / \gamma_{c,t}$

$f_{ctk,0.05}$ = Characteristic 0.05% axial tensile strength of concrete according to EN 1992-1-1

$\gamma_{c,t}$ = Partial safety factor for concrete in tension
= 1.8

f_{cd} = Design value of the concrete compressive strength
= f_{ck} / γ_c

f_{ck} = Characteristic concrete compressive strength according to EN 1992-1-1

γ_c = Partial safety factor for concrete according to EN 1992-1-1

$A_{s,i}$ = Cross-sectional area of reinforcement crossing the interface, including ordinary shear reinforcement (if any), with adequate anchorage at both sides of the interface

$f_{yd,i}$ = Design yield strength of the reinforcement crossing the interface

2.2.5 Connection between structural steel member and supporting reinforced concrete member

2.2.5.1 General

Stud connectors shall be used for connection between structural steel members and supporting reinforced concrete member. Structural analysis of stud connectors for connection shall be carried out in accordance with EN 1992-1-1, EN 1993-1-1, EN 1993-1-4 or EN 1993-1-8 assuming the following specific provisions.

The resistance of the steel structure subjected to bending, shear and/or axial load is calculated according to EN 1993-1-1 and EN 1993-1-8. Hot-dip galvanization in accordance with EN ISO 1461 shall be used for permanent corrosion protection of the steel structure.

The positioning plate as a mounting template of the stud connector is not taken into account in the structural analysis. A temporary corrosion protection is achieved by using galvanization or Sendzimir galvanization. Permanent corrosion protection using hot-dip galvanization according to EN ISO 1461 shall be used for other applications. If ventilation is required for concreting, provision shall be made for an opening with ≥ Ø4 mm in the middle of the positioning plate.

2.2.5.2 Positioning of stud connectors and detailing rules

In ordinary cases the stud connectors are placed in the corners of the fixture end-plate as shown in Figure 12. Intermediate stud connectors are used if the resistance of those in the corners is not sufficient or when the values for spacings are limited due to prevent corrosion. In some cases, multi stud connector layers may be necessary. Detailed information on the mandatory supplementary reinforcement and the corresponding arrangement of stud connectors in the supporting concrete element are stated in the ETA for the specific stud connectors.

The following detailing rules shall be observed:

a) Anchoring of headed stud connector at the far face of the supporting reinforced concrete member in accordance with section 2.2.2.8 or 2.2.3
b) Anchoring of stud connector bent downwards by 90° at the far face of the supporting reinforced concrete member according to section 2.2.2.9 with transmission of the force into the column longitudinal reinforcement by a lap according to EN 1992-1-1, Clause 8.7
c) Minimum edge distance c_2 and spacing p_2 of stud connectors in a layer as shown in Figure 12 according to the ETA for the specific stud connector
d) Minimum screw-in depth in the socket in accordance with the ETA for the specific stud connector
e) One column longitudinal reinforcement bar shall be positioned at each corner on near face of connection as shown in Figure 12 with a minimum bar diameter of $\phi d_{plate,L1}$ according to the ETA for the specific stud connector
f) Additional longitudinal reinforcement shall be placed between the sockets of the stud connectors on near face of connection as shown in Figure 12 with a minimum bar diameter of $\phi d_{plate,L2}$ according to the ETA for the specific stud connector
g) Stepped distribution of column ties as a splitting reinforcement with a minimum bar diameter of $\phi d_{w,plate}$ below each stud connector layer shall be provided according to section 2.2.5.13

The longitudinal reinforcement bars with $\phi d_{plate,L2}$ shall be anchored outside the fixture end-plate with an adequate anchorage length l_{bd} according to EN 1992-1-1.

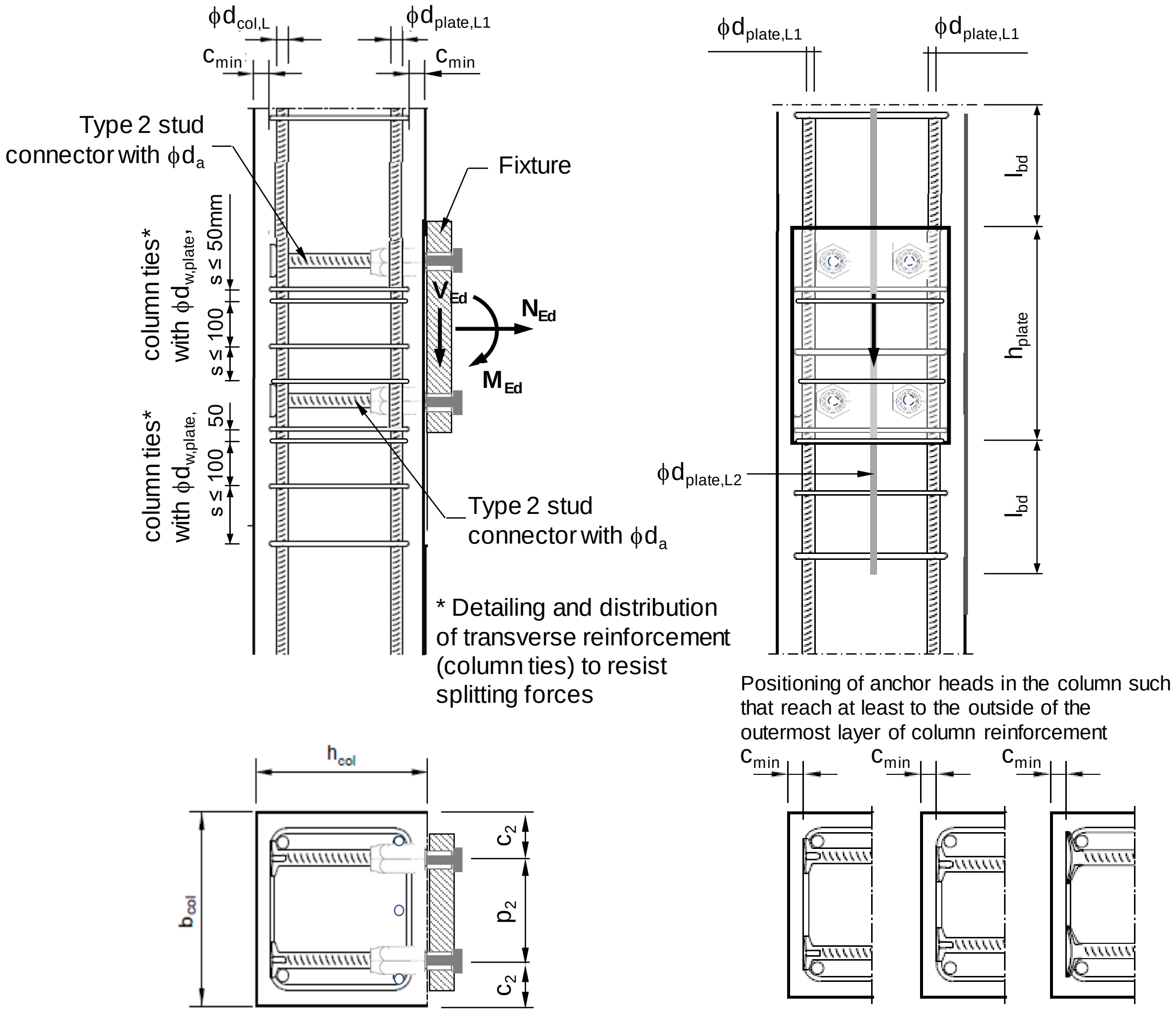


Figure 12: Dimensions and reinforcement details of a connection between structural steel member and supporting reinforced concrete member

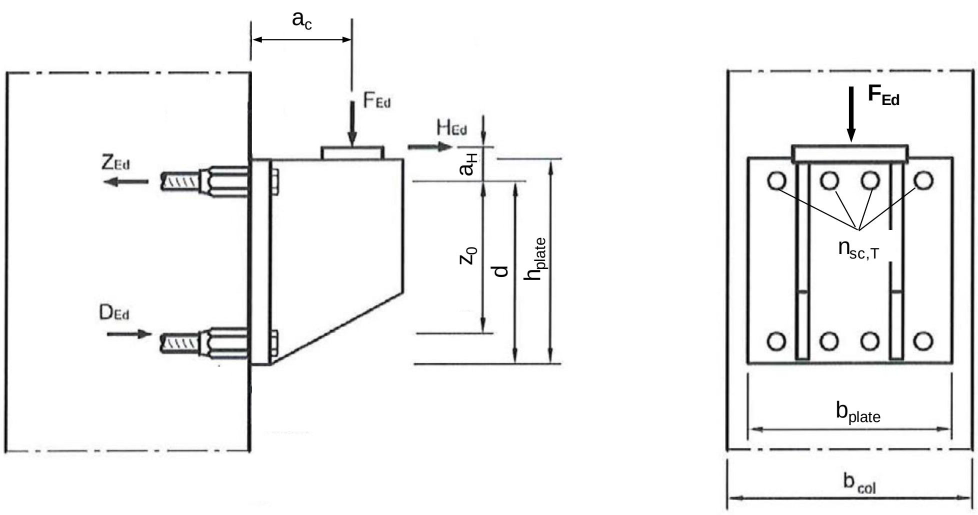


Figure 13: Strut-and-tie model of a corbel connection

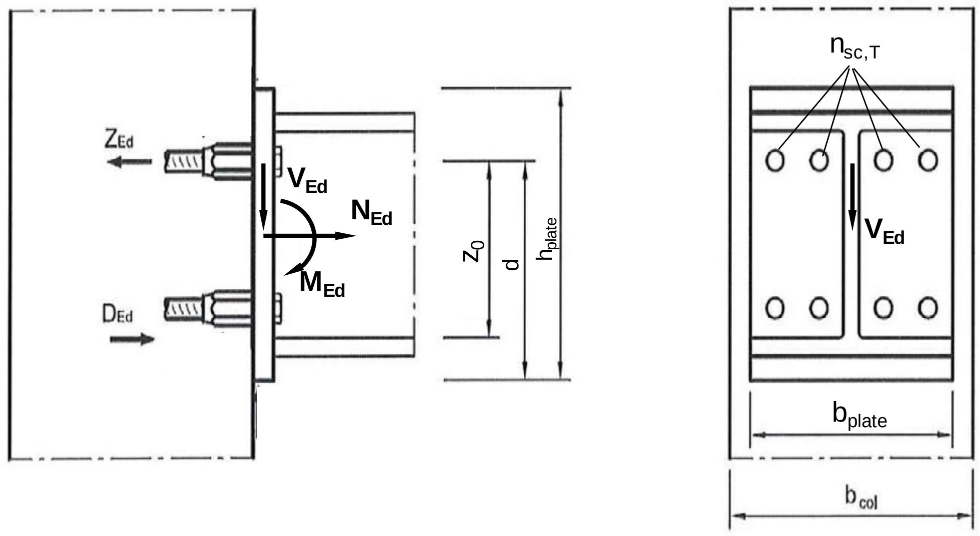


Figure 14: Strut-and-tie model of an end-plate connection (loads act at centroid of the end-plate)

2.2.5.3 Forces acting between steel and concrete element

- Corbel connection:

The design value of the shear force according to Figure 13 results from the following equation:

$$V_{Ed} = F_{Ed} \tag{17}$$

Unbeneficial effects of horizontal restraint at support bearing/loading plate caused by friction shall be considered with a horizontal outward force results from the following equation:

$$H_{Ed} \geq 0.2 \cdot F_{Ed} \tag{18}$$

- End-plate connection:

The design values of acting moment M_{Ed} and/or forces V_{Ed}, N_{Ed} at the connection between steel and concrete results from Figure 14.

2.2.5.4 Determination of tensile chord forces

- Corbel connection:

$$Z_{Ed} = V_{Ed} \cdot \frac{a_c}{z_0} + H_{Ed} \cdot \frac{a_H + z_0}{z_0} \tag{19}$$

where, see Figure 13:

V_{Ed} = Shear force according to equation (17)

H_{Ed} = Horizontal force according to equation (18) (if any)

a_c = Shear span

a_H = Distance from the centroid of the main tension reinforcement to the horizontal load H_{Ed}

z_0 = Lever arm of internal forces to determine a resulting chord force, d is the distance from centroid of the main tension reinforcement to the bottom edge of connected corbel end-plate
= 0.9 · d

- End-plate connection:

$$Z_{Ed} = \frac{M_{Ed}}{z_0} + N_{Ed} \cdot \frac{0.5 \cdot h_{plate} - 0.1 \cdot d}{z_0} \quad (20)$$

where, see Figure 14:

M_{Ed} = Design value of bending moment

N_{Ed} = Design value of axial force (if any)

h_{plate} = Heigth of fixture end-plate

d = Distance from centroid of the main tension reinforcement to the bottom edge of connected end-plate

z_0 = Lever arm of internal forces to determine a resulting chord force
= 0.9 · d

2.2.5.5 Determination of compression chord forces

- Corbel connection:

$$D_{Ed} = V_{Ed} \cdot \frac{a_c}{z_0} \quad (21)$$

where, see Figure 13:

V_{Ed} = Shear force according to equation (17)

a_c = Shear span

z_0 = Lever arm of internal forces to determine a resulting chord force, d is the distance from centroid of the main tension reinforcement to the bottom edge of connected corbel end-plate
= 0.9 · d

- End-plate connection:

$$D_{Ed} = \frac{M_{Ed}}{z_0} - N_{Ed} \cdot \frac{d - 0.5 \cdot h_{plate}}{z_0} \quad (22)$$

where, see Figure 14:

M_{Ed} = Design value of bending moment

N_{Ed} = Design value of axial force (if any)

h_{plate} = Height of fixture end-plate

d = Distance from centroid of the main tension reinforcement to the bottom edge of connected end-plate

z_0 = Lever arm of internal forces to determine a resulting chord force
= 0.9 · d

2.2.5.6 Determination of frictional forces

Shear force can be resisted by surface friction between the solid surfaces of steel or concrete due to the compressive force. The coefficients of friction for the defined solid surfaces are stated in the ETA for the specific stud connector.

Frictional force with favourable effect $V_{Ed,fr,inf}$ to be used for verification of screws, sockets and local concrete blow-out results from the following equation:

$$V_{Ed,fr,inf} = D_{Ed} \cdot \mu_{inf} \quad (23)$$

where:

D_{Ed} = Compressive force according to equation (21) or (22)

μ_{inf} = Coefficient of friction with favourable effect according to the ETA for the specific stud connector

If this resistance from friction with favourable effect shall be used in the design, appropriate measures shall be taken on site to ensure that frictional forces can be transmitted between the solid surfaces.

Frictional force with unfavourable effect $V_{Ed,fr,sup}$ to be used for verification of concrete edge failure results from the following equation:

$$V_{Ed,fr,sup} = D_{Ed} \cdot \mu_{sup} \quad (24)$$

where:

D_{Ed} = Compressive force according to equation (21) or (22)

μ_{sup} = Coefficient of friction with unfavourable effect according to the ETA for the specific stud connector

2.2.5.7 Determination of actions on the most stressed screw or stud connector

Interaction of shear, axial force and/or bending moment is taken into account by considering each individual screw or stud connector separately. Since the bending and axial loading result in tensile forces in the individual screw or stud connector, the interaction problem is simplified to interaction of tensile and shear force.

The tensile force N_{Ed}^h on the most stressed screw or stud connector of a group results from the following equation:

$$N_{Ed}^h = \frac{Z_{Ed}}{n_{sc,T}} \quad (25)$$

where, see Figure 13 or Figure 14:

Z_{Ed} = Tensile chord force according to equation (19) or (20)

$n_{sc,T}$ = Number of stud connectors placed in the tensile chord of connection

The shear force V_{Ed}^h on the most stressed screw or stud connector of a group is calculated from:

$$V_{Ed}^h = \frac{V_{Ed} - V_{Ed,fr,inf}}{n_{sc}} \quad (26)$$

where, see Figure 13 or Figure 14:

V_{Ed} = Design value of the shear force

$V_{Ed,fr,inf}$ = Frictional force with favourable effect according to equation (23)

n_{sc} = Total number of stud connectors

Frictional forces acting favourably on the shear force V_{Ed}^h may only be taken into account if their occurrence can be proven beyond doubt.

2.2.5.8 Verification of resistance to steel failure of an individual screw

The verification of shear resistance of an individual screw results from the following equation:

$$V_{Ed}^h \leq F_{v,Rd} \quad (27)$$

where:

V_{Ed}^{h} = Shear force according to equation (26)

$F_{v,Rd}$ = Design shear resistance according to EN 1993-1-4 or EN 1993-1-8

The simultaneous tensile force N_{Ed}^{h} and shear force V_{Ed}^{h} in an individual screw shall satisfy the conditions:

$$\left(\frac{N_{Ed}^{h}}{F_{t,Rd}}\right)^{2} + \left(\frac{V_{Ed}^{h}}{F_{v,Rd}}\right)^{2} \leq 1{,}0 \qquad (28)$$

$$N_{Ed}^{h} \leq F_{t,Rd} \qquad (29)$$

where:

N_{Ed}^{h} = Tensile force according to equation (25)

$F_{t,Rd}$ = Design tension resistance according to EN 1993-1-4 or EN 1993-1-8

2.2.5.9 Verification of resistance to steel failure of an individual stud connector socket

The verification of shear resistance of an individual stud connector socket results from the following equation:

$$V_{Ed}^{h} \leq V_{Rd,socket} \qquad (30)$$

where

V_{Ed}^{h} = Shear force according to equation (26)

$V_{Rd,socket}$ = Design shear strength from a simultaneous tensile and shear resistance relationship per stud connector socket according to the ETA for the specific stud connector

The verification of tensile resistance of an individual stud connector socket results from the following equation:

$$N_{Ed}^{h} \leq N_{Rd,socket} \qquad (31)$$

where

N_{Ed}^{h} = Tensile force according to equation (25)

$N_{Rd,socket}$ = Design tensile strength from a simultaneous tensile and shear resistance relationship per stud connector socket according to the ETA for the specific stud connector

2.2.5.10 Verification of tensile resistance to steel failure of an individual stud connector bar

The verification of tensile resistance $N_{Rd,s,sc}$ for an individual stud connector bar results from the following equation:

$$N_{Ed}^{h} \leq N_{Rd,s,sc} = \pi/4 \cdot d_{a}^{2} \cdot f_{yd,sc} \qquad (32)$$

where

N_{Ed}^{h} = Tensile force according to equation (25)

d_{a} = Nominal diameter of a stud connector bar according to the ETA for the specific stud connector

$f_{yd,sc}$ = Design yield strength of the stud connector according to the ETA for the specified stud connector

2.2.5.11 Verification of resistance to local concrete blow-out failure

The verification of shear load resistance $V_{Rd,c,l,bcj}$ to local concrete blow-out failure for an individual stud connector in shear results from the following equation:

$$V_{Ed}^{h} \leq V_{Rd,c,l,bcj} = \frac{k_8}{\gamma_c} \cdot d_{socket}^2 \cdot \left(f_{ck} \cdot R_{p,0.2}\right)^{0,5} \tag{33}$$

where

V_{Ed}^{h} = Shear force according to equation (26)

k_8 = Coefficient for accounting the local concrete shear resistance according to the ETA for the specific stud connector

d_{socket} = Diameter of the stud connector socket according to the ETA for the specific stud connector

f_{ck} = Characteristic concrete compressive strength according to EN 1992-1-1, for concrete strength classes > C50/60, f_{ck} = 50 MPa applies

$R_{p,0.2}$ = Characteristic yield strength of the stud connector socket according to the ETA for the specific stud connector

γ_c = Partial safety factor for concrete according to EN 1992-1-1

2.2.5.12 Verification of resistance to concrete edge failure

The verification of shear load resistance to concrete edge failure results from the following equation:

$$V_{Ed,c} \leq V_{Rd,c,bcj} \tag{34}$$

where

$V_{Ed,c}$ = Shear force acting at the concrete edge according to equation (35)

$V_{Rd,c,bcj}$ = Design shear resistance of concrete edge failure according to equation (36)

The shear force acting at the concrete edge $V_{Ed,c}$ results from the following equation:

$$V_{Ed,c} = \frac{V_{Ed} + V_{Ed,fr,sup}}{2} \tag{35}$$

where

V_{Ed} = Design value of shear force

$V_{Ed,fr,sup}$ = Frictional force with unfavourable effect according to equation (24)

The resistance to concrete edge failure $V_{Rd,c,bcj}$ results from the following equation:

$$V_{Rd,c,bcj} = k_9 \cdot b_{plate} \cdot l_{socket} \cdot \frac{\alpha_{cc}}{\gamma_c} \cdot (f_{ck})^{0,25} \tag{36}$$

where

k_9 = Coefficient for accounting the effective shear resistance on concrete edge according to the ETA for the specific stud connector

l_{socket} = Socket length according to the ETA for the specific stud connector [mm]

f_{ck} = Characteristic concrete compressive strength according to EN 1992-1-1, for concrete strength classes > C50/60, f_{ck} = 50 MPa applies [MPa]

b_{plate} = Width of fixture end-plate [mm]

α_{cc} = Coefficient taking account of long-term effects on the compressive strength and of unfavourable effects resulting from the way the load is applied according to EN 1992-1-1

γ_c = Partial safety factor for concrete according to EN 1992-1-1

2.2.5.13 Determination of splitting tensile reinforcement

A stepped distribution of adequate transverse reinforcement shall be provided to resist the splitting forces in the section of load transfer from the stud connector socket to the concrete, as indicated in Figure 15. The primary splitting reinforcement shall be placed directly below each stud connector layer. The secondary splitting reinforcement shall be distributed uniformly in the direction of the splitting over a section length of h_{sp}. The minimum link diameter of $\phi d_{w,plate}$ for the splitting reinforcement is stated in the ETA for the specific stud connector.

Existing column ties may be taken into account for the cross-sectional area of splitting reinforcement when placed in the section of splitting failure.

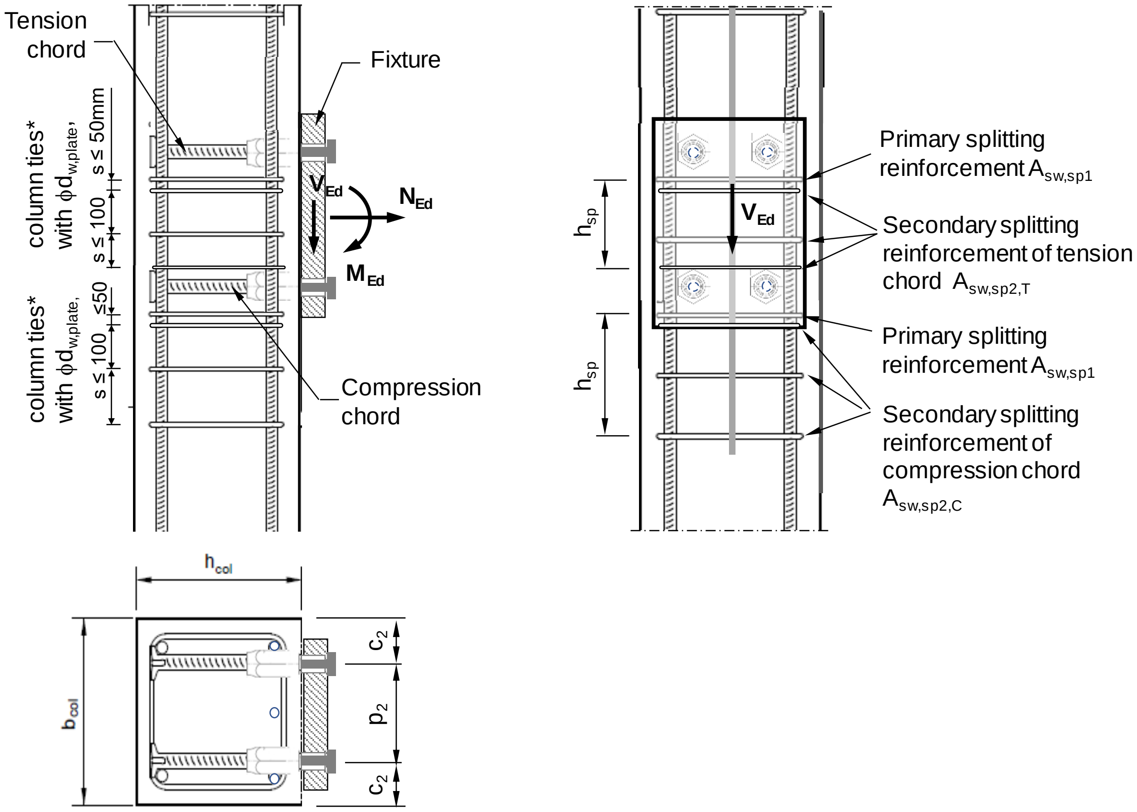


Figure 15: Splitting reinforcement of an end-plate connection

The design splitting force $Z_{Ed,sp1}$ is introduced to take account of primary splitting of the concrete due to transverse shear directly at each stud connector layer results from the following equation:

$$Z_{Ed,sp1} = \frac{V_{Ed}}{4 \cdot n_{sc}} \cdot \left(1 - \frac{d_{socket}}{\max p_2}\right) \tag{37}$$

where, see Figure 15

V_{Ed} = Design value of shear force

n_{sc} = Total number of stud connectors

d_{socket} = Socket diameter according to the ETA for the specific stud connector

max p_2 = Maximum value of horizontal spacings between adjacent stud connectors in the tension or compression chord layer

The primary splitting reinforcement $A_{sw,sp1}$ results from the following equation:

$$A_{sw,sp1} = \frac{Z_{Ed,sp,1}}{f_{ywd}} \tag{38}$$

where

$Z_{Ed,sp1}$ = Design splitting force according to equation (37)

f_{ywd} = Design yield strength of the stirrup reinforcing steel according to EN 1992-1-1

The design splitting forces for the tension chord $Z_{Ed,sp2,T}$ and for the compression chord $Z_{Ed,sp2,C}$ introduced to take account of secondary splitting of the concrete due to transverse shear over a length of h_{sp} = 2/3 · b_{plate} as measured from each stud connector layer which result from the following equations:

$$Z_{Ed,sp2,T} = 0.25 \cdot \frac{V_{Ed}}{2} \cdot \left(1 - \frac{\sum p_{2,i}}{b_{col}}\right) \tag{39}$$

$$Z_{Ed,sp2,C} = 0.25 \cdot V_{Ed,c} \cdot \left(1 - \frac{\sum p_{2,i}}{b_{col}}\right) \tag{40}$$

where

V_{Ed} = Design value of shear force

$V_{Ed,c}$ = Shear force acting at the concrete edge according to equation (35)

$p_{2,i}$ = Spacings between adjacent stud connectors of a layer

b_{col} = Column width, limited to $b_{col} \leq 3 \cdot \sum p_{2,i}$

The secondary splitting reinforcements $A_{sw,sp2,T}$ and $A_{sw,sp2,C}$ result from the following equation:

$$A_{sw,sp2,T} = \frac{Z_{Ed,sp2,T}}{f_{ywd}} \tag{41}$$

$$A_{sw,sp2,C} = \frac{Z_{Ed,sp2,C}}{f_{ywd}} \tag{42}$$

where

$Z_{Ed,sp2,T}$ = Design splitting force for the tension chord according to (39)

$Z_{Ed,sp2,C}$ = Design splitting force for the compression chord according to (40)

f_{ywd} = Design yield strength of the stirrup reinforcing steel according to EN 1992-1-1

2.3 Resistance to high-cycle fatigue

A fatigue verification of stud connectors shall be carried out in accordance with EN 1992-1-1, Clause 6.8. Fatigue characteristics of the stud connectors are in accordance with the ETA for the specific stud connector.

Two different verification procedures may be used:

- Stress range at $N=2 \cdot 10^6$ cycles $\Delta\sigma_{Rsk}$
- Stress exponents k_1 and k_2 of a S-N curve for reinforcing steel according to EN 1992-1-1, Clause 6.8, Figure 6.30

3 Reference documents

EN 206:2013+A2:2021	Concrete - Specification, performance, production and conformity
EN 1990:2002 + A1:2005 + A1:2005/AC:2010	Eurocode: Basis of structural design
EN 1992-1-1:2004 + AC:2010	Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings
EN 1993-1-1:2005 + AC:2009	Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings
EN 1993-1-4:2006 + A1:2015	Eurocode 3: Design of steel structures - Part 1-4: General rules - Supplementary rules for stainless steels
EN 1993-1-8:2005 + AC:2009	Eurocode 3: Design of steel structures - Part 1-8: Design of joints
EN 10025-2:2019	Hot rolled products of structural steels - Part 2: Technical delivery conditions for non-alloy structural steels
EN 10088-2:2014	Stainless steels - Part 2: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for general purposes
EN ISO 1461:2009	Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods
EN ISO 3506-1:2020	Fasteners - Mechanical properties of corrosion-resistant stainless- steel fasteners - Part 1: Bolts, screws and studs with specified grades and property classes
EN ISO 4014:2011	Hexagon head bolts - Product grades A and B
EN ISO 4016:2011	Hexagon head bolts - Product grade C
EN ISO 4017:2014	Fasteners - Hexagon head screws - Product grades A and B
EN ISO 4018:2011	Hexagon head screws - Product grade C
EAD 160202-00-0301	Stud connectors for anchoring in reinforced concrete members as well as for connecting steel members with reinforced concrete members

ANNEX A Specification of the Stud Connectors

This Technical Report (TR) covers a range of stud connectors made of carbon steel or stainless steel. Stud connectors are reinforcing steel bars, which are equipped with a rectangular or round head for end anchorage of reinforcement in concrete and/or a socket for fixing of a structural steel member.

A.1 Types of stud connectors

There are three different types of stud connectors:

- Type 1 (examples are given in figure A.1.1):
  Stud connectors with a rectangular anchor head on one or both ends of the reinforcing steel bar with the purpose to anchor rebar in reinforced concrete structures. The head is integrally forged from the reinforcing bar. The load-bearing area of the head shall be approximately 8 times of the cross-sectional area of the stud connector bar. If anchor heads are forged onto both ends of the bar, the heads are of the same type and size. A coupler for mechanical splices of reinforcing steel may also be used for the stud connector.
- Type 2 (examples are given in figure A.1.2):
  Stud connectors with an attached internal threaded socket on one or both ends of the ribbed reinforcement bar with the purpose of connecting a steel member with a concrete member to transmit loads into the concrete. The connection between stud connector bar and socket is realized by a screw connection.
- Type 3 (examples are given in figure A.1.3):
  A combination of type 1 and type 2 stud connector with the purpose of connecting a steel member and a concrete member and anchoring the bar in concrete.

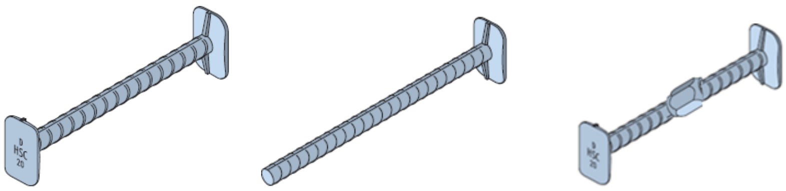


Figure A.1.1: Examples for type 1 - stud connectors with an integrally forged rectangular head on one or both ends, double headed stud connectors with a coupler for mechanical splice of stud connector bar

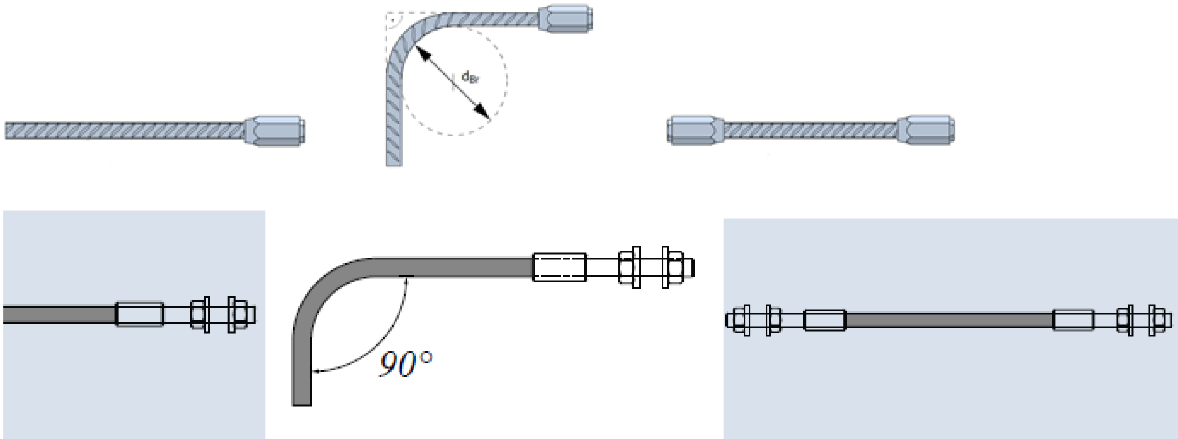


Figure A.1.2: Examples for type 2 - stud connectors with an internal threaded socket on one or both ends

Figure A.1.3: Example for type 3 - stud connector of a combination of type 1 and type 2

A.2 Applications of the intended use

Examples for applications of the intended use of stud connectors are shown in Figure A.2.1 – Figure A.2.6.

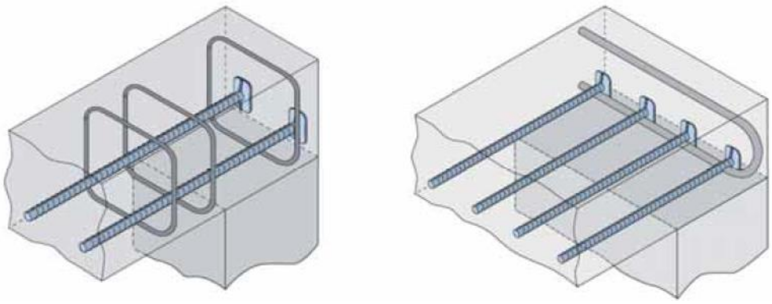


Figure A.2.1: Type 1 stud connectors in reinforced concrete slabs and beams

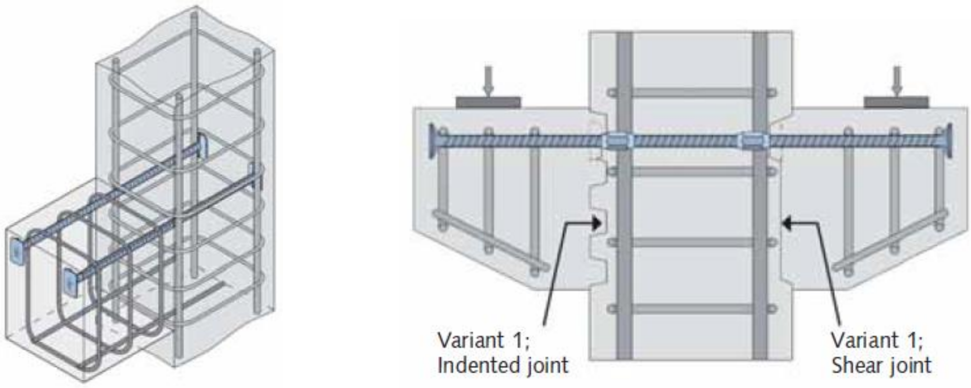


Figure A.2.2: Type 1 stud connectors in reinforced concrete corbels

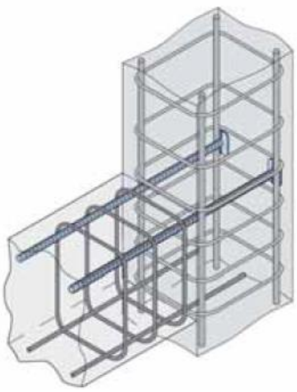


Figure A.2.3: Type 1 stud connectors in an exterior beam-column joint

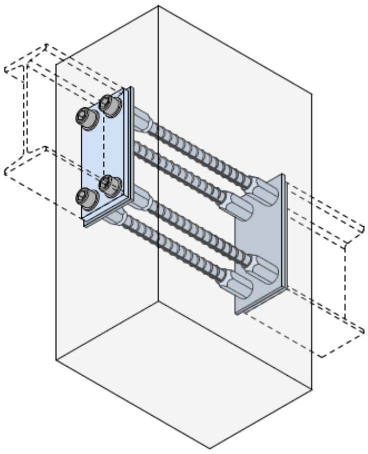


Figure A.2.4: Double-sided joint configuration with type 2 stud connectors for connection of steel members

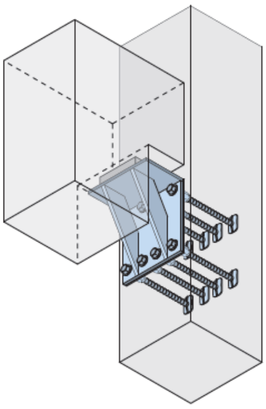


Figure A.2.5: Type 3 stud connectors for connection of steel corbels

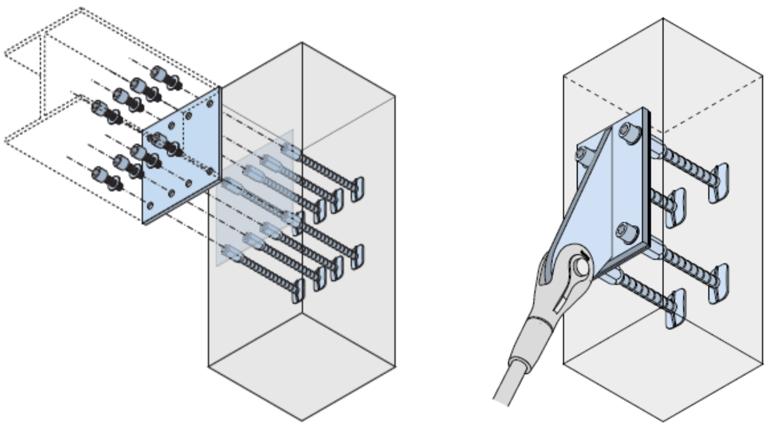


Figure A.2.6: Type 3 stud connectors for connection of steel members