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European Assessment Document for

# Stud connectors for anchoring in reinforced concrete members as well as for connecting steel members with reinforced concrete members

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This European Assessment Document (EAD) has been developed taking into account up-to-date technical and scientific knowledge at the time of issue and is published in accordance with the relevant provisions of Regulation (EU) 305/2011 as a basis for the preparation and issuing of European Technical Assessments (ETA).

# Contents

# 1 SCOPE OF THE EAD

## 1.1 Description of the construction product

### 1.1.1 General

This European Assessment Document (EAD) covers stud connectors for anchoring in reinforced concrete members as well as for connecting steel members with reinforced concrete members (in the following referred to as “stud connectors”), i.e., a range of stud connectors made of carbon steel or stainless steel. Stud connectors are reinforcing steel bars, which are equipped with a rectangular head for end anchorage of reinforcement in concrete or with a socket for fixing of a structural steel member or with both. The stud connectors do not contain any organic materials.

There are three different types of stud connectors:

- Type 1 (examples are given in Figure 1.1.1.1, (a) and (b)):
  Stud connectors with a rectangular anchor head on one or both ends of the ribbed 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 is minimum eight times 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 1.1.1.2):
  Stud connectors with an attached internal threaded socket on one or both ends of the ribbed reinforcing steel 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 1.1.1.3):
  A combination of type 1 and type 2 stud connectors with the purpose of connecting a steel member and a concrete member and anchoring the bar in concrete.

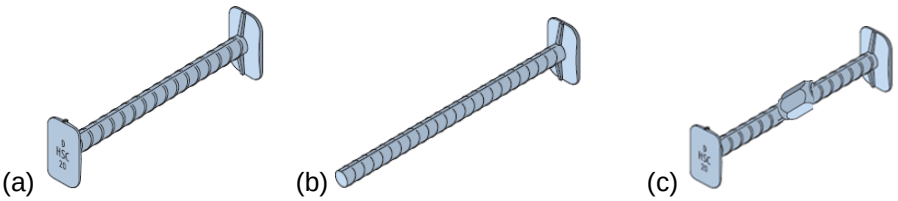
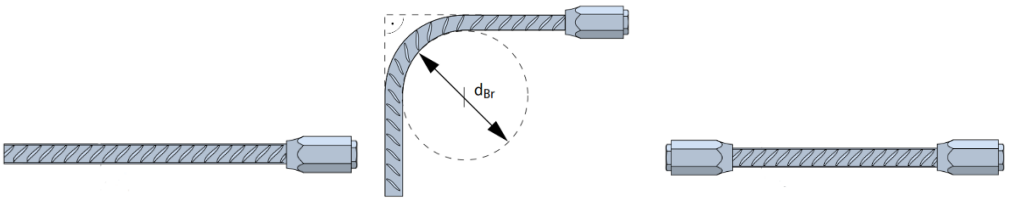



**Figure 1.1.1.1: Examples for type 1 - stud connectors with an integrally forged rectangular head on one (b) or both (a) ends, double headed stud connectors with a coupler (c) for mechanical splicing of stud connector bars**




$d_{Br}$ Diameter of mandrel

**Figure 1.1.1.2: Examples for type 2 - stud connectors with an attached internal threaded socket on one or both ends**

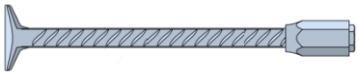
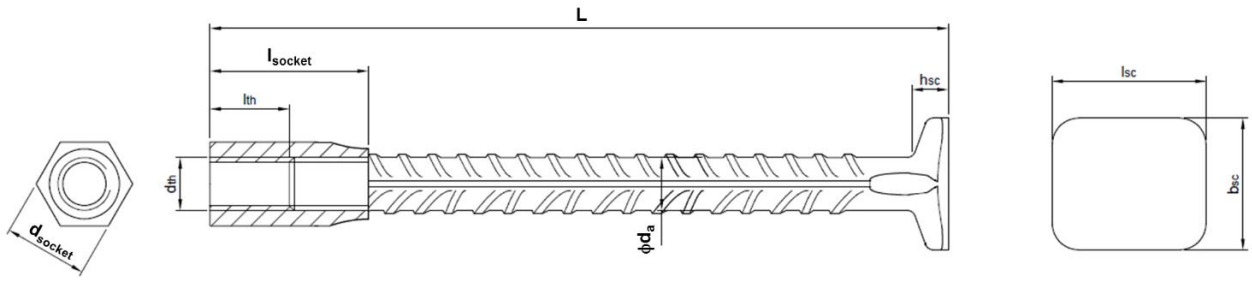


**Figure 1.1.1.3: Example for type 3 - stud connector of a combination of type 1 and type 2**

Details of the stud connector are given in figure 1.1.1.4.




| | | | |
|---|---|---|---|
| L | = length of the stud connector | $b_{sc}$ | = width of anchor head |
| $l_{socket}$ | = length of socket | $l_{sc}$ | = length of anchor head |
| $l_{th}$ | = length of internal thread | $h_{sc}$ | = height of anchor head |
| $d_{th}$ | = thread diameter | $\phi d_a$ | = nominal diameter of stud connector reinforcing steel bar |
| $d_{socket}$ | = outer diameter of socket | | |

**Figure 1.1.1.4: Details of the stud connector with rectangular anchor head and socket**

The product is not covered by a harmonised European standard (hEN).

Concerning product packaging, transport, storage, maintenance, replacement and repair it is the responsibility of the manufacturer to undertake the appropriate measures and to advise his clients on the transport, storage, maintenance, replacement and repair of the product as he considers necessary.

It is assumed that the product will be installed according to the manufacturer's instructions or (in absence of such instructions) according to the usual practice of the building professionals.

Relevant manufacturer's stipulations, e.g., with regard to the intended end use conditions, having influence on the performance of the product covered by this European Assessment Document shall be considered for the determination of the performance and detailed in the ETA as long as the details of the assessment methods as laid down in this EAD are respected.

### 1.1.2 Load-bearing components

The load-bearing components transfer tension, compression or shear forces.

This EAD covers stud connectors with the following load-bearing components:

*Stud connector with or without integrally forged rectangular anchor head:*

Reinforcing steel in accordance with EN 1992-1-1[1], Annex C, or

Stainless reinforcing steel in accordance with EN 1992-1-1, Annex C (e.g., material no. 1.4003, 1.4362, 1.4404, 1.4462, 1.4482, 1.4571)

with the following characteristics:

- Nominal diameter of stud connector reinforcing steel bar: $12\ mm \le d_a \le 25\ mm$
- Characteristic yield strength: $f_{yk} \ge 500\ MPa$
- Stress ratio (maximum strength / tensile yield strength): $(f_u / f_y)_k \ge 1,05$
- Elongation at maximum load: $\varepsilon_{uk} \ge 2,5\%$
- Load-bearing area of rectangular anchor head: $A_h \approx 8 \cdot \pi/4 \cdot d_a^2$
- Weldability (where relevant): chemical composition in accordance with EN 10080, Table 2.

Mechanical splices of reinforcing steel bars in accordance with EAD 160129-00-0301 (where relevant).

*Socket*:

Carbon steel (e.g., material no. 1.0715 in accordance with EN ISO 683-7, 1.0535, 1.1170 in accordance with EN ISO 683-1)

Zinc coated (e.g., electroplated according to EN ISO 4042 or hot dip galvanised in accordance with EN ISO 1461 or EN ISO 10684) or

Stainless steel (e.g., material no. 1.4571, 1.4404, 1.4362 in accordance with EN 10088-3, EN 10088-4, EN 10088-5).

Threaded standard or transition coupler in accordance with EAD 160129-00-0301.

### 1.1.3 Ancillary components

The following ancillary components are used with stud connectors. The intended use of the ancillary components is described in the manufacturer's product installation instruction. Ancillary components are not part of the product covered by this EAD. Ancillary components are specified by geometric parameters (such as form and dimensions) and material parameters (such as type of material, mechanical properties).

*Positioning-plate (optional)*

The positioning-plate is usually a steel plate of small thickness with screw holes to provide a mounting template that enables all sockets of type 2 stud connectors to be located in correct position and embedded surface-flush in the structural concrete member. The positioning-plate does not contribute to the load-bearing capacity of the type 2 stud connectors. The positioning-plate does not contribute to the stability of the connection on which it is installed. The positioning-plate will normally contribute to durability of the works by providing enhanced protection from the effect of weathering. The arrangement of type 2 stud connectors in the connection level by using a positioning plate is shown in Figure 1.1.3.1. The use of the positioning-plate on site is described in the manufacturer's product installation instruction.

1 All undated references to standards in this EAD are to be understood as references to the dated versions listed in chapter 4.

*End-plate of a structural steelwork member (fixture)*

The end-plate is a rectangular steel plate which is used for the fixture assembly as shown in Figure 1.1.3.2. The end-plate is usually welded on the end of a structural steel profile. The end-plate is then mechanically fastened to the type 2 stud connectors embedded in a structural concrete member by screws and washers. The use of the end-plate on site is described in the manufacturer's product installation instruction.

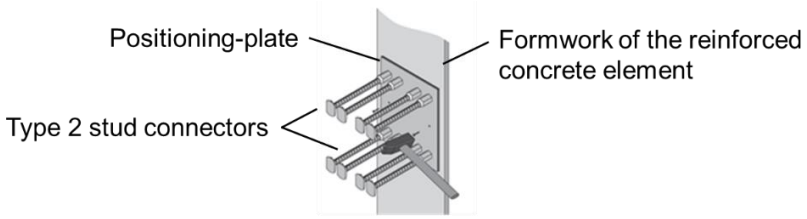



**Figure 1.1.3.1: Fastening of type 2 stud connectors at the formwork by using a positioning-plate**

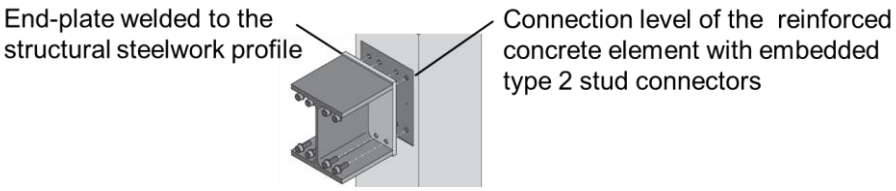



**Figure 1.1.3.2: End-plate connection of a structural steelwork profile to be connected to type 2 stud connecters**

## 1.2 Information on the intended use of the construction product

### 1.2.1 Intended use

Type 1 stud connectors are intended to be used to anchor flexural bending reinforcement in structural concrete members as illustrated in Figure 1.2.1.1 (a) - (d). The type 1 stud connector provides an end anchorage by a combination of bond and mechanical interlock between the anchor head and the concrete member or an alternative to developing reinforcement through the combination of bond and bends/hooks.

Type 2 stud connectors are intended to be used for mechanical fastening of steel members at supporting concrete members by screws. The stud connector socket is embedded surface-flush in the concrete member. A fixture is connected to the type 2 stud connectors with appropriate screws and washers as illustrated in Figure 1.2.1.1 (e) - (f). The fixture is in contact with the concrete surface (steel-to-concrete contact) or is in contact with the surface of the positioning-plate (steel-to-steel contact).

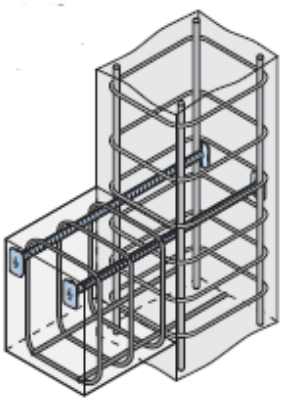
This EAD covers the following specifications of the intended use:

- Structural concrete members made of reinforced normal weight concrete of strength class in the range C20/25 to C70/85 in accordance with EN 206,
- End anchoring of type 1 stud connectors in exterior beam-column joints with dimensions and supplementary reinforcement as illustrated in Figure 1.2.1.2, calculated and designed according to EOTA TR 081;
- End anchoring of type 1 stud connectors in column/corbel joints with dimensions, concrete cover and supplementary reinforcement as illustrated in Figure 1.2.1.3, calculated and designed according to EOTA TR 081;
- Transmission of shear loads between concrete corbels cast at later time to supporting reinforced concrete members with indented interface surfaces as illustrated in Figure 1.2.1.4, calculated and designed according to EOTA TR 081;
- Transmission of tension and/or shear loads from fixtures onto type 2 stud connectors embedded in supporting reinforced concrete members with dimensions, supplementary reinforcement, edge distance and spacing of stud connectors as illustrated in Figure 1.2.1.5, calculated and designed according to EOTA TR 081;
- Resistance to quasi-static loading in accordance with Clause 2.2.1 and Table 2.2.1.1(3);
- Any fixture is fastened to the type 2 stud connector using a screw and washer. Screws are in accordance with EN ISO 4014, EN ISO 4016, EN ISO 4017, EN ISO 4018 or EN 1993-1-8; hexagon socket screws in accordance with EN ISO 4762 as well as stainless steel screws in accordance with EN ISO 3506-1 are used. The hardness of the washers corresponds to the screw property class. The design of the screws is in accordance with EOTA TR 081. The minimum and maximum value for the screw in depth for the structural steelwork socket is according to the manufacturer's product installation instructions. If there are no MPII then the following default values apply for the tolerance of the screw in depth for the structural steelwork socket:
  Minimum value: 1 time thread size of the screw,
  Maximum value: 1,4 times thread size of the screw;
- Minimum dimensions of members comply with the provisions in accordance with Figures 1.2.1.2, 1.2.1.3 and 1.2.1.5;
- Dimensions of indented construction joint and coefficients of interface surface comply with the provisions in accordance with Figure 1.2.1.4;
- Minimum diameter and positioning of supplementary reinforcement made or reinforcing steel B500B in accordance with EN 1992-1-1 comply with the provisions in accordance with Figures 1.2.1.2, 1.2.1.3 and 1.2.1.5 to ensure the load-bearing capacity and to avoid splitting of the reinforced concrete member due to load transfer;
- Minimum concrete cover complies with the provisions in accordance with Figures 1.2.1.2, 1.2.1.3 and 1.2.1.5;
- Minimum edge distance, spacing and coefficients of friction comply with the provisions in accordance with Figure 1.2.1.5;
- Positioning of stud connector anchor heads such that reach at least to the outside of the outermost layer of column reinforcement (outer column side) in accordance with Figures 1.2.1.2, 1.2.1.3 and 1.2.1.5.

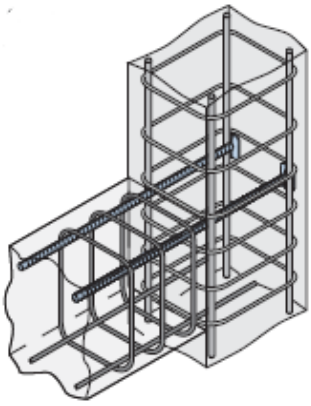
The stud connectors are intended for uses if there is no uncontrolled slip and a controlled cracking capacity in the joint shear plate up to 70 % of the maximum failure capacity of the stud connectors (see Clauses 2.2.2 to 2.2.5).

In this EAD the assessment is made to determine performances of the stud connectors which can be used for establishing mechanical resistance and stability of works under static and quasi-static loading and high-cycle fatigue loading in accordance with:

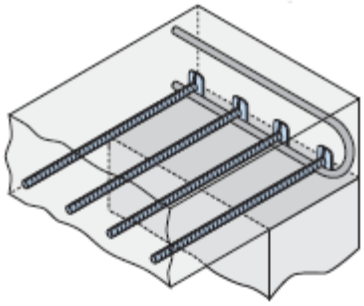
- EN 1992-1-1, EN 1993-1-1 and EN 1993-1-8
  and
- Technical Report TR 081.



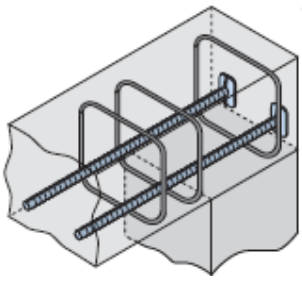
(a)



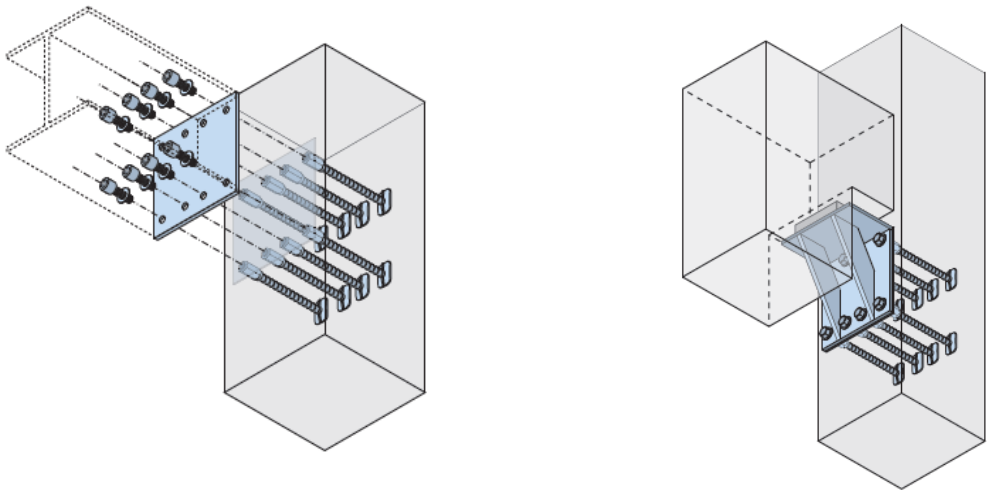
(b)



(c)

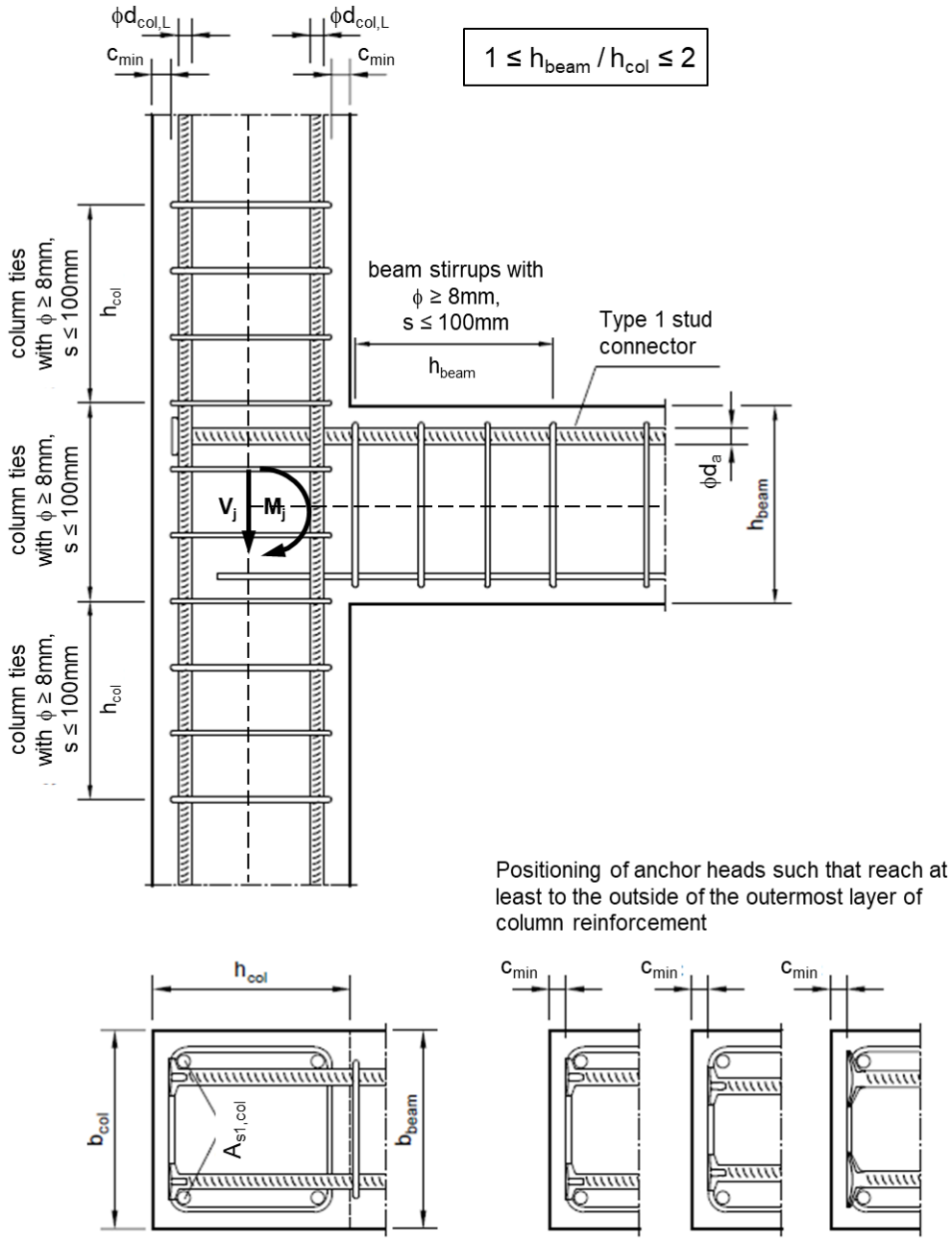


(d)



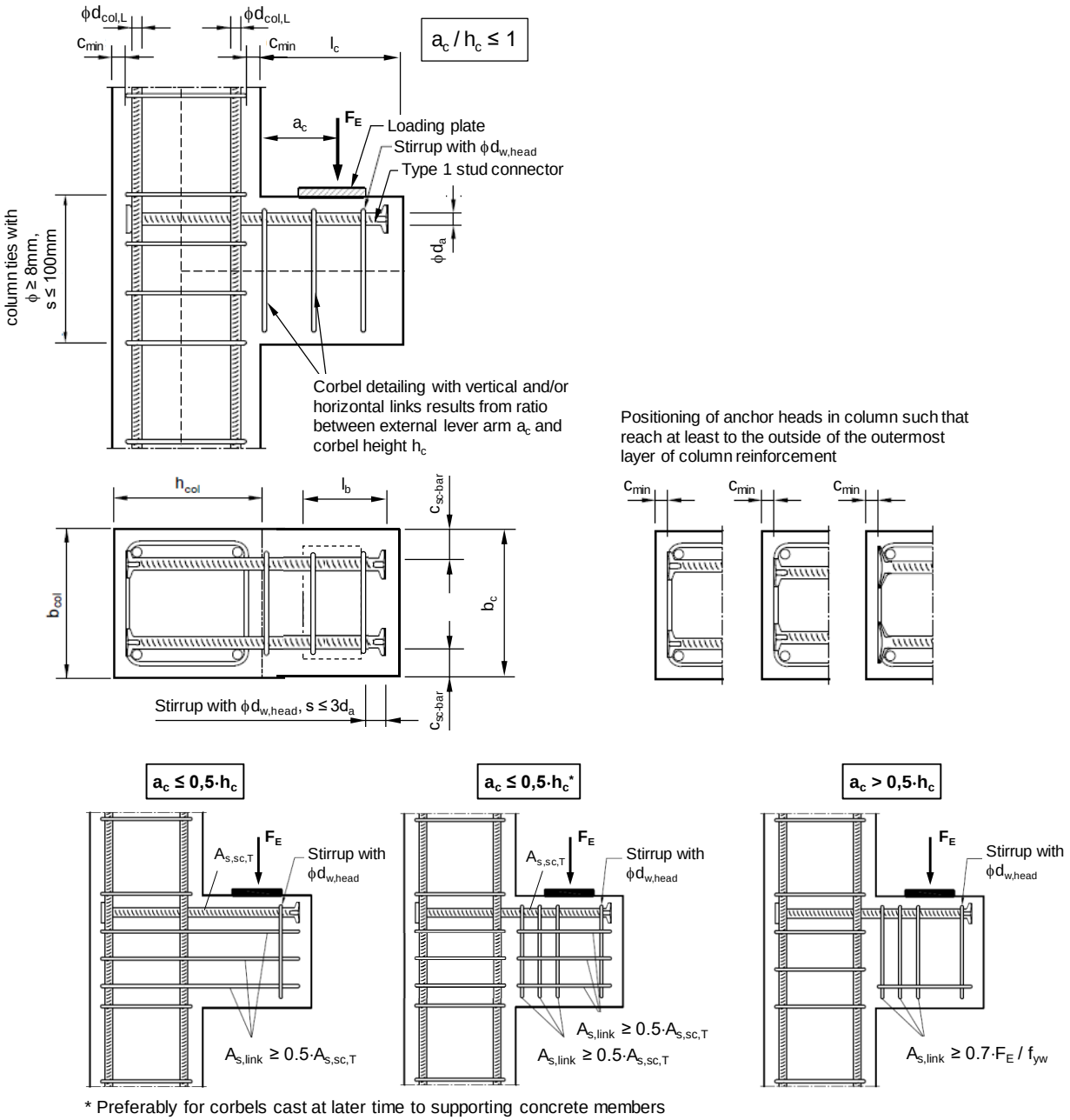
(e) (f)

**Figure 1.2.1.1: Examples for application of intended use for the stud connectors**




| Stud Connector | Column | | | Beam | | Concrete strength class |
|---|---|---|---|---|---|---|
| $\phi d_a$ | $h_{col}$ | $b_{col}$ | $\phi d_{col,L}$ | $h_{beam}$ | $b_{beam}$ | |
| [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [-] |
| 12<br>14<br>16 | ≥ 240 | ≥ 240 | ≥ 12 | ≥ 240 | ≥ 160 | C20/25 - C70/85 |
| 20 | ≥ 300 | ≥ 300 | ≥ 16 | ≥ 300 | ≥ 160 | C20/25 - C35/45 |
| | ≥ 240 | ≥ 240 | ≥ 16 | ≥ 240 | ≥ 160 | C40/50 - C70/85 |
| 25 | ≥ 400 | ≥ 300 | ≥ 20 | ≥ 400 | ≥ 160 | C20/25 |
| | ≥ 350 | ≥ 300 | ≥ 20 | ≥ 350 | ≥ 160 | C25/30 - C30/37 |
| | ≥ 300 | ≥ 300 | ≥ 20 | ≥ 300 | ≥ 160 | C35/45 - C 70/85 |

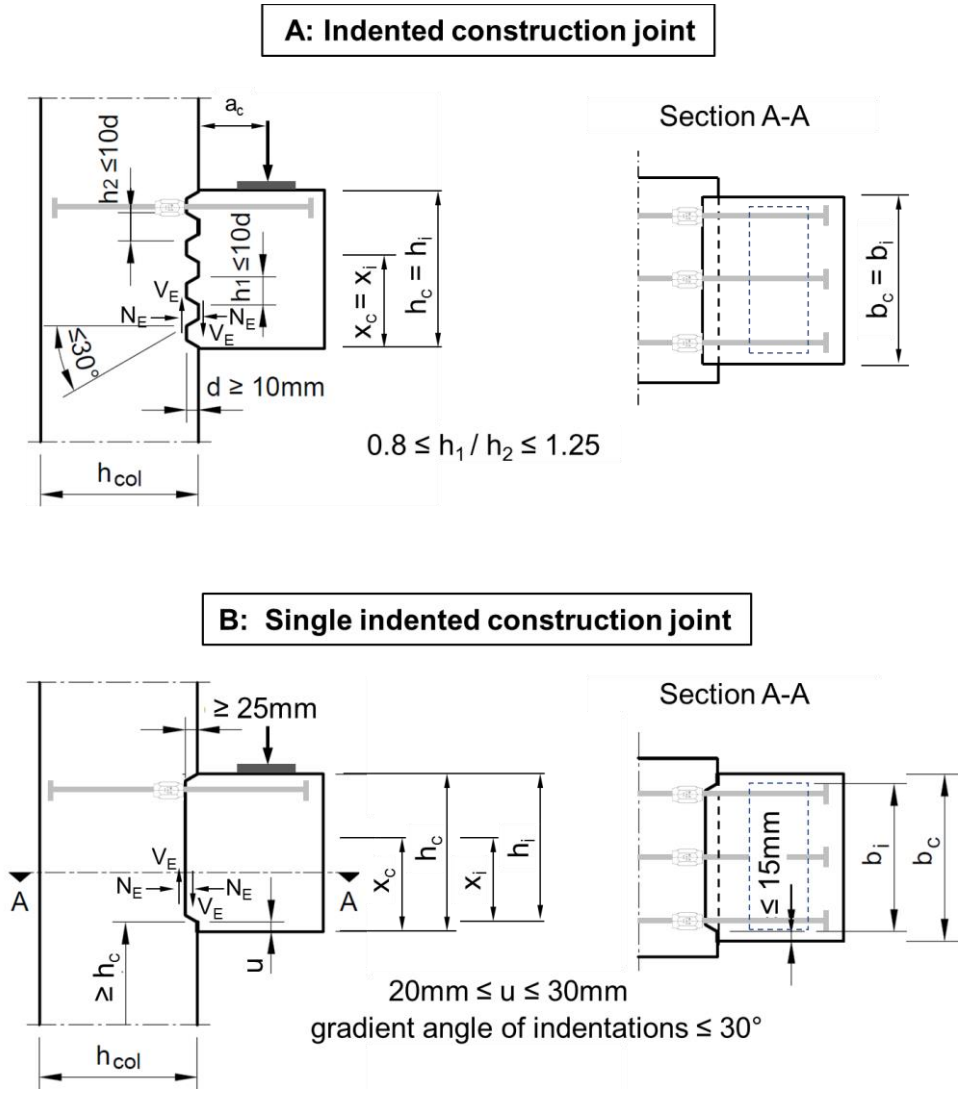
**Figure 1.2.1.2: Dimensions and arrangement of supplementary reinforcement for end anchoring of type 1 stud connectors in exterior beam-column joints**




* Preferably for corbels cast at later time to supporting concrete members

| Stud Connector | Column | | | Corbel | | | | Concrete strength class |
|---|---|---|---|---|---|---|---|---|
| $\phi d_a$ | $h_{col}$ | $b_{col}$ | $\phi d_{col,L}$ | $l_c$* | $b_c$ | $\phi d_{w,head}$ | $c_{SC-bar}$ | |
| [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [-] |
| 12 | ≥ 240 | ≥ 240 | ≥ 12 | ≥ 200 | ≥ 200 | ≥ 6 | ≥ 30 | C20/25 - C70/85 |
| 14 | ≥ 240 | ≥ 240 | ≥ 12 | ≥ 200 | ≥ 200 | ≥ 6 | ≥ 35 | C20/25 - C70/85 |
| 16 | ≥ 240 | ≥ 240 | ≥ 12 | ≥ 200 | ≥ 200 | ≥ 6 | ≥ 40 | C20/25 - C70/85 |
| 20 | ≥ 300 | ≥ 300 | ≥ 16 | ≥ 300 | ≥ 300 | ≥ 8 | ≥ 50 | C20/25 - C25/30 |
| | ≥ 300 | ≥ 300 | ≥ 16 | ≥ 200 | ≥ 240 | ≥ 8 | ≥ 50 | C30/37 - C35/45 |
| | ≥ 240 | ≥ 240 | ≥ 16 | ≥ 200 | ≥ 200 | ≥ 8 | ≥ 50 | C40/50 - C70/85 |
| 25 | ≥ 400 | ≥ 300 | ≥ 20 | ≥ 400 | ≥ 300 | ≥ 10 | ≥ 60 | C20/25 |
| | ≥ 350 | ≥ 300 | ≥ 20 | ≥ 350 | ≥ 300 | ≥ 10 | ≥ 60 | C25/30 - C30/37 |
| | ≥ 300 | ≥ 300 | ≥ 20 | ≥ 300 | ≥ 300 | ≥ 10 | ≥ 60 | C35/45 - C 70/85 |
| * Minimum dimension of corbel length $l_c$ can be reduced if the anchoring force can be verified. | | | | | | | | |

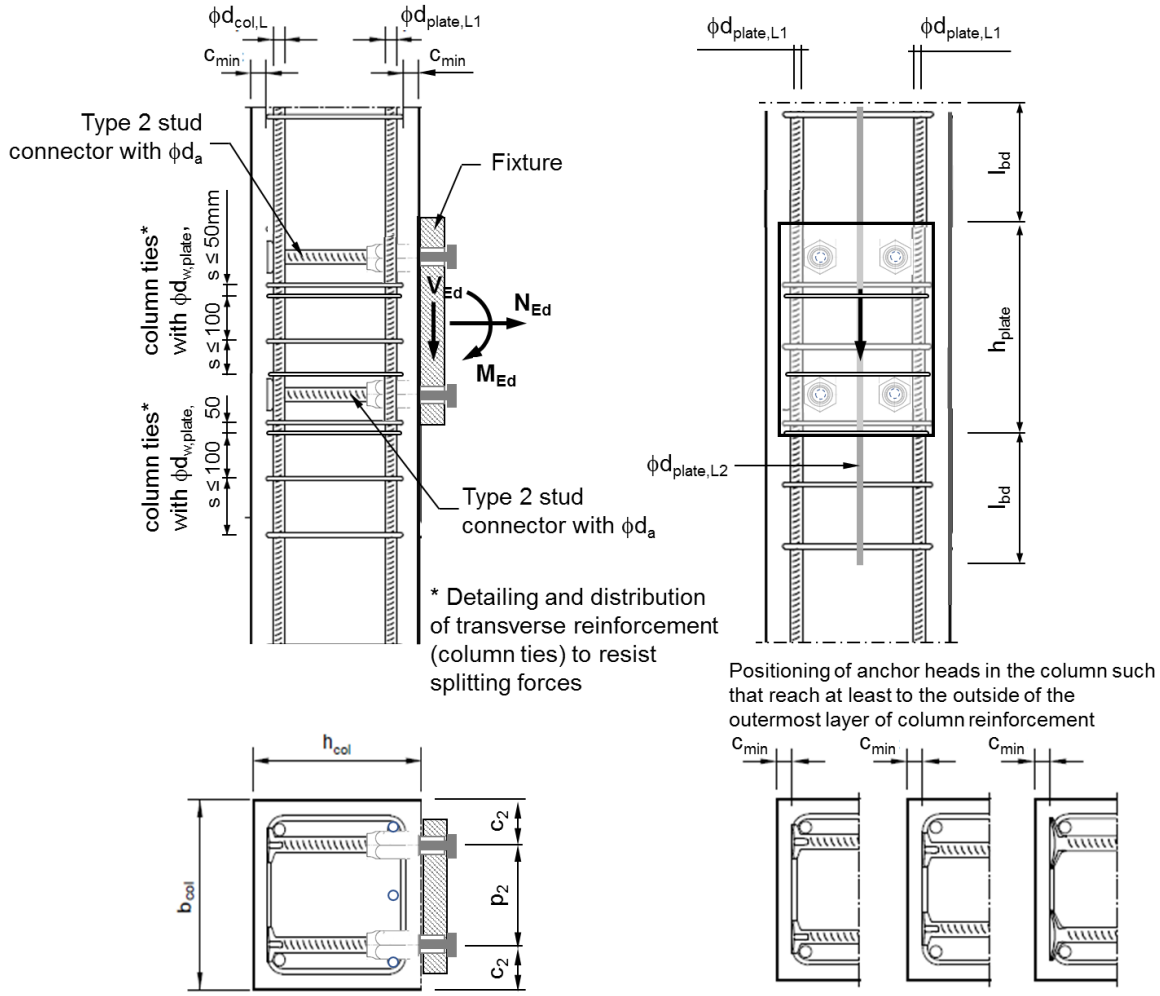
**Figure 1.2.1.3: Dimensions, concrete cover and arrangement of supplementary reinforcement for end anchoring of type 1 stud connectors in column/corbel joints**




(reinforcement of column/corbel joint is not shown in the figures)

| Classification / Type of construction joint | | c | μ | $\nu_i$ |
|---|---|---|---|---|
| | | [-] | [-] | [-] |
| A | Indented construction joint | 0.5 | 0.9 | 0.7 |
| B | Single indented construction joint | 0.4 | 0.7 | 0.5 |

**Figure 1.2.1.4: Dimensions and coefficients of interface surface for concrete corbels cast at later time to supporting reinforced concrete members**




(Positioning-plate is not shown in the figures)

| Type of contact between fixture and column | Steel-to-Steel | | Steel-to-Concrete | |
|---|---|---|---|---|
| | $\mu_{inf}$ | $\mu_{sup}$ | $\mu_{inf}$ | $\mu_{sup}$ |
| Friction which can be activated | 0.1 | 0.2 | 0.2 | 0.45 |
| Friction which cannot be activated | 0 | | 0 | |

| Stud connector $\phi d_a$ | Supporting concrete column | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $h_{col}$ | $b_{col}$ | $c_2$ | $p_2$ | $\phi d_{col,L}$ | $\phi d_{plate,L1}$ | $\phi d_{plate,L2}$ | $\phi d_{w,plate}$ | Concrete strength class |
| [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [mm] | [-] |
| 12 | ≥ 240 | ≥ 240 | ≥ 40 | ≥ 30 | ≥ 12 | ≥ 12 | ≥ 10 | ≥ 6 | C20/25 - C70/85 |
| 14 | ≥ 240 | ≥ 240 | ≥ 46 | ≥ 35 | ≥ 12 | ≥ 12 | ≥ 10 | ≥ 6 | C20/25 - C70/85 |
| 16 | ≥ 240 | ≥ 240 | ≥ 50 | ≥ 38 | ≥ 12 | ≥ 12 | ≥ 10 | ≥ 6 | C20/25 - C70/85 |
| 20 | ≥ 300 | ≥ 300 | ≥ 63 | ≥ 48 | ≥ 16 | ≥ 12 | ≥ 12 | ≥ 8 | C20/25 - C25/30 |
| | ≥ 300 | ≥ 300 | ≥ 63 | ≥ 48 | ≥ 16 | ≥ 12 | ≥ 12 | ≥ 8 | C30/37 - C35/45 |
| | ≥ 240 | ≥ 240 | ≥ 63 | ≥ 48 | ≥ 16 | ≥ 12 | ≥ 12 | ≥ 8 | C40/50 - C70/85 |
| 25 | ≥ 400 | ≥ 300 | ≥ 86 | ≥ 66 | ≥ 20 | ≥ 20 | ≥ 20 | ≥ 12 | C20/25 |
| | ≥ 350 | ≥ 300 | ≥ 86 | ≥ 66 | ≥ 20 | ≥ 20 | ≥ 20 | ≥ 12 | C25/30 - C30/37 |
| | ≥ 300 | ≥ 300 | ≥ 86 | ≥ 66 | ≥ 20 | ≥ 20 | ≥ 20 | ≥ 12 | C35/45 - C 70/85 |

**Figure 1.2.1.5: Dimensions, coefficients of friction, arrangement of supplementary reinforcement, edge distances and spacing of type 2 stud connectors for connection of fixtures to supporting concrete columns**

### 1.2.2 Working life/Durability

The assessment methods included or referred to in this EAD have been written based on the manufacturer's request to take into account a working life of the stud connectors for the intended use of 50 years when installed in the works (provided that the product is subject to appropriate installation (see 1.1)). These provisions are based upon the current state of the art and the available knowledge and experience.

When assessing the product, the intended use as foreseen by the manufacturer shall be taken into account. The real working life may be, in normal use conditions, considerably longer without major degradation affecting the basic requirements for works[2].

The indications given as to the working life of the construction product cannot be interpreted as a guarantee neither given by the product manufacturer or his representative nor by EOTA when drafting this EAD nor by the Technical Assessment Body issuing an ETA based on this EAD, but are regarded only as a means for expressing the expected economically reasonable working life of the product.

## 1.3 Specific terms used in this EAD

### 1.3.1 Terminology

Stud connector

Industrially manufactured, assembled part consisting of either forged rectangular anchor heads or assembled sockets, which serves to end anchorages in concrete or to fasten structural steel elements to a supporting reinforced concrete element.

Rectangular anchor head

Rectangular anchor head integrally forged from the reinforcement 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.

### 1.3.2 Abbreviations

**Indices**

| | |
|---|---|
| E | Action |
| L | Longitudinal |
| N | Normal force |
| R | Resistance |
| T | Tension chord |
| V | Shear |
| a | Anchor |
| b | Bond |
| bar | Reinforcing bar |
| bcj | Bolted connection joint |
| beam | Beam |
| c | Concrete, Corbel |

2 The real working life of a product incorporated in a specific works depends on the environmental conditions to which that works is subjected, as well as on the particular conditions of the design, execution, use and maintenance of that works. Therefore, it cannot be excluded that in certain cases the real working life of the product may also be shorter than referred to above.

| | |
|---|---|
| cyl | Cylinder |
| col | Column |
| ef | Effective |
| d | Design value |
| fr | Friction |
| h | Head |
| i | Interface |
| ircc | Reinforced concrete corbel with interface to column |
| inf | With favourable effect |
| j | Joint |
| k | Characteristic value |
| l | Local |
| max | Maximum |
| min | Minimum |
| plate | Plate |
| rcc | Reinforced concrete corbel |
| s | Steel |
| sc | Stud connector |
| socket | Stud connector socket |
| sup | With unfavourable effect |
| t | Tensile |
| th | Thread |
| v | Shear |
| w | Web |
| y | Yield |

**Actions, resistances, mechanical characteristics**

| | |
|---|---|
| $A_{gt,act}$ | Actual total elongation at maximum tensile force in the connected bars in case of failure inside the length of the mechanical splice |
| $A_{gt,nom}$ | Nominal total elongation at maximum tensile force of the reinforcing bar |
| COV | Coefficient of variation taken from the tests |
| $F_E$ | Corbel load |
| $F_{t,Rk}$ | Tensile resistance per screw |
| $F_{v,Rk}$ | Shear resistance per screw |
| N | Specified number of load cycles in fatigue test |
| N* | Number of load cycles in fatigue test at the kink point of S-N-curve |
| $N_{col}$ | Axial column compression load |
| $N_{Rk,socket}$ | Tension resistance per stud connector socket |
| $R_{e,act}$ | Actual yield strength of the stud connector reinforcing bar |
| $R_{e,nom}$ | Nominal yield strength of the stud connector reinforcing bar |

| | |
|---|---|
| $R_{p,0.02}$ | Yield strength of the stud connector socket steel |
| $R_{calc,i}$ | Value of resistance by calculation |
| $R_{test,i}$ | Value of failure load obtained from test |
| $(R_m/R_e)_k$ | Tensile/yield strength ratio |
| $V_{Ek,j}$ | Horizontal shear load in the joint |
| $V_{Rk,a,rcc}$ | Resistance to anchorage failure of stud connectors in corbels |
| $V_{Rk,bcj}$ | Resistance to shear failure of a bolted connection between a fixture and a supporting concrete member |
| $V_{Rk,c,j}$ | Resistance to joint shear failure without shear reinforcement |
| $V_{Rk,c,rcc}$ | Resistance to maximum concrete shear failure in corbels |
| $V_{Rk,c,bcj}$ | Resistance to concrete edge failure |
| $V_{Rk,c,l,bcj}$ | Resistance to local concrete blow-out failure |
| $V_{Rk,ircc}$ | Resistance to shear failure at the interface between a concrete corbel cast at later time to the supporting concrete column |
| $V_{Rk,j}$ | Resistance to joint shear failure |
| $V_{Rk,rcc}$ | Resistance to reinforced concrete corbel shear failure |
| $V_{Rk,s,rcc}$ | Resistance to steel failure of stud connectors in corbels |
| $V_{Rk,s,b,bcj}$ | Resistance to steel failure of the screw |
| $V_{Rk,s,socket,bcj}$ | Resistance to steel failure of the stud connector socket |
| $V_{Rk,s,sc,bcj}$ | Resistance to steel failure of the stud connector reinforcing bar |
| $V_{Rk,socket}$ | Shear resistance per stud connector socket |
| $X_i$ | Ratio of value of failure load obtained from test to value of resistance by calculation |
| $X_{i,5\%}$ | 5%-quantile of ratio $X_i$ |
| $X_m$ | Mean value of ratio $X_i$ |
| $\alpha_{ct}$ | Coefficient for the consideration of long-term effects on the concrete tensile strength |
| c~~C~~ | Coefficient which depends on the roughness of the interface surface |
| $\Delta\sigma_{Rsk}$ | Characteristic fatigue strength for N* load cycles |
| $\Delta\sigma_{Rsk,n=2\cdot10^6}$ | Characteristic fatigue strength for N = $2\cdot10^6$ load cycles |
| $\varepsilon_{uk}$ | Elongation at maximum load |
| $\overline{f_c}$ | Increased concrete strength in compression nodes |
| $f_{bk}$ | Bond strength |
| $f_{ck}$ | Concrete compressive cylinder strength (150 mm diameter by 300 mm height) |
| $f_{cm}$ | Mean value of concrete cylinder compressive strength in the test |
| $f_{ctk}$ | Concrete tensile strength |
| $f_{ctk;0.05}$ | Characteristic 0,05 % tensile strength of concrete |
| $f_{c,cyl}$ | Concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm |
| $f_{ctm}$ | Mean value of axial tensile strength of concrete in the test |
| $f_{u,min,bar,inside}$ | Minimum strength at failure inside the splice length (shear of thread, failure of the rebar inside the socket, bar pull-out out of the socket) |
| $f_{u,min,bar,outside}$ | Minimum strength at failure outside the splice length or failure of stud connector bar |

| | |
|---|---|
| $f_{u,min,socket}$ | Minimum strength at failure of the socket |
| $f_{y,i}$ | Yield strength of reinforcement crossing the interface |
| $f_{yk}$ | Characteristic value of yield strength of the stud connector reinforcing steel |
| $f_{yw}$ | Characteristic value of yield strength of the joint shear reinforcement |
| $\gamma_c$ | Partial factor for concrete |
| $\gamma_{N1}$ | Coefficient for accounting the column axial force |
| $\gamma_{N2}$ | Coefficient for accounting the shear slenderness |
| $\gamma_s$ | Partial factor for reinforcement steel |
| $\eta_1$ | Coefficient related to the quality of the bond condition and the position of the bar during concreting |
| $k_n$ | Fractile factor in accordance with EN 1990, Table D.1, for an unknown standard deviation of the population |
| $k_1$, $k_2$ | Stress exponent for S-N-curve |
| $k_6$ | Coefficient for accounting the anchorage effect of stud connector anchor head |
| $k_7$ | 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 |
| $k_{10}$ | Coefficient for accounting the anchorage effect of stud connector anchor head |
| $\rho_{s1,col}$ | Reinforcement ratio for column longitudinal reinforcement $A_{s1,col}$ |
| $\sigma_{up}$ | Upper stress level for the high-cycle fatigue test |
| $2\cdot\sigma_a$ | Stress range for the high-cycle fatigue test |
| $\nu$ | Strength reduction factor for concrete cracked in shear |
| $\nu_i$ | Strength reduction factor for the roughness of the interface surface |
| $\mu$ | Coefficient which depends on the roughness of the interface surface |
| $\mu_{inf}$ | Friction coefficient with favourable effect |
| $\mu_{sup}$ | Friction coefficient with unfavourable effect |

**Concrete, reinforcement and stud connector**

| | |
|---|---|
| $A_{c0}$ | Loaded concrete area caused by stud connector anchor heads |
| $A_{c1}$ | Design distribution area with similar shape to $A_{c0}$ |
| $A_h$ | Load-bearing area of rectangular stud connector anchor head |
| $A_{s,i}$ | Area of reinforcement crossing the interface |
| $A_{s,link}$ | Cross sectional area of corbel shear reinforcement (closed stirrups or links) |
| $A_{s,sc}$ | Area of stud connector reinforcement |
| $A_{s,sc,T}$ | Area of stud connector reinforcement in tension chord |
| $A_{sj,ef}$ | Area of the effective joint reinforcement in shear |
| $A_{s1,col}$ | Column longitudinal reinforcement of outer column face |
| $A_{s2,col}$ | Column longitudinal reinforcement of inner column face |
| L | Length of the stud connector |
| $a_c$ | Distance from column edge to vertical load |

| | |
|---|---|
| $b_{beam}$ | Width of beam |
| $a_1$ | Bearing length |
| $b_1$ | Bearing width |
| $b_c$ | Width of corbel |
| $b_{col}$ | Width of column |
| $b_{ef}$ | Effective joint width |
| $b_i$ | Width of interface surface |
| $b_{sc}$ | Width of stud connector anchor head |
| $b_{plate}$ | Width of fixture end-plate |
| $c_{min}$ | Concrete cover of reinforcement |
| $c_2$ | Edge distance from the centre of a fastener hole to the adjacent edge of any concrete member part, measured at right angles to the direction of shear load, see Figure 1.2.1.5 |
| $c_{sc\text{-}bar}$ | Concrete cover of stud connector reinforcing bar, see Figure 1.2.1.3 |
| d | Effective depth |
| $d_a$ | Nominal diameter of stud connector reinforcing steel bar |
| $d_{Br}$ | Diameter of mandrel |
| $d_{col,L}$ | Diameter of column longitudinal reinforcement |
| $d_{plate,L1}$ | Diameter of edge-strengthened column longitudinal reinforcement, see Figure 1.2.1.5 |
| $d_{plate,L2}$ | Diameter of column longitudinal reinforcement placed intermediate the socket, see Figure 1.2.1.5 |
| $d_{socket}$ | Outer diameter of stud connector socket |
| $d_{th}$ | Thread diameter |
| $d_{w,head}$ | Diameter of transverse reinforcement placed at each row of stud connector anchor head |
| $d_{w,plate}$ | Diameter of column transverse reinforcement placed below the sockets, see Figure 1.2.1.5 |
| $h_{beam}$ | Height of beam |
| $h_c$ | Height of corbel |
| $h_{col}$ | Thickness of column |
| $h_i$ | Height of interface |
| $h_{sc}$ | Thickness of stud connector anchor head |
| $h_{plate}$ | Height of fixture end-plate |
| $l_b$ | Anchorage length of stud connector bar in the corbel |
| $l_c$ | Length of corbel |
| $l_{col}$ | Length of column |
| $l_{sc}$ | Length of stud connector anchor head |
| $l_{socket}$ | Length of stud connector socket |
| $l_{th}$ | Length of internal thread |
| $n_{sc}$ | Total number of stud connectors |
| $n_{sc,T}$ | Number of stud connectors in tension chord |

| | |
|---|---|
| p | Pitch of thread |
| $p_2$ | Spacing measured perpendicular to the shear load transfer direction between adjacent lines of stud connector sockets, see Figure 1.2.1.5 |
| t | Thickness of zinc coating |
| $x_c$ | Effective concrete height under compression |
| $x_i$ | Effective height of interface under compression |
| z | Lever arm to analyse the resistance to concrete shear failure |
| $z_0$ | Lever arm of internal forces |

# 2 ESSENTIAL CHARACTERISTICS AND RELEVANT ASSESSMENT METHODS AND CRITERIA

## 2.1 Essential characteristics of the product

Table 2.1.1 shows how the performance of the stud connectors is assessed in relation to the essential characteristics.

**Table 2.1.1 Essential characteristic of the product and methods and criteria for assessing the performance of the product in relation to those essential characteristics**

| No | Essential characteristic | Assessment method | Type of expression of product performance |
|---|---|---|---|
| **Basic Works Requirement 1: Mechanical resistance and stability** | | | |
| Characteristic resistance under static and quasi-static loading | | | |
| 1 | Tension resistance of stud connectors | 2.2.1 | Level:<br>$f_{u,min,bar,outside}$ [MPa]<br>or<br>$f_{u,min,bar,inside}$ [MPa]; $A_{gt,act}$ [%]<br>or<br>$f_{u,min,bar,socket}$ [MPa]; $A_{gt,act}$ [%] |
| 2 | Resistance to joint shear failure of exterior beam-column joints | 2.2.2 | Level:<br>B1, B2 or B3 |
| 3 | Resistance to shear failure of concrete corbels | 2.2.3 | Level:<br>B1, B2 or B3 |
| 4 | Resistance to interface shear failure of concrete corbels cast at later time to supporting reinforced concrete members | 2.2.4 | Level:<br>B1, B2 or B3 |
| 5 | Resistance to failure of connection between structural steel members and supporting reinforced concrete members | 2.2.5 | Level:<br>B1, B2 or B3 |
| Characteristic resistance under fatigue loading | | | |
| 6 | Fatigue strength for N = $2 \cdot 10^6$ load cycles | Table 2.2.6.1, Row 1 | Level:<br>$\Delta\sigma_{Rsk,n=2 \cdot 10^6}$ [MPa] |
| 7 | Fatigue strength for S-N curve with specific $k_1$ [-] and $k_2$ [-] | Table 2.2.6.1, Row 2 | Level:<br>$\Delta\sigma_{Rsk}$ [MPa]; $k_1$ [-] and $k_2$ [-] |
| **Basic Works Requirement 2: Safety in case of fire** | | | |
| 8 | Reaction to fire | 2.2.7 | Class |

## 2.2 Methods and criteria for assessing the performance of the product in relation to essential characteristics of the product

This chapter is intended to provide instructions for TABs. Therefore, the use of wordings such as “shall be stated in the ETA” or “it has to be given in the ETA” shall be understood only as such instructions for TABs on how results of assessments shall be presented in the ETA. Such wordings do not impose any obligations for the manufacturer and the TAB shall not carry out the assessment of the performance in relation to a given essential characteristic when the manufacturer does not wish to declare this performance in the Declaration of Performance.

### 2.2.1 Tension resistance of stud connectors

The tension resistance in accordance with Table 2.2.1.1 shall be determined by means of testing. The tests shall be performed and assessed in accordance with the method given in Table 2.2.1.1.

In static tensile tests, 3 modes of failure, or a combination thereof, are possible:

a) Failure of the stud connector bar outside the length of the socket or failure of the anchor head or failure of the weld between the reinforcement bar and the socket;
b) Failure of the stud connector bar inside the length of the socket;
c) Failure of the socket.

The resistance is the minimum failure load of all tests.

For failure mode a) the resistance is $f_{u,min,bar,outside}$ [MPa].

For failure mode b) the resistance is $f_{u,min,bar,inside}$ [MPa].

For failure mode c) the resistance is $f_{u,min,socket}$ [MPa].

The tension resistance to quasi-static loading is verified in fatigue tensile tests according to Annex B.1.2. If no failure occurs up to $N = 2 \cdot 10^6$ load cycles the performance for quasi-static loading shall be specified in the ETA. Otherwise, in the ETA only the characteristic of static loading shall be specified.

**Table 2.2.1.1 Resistance to tension loading**

| No | Characteristic | Number of specimens per type of stud connector | Test method and assessment | Expression of performance to be stated in the ETA |
|---|---|---|---|---|
| 1 | Minimum force at failure due to tension loading (static and quasi-static loading) | **Type 1 stud connector**:<br>≥ 3 for min $d_a$<br>≥ 3 for medium $d_a$<br>(where $\Delta d_a$ > 10 mm)<br>≥ 3 for max $d_a$ | Annex A.3 | $f_{u,min,bar,outside}$ [MPa] |
| 2 | Minimum force at failure due to tension loading (static loading) | **Type 2 stud connector:**<br>≥ 3 for min $d_a$<br>≥ 3 for medium $d_a$<br>(where $\Delta d_a$ > 10 mm)<br>≥ 3 for max $d_a$ | Annex A.3 | $f_{u,min,bar,outside}$ [MPa]<br>or<br>$f_{u,min,bar,inside}$ [MPa]; $A_{gt,act}$ [%]<br>or<br>$f_{u,min,bar,socket}$ [MPa]; $A_{gt,act}$ [%] |
| 3 | Resistance to quasi-static loading | **Type 2 stud connector:**<br>≥ 3 for min $d_a$<br>≥ 3 for medium $d_a$<br>(where $\Delta d_a$ > 10 mm)<br>≥ 3 for max $d_a$ | Annex B.1.2 | $f_{u,min,bar,outside}$ [MPa]<br>or<br>$f_{u,min,bar,inside}$ [MPa]; $A_{gt,act}$ [%]<br>or<br>$f_{u,min,bar,socket}$ [MPa]; $A_{gt,act}$ [%] |

### 2.2.2 Resistance to joint shear failure of exterior beam-column joints

This test is performed in order to assess the suitability of the headed stud connector for improving the joint shear resistance of exterior beam-column joints and to determine the category to which it belongs.

The assessment of the test results shall be performed in accordance with clause A.4 of Annex A. The failure load of the exterior beam-column joint is the maximum joint shear force obtained in the test when the force cannot be increased any more.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing:

$$k_{V\_Rk,j} = \frac{R_{test,i}}{R_{calc,i}} \qquad (2.2.2.1)$$

with:

| | | | |
|---|---|---|---|
| $R_{test,j}$ | = | Failure load from the individual exterior beam-column joint test in accordance with Table A.4.1.1 of Annex A.4.1 | [N] |
| $R_{calc,i}$ | = | Load capacity of the exterior beam-column joint reinforced with type 1 stud connectors in accordance with equation (2.2.2.2) | [N] |

The characteristic factor for joint shear resistance $k_{V\_Rk,j}$ shall be determined as 5%-fractile of all tests in accordance with Annex A.8.

Equation (2.2.2.2) represents a self-contained calculation concept that takes into account various resistances of the specified exterior beam-column joints reinforced with type 1 stud connectors. Predefined parameter sets $k_6$ and $k_7$ shall be used to account for the different anchorage effect of the stud connectors. The parameter sets shall be divided into three categories B1, B2 or B3. The categories represent the degree of achievement of joint shear performance.

The categories B1, B2 or B3 differ in terms of the pre-defined parameters $k_6$ and $k_7$ used in the calculation in accordance with Equation (2.2.2.2). All calculation results shall be determined with the parameter set for given category.

The category of joint shear performance shall be stated in the ETA. The category is applicable for calculation of the shear resistance of exterior beam-column joints in accordance with EOTA TR 081.

$$R_{calc,i} = V_{Rk,j} = Min\begin{cases} \left(V_{Rk,c,j} + k_7 \cdot A_{sj,ef} \cdot f_{yw}\right) \\ 2 \cdot V_{Rk,c,j} \\ \gamma_{N1} \cdot \gamma_{N2} \cdot 0{,}3 \cdot f_{c,cyl} \cdot b_{ef} \cdot h_{col} \end{cases} \quad \text{[N]} \quad (2.2.2.2)$$

with:

| | | | |
|---|---|---|---|
| $V_{Rk,c,j}$ | = | Resistance to joint shear failure without shear reinforcement in accordance with Equation (2.2.2.3) | [N] |
| $A_{sj,ef}$ | = | Area of the effective joint reinforcement in shear (links or stirrups) | [mm²] |
| $b_{ef}$ | = | Effective joint width | [mm] |
| | = | $(b_{beam} + b_{col}) / 2 \leq b_{col}$ | |
| $b_{beam}$ | = | Width of beam | [mm] |
| $b_{col}$ | = | Width of column | [mm] |
| $h_{col}$ | = | Thickness of column | [mm] |
| $f_{c,cyl}$ | = | Concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |
| $f_{yw}$ | = | Characteristic value of yield strength of joint shear reinforcement | [MPa] |
| $k_7$ | = | Coefficient for accounting the effective joint shear reinforcement, related to the category of joint shear performance according to Table 2.2.2.1 | [-] |
| | = | | |
| $\gamma_{N1}$ | = | $1{,}5 \cdot \left(1 + 0{,}8 \cdot \frac{N_{col}}{b_{col} \cdot h_{col} \cdot f_{c,cyl}}\right) \leq 1$ | |

$\gamma_{N2}$ = $1{,}9 - 0{,}6 \cdot \frac{h_{beam}}{h_{col}} \leq 1$

$N_{col}$ = Axial column load (compression: negative) [N]

The resistance to joint shear failure without shear reinforcement shall be calculated in accordance with the following Equation:

$$V_{Rk,c,j} = k_6 \left(1{,}2 - 0{,}3 \cdot \frac{h_{beam}}{h_{col}}\right) \cdot \left(1 + \frac{\rho_{s1,col} - 0{,}5}{7{,}5}\right) \cdot b_{ef} \cdot h_{col} \cdot f_{c,cyl}{}^{\frac{1}{4}} \quad \text{[N]} \quad (2.2.2.3)$$

with:

$k_6$ = Coefficient for accounting the anchorage effect of stud connector anchor head related to the category of joint shear performance in accordance with Table 2.2.2.1 [-]

=

$\rho_{s1,col}$ = reinforcement ratio for column longitudinal reinforcement $A_{s1,col}$ according to Clause 1.2.1, Figure 1.2.1.2 [%]

= $A_{s1,col}$ / ($b_{col} \cdot h_{col}$) · 100% with $0{,}5 \leq \rho_{s1,col} \leq 2{,}0$

$h_{beam}/h_{col}$ = shear slenderness [-]

$h_{beam}$ = height of beam [mm]

$f_{c,cyl}$ = concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm [MPa]

For calculation of $R_{calc,i}$ the characteristic compressive cylinder strength $f_{ck}$ shall be determined as follows:

$$f_{c,cyl} = f_{cm} - 4 \text{ [MPa]} \quad \text{[MPa]} \quad (2.2.2.4)$$

with:

$f_{cm}$ = measured value of concrete cylinder compressive strength of an exterior beam-column joint test according to EN 206

**Table 2.2.2.1 Category of joint shear performance**

| Category of joint shear performance | B1 | B2 | B3 |
|---|---|---|---|
| $k_6$ | 0,475 | 0,455 | 0,435 |
| $k_7$ | 1,55 | 1,20 | 1,00 |

### 2.2.3 Resistance to shear failure of concrete corbels

This test is performed in order to assess the suitability of type 1 stud connectors for end anchoring of tension reinforcement in concrete corbels and to determine the category to which it belongs.

The assessment of the test results shall be performed in accordance with Clause A.5 of Annex A. The failure load of the corbel is the maximum shear force obtained in the test when the force cannot be increased any more.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing:

$$k_{V\_Rk,rcc} = \frac{R_{test,i}}{R_{calc,i}} \qquad (2.2.3.1)$$

with:

$R_{test,j}$ = Failure load from the individual exterior beam-column joint test according to Table A.5.1.1 of Annex A.5.1 [N]

$R_{calc,i}$ = Load capacity of the concrete corbel reinforced with type 1 stud connectors according to equation (2.2.3.2) [N]

The characteristic factor for corbel shear resistance $k_{V\_Rk,rcc}$ shall be determined as 5%-fractile of all tests according to Annex A.8.

Equation (2.2.3.2) represents a self-contained calculation concept that takes into account various resistances of the specified concrete corbels reinforced with type 1 stud connectors. Predefined parameter $k_{10}$ shall be used to account for the different anchorage effect of the stud connectors. The parameter shall be divided into three categories B1, B2 or B3. The categories represent the degree of achievement of corbel shear performance.

The categories B1, B2 or B3 differ in terms of the pre-defined parameter $k_{10}$ used in the calculation in accordance with Equation (2.2.3.2). All calculation results shall be determined with the parameter for given category.

The category of corbel shear performance shall be stated in the ETA. The category is applicable for calculation of the shear resistance of concrete corbels according to EOTA TR 081.

$$R_{calc,i} = V_{Rk,rcc} = \min \begin{cases} V_{Rk,c,rcc} \\ V_{Rk,s,rcc} \\ V_{Rk,a,rcc} \end{cases} \quad [N] \qquad (2.2.3.2)$$

with:

$V_{Rk,c,rcc}$ = Resistance to maximum concrete shear failure in accordance with Equation (2.2.3.3) [N]

$V_{Rk,s,rcc}$ = Resistance to steel failure of the stud connectors in accordance with Equation (2.2.3.4) [N]

$V_{Rk,a,rcc}$ = Resistance to anchorage failure of the stud connectors in accordance with Equation (2.2.3.5) [N]

$$V_{Rk,c,rcc} = 0{,}5 \cdot \nu \cdot b_c \cdot z \cdot f_{c,cyl} \quad [N] \qquad (2.2.3.3)$$

with:

$\nu$ = $\left(0{,}7 - \frac{f_{c,cyl}}{200\ MPa}\right) \geq 0{,}5$

| | | | |
|---|---|---|---|
| $b_c$ | = | Width of concrete corbel | [mm] |
| z | = | Lever arm to analyse the resistance to concrete shear failure | [mm] |
| | = | 0,9 · d | |
| d | = | Effective depth | [mm] |
| $f_{c,cyl}$ | = | concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |

$$V_{Rk,s,rcc} = A_{s,sc,T} \cdot R_{e,act} \cdot k_{10} \cdot \frac{z_0}{a_c} \quad [N] \quad (2.2.3.4)$$

with

| | | | |
|---|---|---|---|
| $A_{s,sc,T}$ | = | Area of stud connector reinforcement in the tension chord | [mm²] |
| $R_{e,act}$ | = | Actual yield strength of the stud connector reinforcing bar | [MPa] |
| $k_{10}$ | = | Coefficient for accounting the anchorage effect of stud connector anchor head related to the category of corbel shear performance according to Table 2.2.3.1 | [-] |
| $z_0$ | = | Lever arm of internal forces | [mm] |
| | = | 0,6·d | |
| d | = | Effective depth | [mm] |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |

$$V_{Rk,a,rcc} = \left(n_{sc,T} \cdot \pi \cdot d_a \cdot l_b \cdot f_{bk} + A_{c0} \cdot \overline{f_c}\right) \cdot k_{10} \cdot \frac{z_0}{a_c} \quad [N] \quad (2.32.3.5)$$

with:

| | | | |
|---|---|---|---|
| $n_{sc,T}$ | = | Number of stud connectors in the tension chord | [-] |
| $d_a$ | = | Diameter of the stud connector bar | [mm] |
| $l_b$ | = | Anchorage length of stud connector in the corbel; measured from the inner face of the loading plate to the edge of the stud connector anchor head | [mm] |
| $f_{bk}$ | = | Bond strength | [MPa] |
| | = | 2,25 · $\eta_1$ · $f_{ctk;0,05}$ | |
| $\eta_1$ | = | Coefficient related to the quality of the bond condition and the position of the bar during concreting | [-] |
| | = | 1,0 when $h_c \leq 250$mm | |
| | = | 0,7 for all other cases | |
| $f_{ctk;0,05}$ | = | 0,7 · $f_{ctm}$ | [MPa] |

| | | | |
|---|---|---|---|
| $f_{ctm}$ | = | $0,3 \cdot f_{c,cyl}{}^{2/3}$ | [MPa] |
| $\overline{f_c}$ | = | Increased concrete strength in compression nodes | [MPa] |
| | = | $f_{c,cyl} \cdot \sqrt{\frac{A_{c1}}{A_{c0}}} \leq 3,0 \cdot f_{c,cyl}$ | |
| $f_{c,cyl}$ | = | concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |
| $A_{c0}$ | = | Loaded concrete area caused by stud connector anchor heads | [mm²] |
| | = | $n_{sc,T} \cdot A_h$ | |
| $A_h$ | = | Load-bearing area of the stud connector anchor head | [mm²] |
| $A_{c1}$ | = | Design distribution area with similar shape to $A_{c0}$ | [mm²] |
| $k_{10}$ | = | Coefficient for accounting the anchorage effect of stud connector anchor head related to the category of corbel shear performance in accordance with Table 2.2.3.1 | [-] |
| $z_0$ | = | Lever arm of internal forces | [mm] |
| | = | 0,6·d | |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |

For calculation of $R_{calc,i}$ the characteristic compressive cylinder strength $f_{ck}$ shall be determined as follows:

$$f_{ck} = f_{cm} - 4 \text{ [MPa]} \quad \text{[MPa]} \quad (2.2.3.6)$$

with:

| | | |
|---|---|---|
| $f_{cm}$ | = | measured value of concrete cylinder compressive strength of a corbel shear test in accordance with EN 206 |

The following conversion factors for measured value of axial tensile strength of concrete to characteristic axial tensile strength of concrete $f_{ctk;0,05}$ or vice versa shall be used:

$$f_{ctk;0,05} = 0,7 \cdot f_{ctm} \quad \text{[MPa]} \quad (2.2.3.7)$$

with:

| | | |
|---|---|---|
| $f_{ctm}$ | = | mean value of concrete axial tensile strength of a corbel shear test in accordance with EN 206 |

**Table 2.2.3.1 Category of corbel shear performance**

| Category of corbel shear performance | B1 | B2 | B3 |
|---|---|---|---|
| $k_{10}$ | 1,0 | 0,9 | 0,8 |

### 2.2.4 Resistance to interface shear failure of concrete corbels cast at later time to supporting reinforced concrete members

This test is performed in order to assess the suitability of the type 1 stud connectors for end anchoring of tension reinforcement in corbels when the corbel is cast at later time to the supporting concrete member with an indented construction joint and to determine the category to which it belongs.

The tests also serve to confirm the coefficients for interface surfaces according to Figure 1.2.1.4 in Clause 1.2.1.

The assessment of the test results shall be performed in accordance with Clause A.6 of Annex A. The failure load of the corbel is the maximum shear force obtained in the test when the force cannot be increased any more.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing:

$$k_{V\_Rk,ircc} = \frac{R_{test,i}}{R_{calc,i}} \qquad (2.2.4.1)$$

with:

| | | | |
|---|---|---|---|
| $R_{test,j}$ | = | Failure load from the individual exterior beam-column joint test according to Table A.6.1.1 of Annex A.6.1 | [N] |
| $R_{calc,i}$ | = | Load capacity of the concrete corbel reinforced with type 1 stud connectors in accordance with equation (2.2.3.2) and equation (2.2.4.2) | [N] |

The characteristic factor for corbel shear resistance $k_{V\_Rk,ircc}$ shall be determined as 5%-fractile of all tests according to Annex A.8.

Equation (2.2.4.2) represents a self-contained calculation concept that takes into account various resistances of the specified concrete corbels reinforced with type 1 stud connectors. Predefined parameter $k_{10}$ shall be used to account for the different anchorage effect of the stud connectors. The parameter shall be divided into three categories B1, B2 or B3. The categories represent the degree of achievement of corbel shear performance.

The categories differ in terms of the pre-defined parameter $k_{10}$ used in the calculation according to Equation (2.2.3.2). All calculation results shall be determined with the parameter for given category.

The category of corbel shear performance shall be stated in the ETA. The category is applicable for calculation of the shear resistance of concrete corbels in accordance withing to EOTA TR 081.

$$R_{calc,i} = V_{Rk,ircc} = \min \begin{cases} c \cdot f_{ct} \cdot b_i \cdot x_i + 1{,}2 \cdot \mu \cdot A_{s,i} \cdot f_{y,i} \\ 0{,}5 \cdot \nu_i \cdot f_{c,cyl} \cdot b_i \cdot h_i \end{cases} \quad [\text{N}] \qquad (2.2.4.2)$$

with:

| | | | |
|---|---|---|---|
| c~~C~~ | = | Coefficient which depends on the roughness of the interface surface in accordance with Clause 1.2.1, Figure 1.2.1.4 | [-] |
| $f_{ctk}$ | = | concrete tensile strength | [MPa] |

| | | | |
|---|---|---|---|
| | = | $0{,}3 \cdot f_{c,cyl}{}^{2/3}$ | |
| $b_i$ | = | Width of surface interface | [mm] |
| $x_i$ | = | Effective height of interface under compression | [mm] |
| $\mu$ | = | Coefficient which depends on the roughness of the interface surface in accordance with Clause 1.2.1, Figure 1.2.1.4 | [-] |
| $A_{s,i}$ | = | Cross-sectional area of reinforcement crossing the interface, including ordinary shear reinforcement (if any), with adequate anchorage at both sides of the interface | [mm²] |
| $f_{y,i}$ | = | Yield strength of the reinforcement crossing the interface | [MPa] |
| $\nu_i$ | = | Strength reduction factor for the roughness of the interface surface in accordance with Clause 1.2.1, Figure 1.2.1.4 | [-] |
| $f_{c,cyl}$ | = | concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |
| $h_i$ | = | Height of the interface | [mm] |

For calculation of $R_{calc,i}$ the characteristic compressive cylinder strength $f_{ck}$ shall be determined as follows:

$$f_{ck} = f_{cm} - 4 \text{ [MPa]} \quad \text{[MPa]} \quad (2.2.4.3)$$

with:

| | | | |
|---|---|---|---|
| $f_{cm}$ | = | measured value of concrete cylinder compressive strength of a corbel shear test according to EN 206 | |

### 2.2.5 Resistance to failure of a connection between structural steel member and supporting reinforced concrete member

This test is performed in order to assess the suitability of type 2 stud connectors for connection between structural steelwork member and a supporting reinforced concrete member and to determine the category to which it belongs.

The assessment of the test results shall be performed in accordance with Clause A.7 of Annex A. The failure load of the connection is the maximum shear force obtained in the test when the force cannot be increased any more.

An evaluation of all tests shall be carried out by comparing the value determined by calculation with the value determined by testing:

$$k_{V\_Rk,bcj} = \frac{R_{test,i}}{R_{calc,i}} \quad (2.2.5.1)$$

with:

| | | | |
|---|---|---|---|
| $R_{test,j}$ | = | Failure load from the individual exterior beam-column joint test in accordance with Table A.7.1.1 of Annex A.7.1 | [N] |
| $R_{calc,i}$ | = | Load capacity of the connection between a structural steelwork member and a supporting concrete member reinforced with type 2 stud connectors in accordance with equation (2.2.5.2) | [N] |

The characteristic factor for connection shear resistance $k_{V\_Rk,bcj}$ shall be determined as 5%-fractile of all tests according to Annex A.8.

Equation (2.2.5.2) represents a self-contained calculation concept that takes into account various resistances of the specified connection with stud connectors. Predefined parameters $k_8$ and $k_9$ shall be used to account for the different effective shear resistance of stud connectors. The parameters shall be divided into three categories B1, B2 or B3. The categories represent the degree of achievement of connection shear performance.

The categories B1, B2 or B3 differ in terms of the pre-defined parameters $k_8$ and $k_9$ used in the calculation in accordance with Equation (2.2.5.2). All calculation results shall be determined with the parameter set for given category.

The category of connection shear performance shall be stated in the ETA. The category is applicable for calculation of the connection of structural steelwork members to supporting reinforced concrete members in accordance withing to EOTA TR 081.

$$R_{calc,i} = V_{Rk,bcj} = \min \begin{cases} V_{Rk,c,l,bcj} \\ V_{Rk,c,bcj} \\ V_{Rk,s,b,bcj} \\ V_{Rk,s,socket,bcj} \\ V_{Rk,s,sc,bcj} \end{cases} \quad \text{[N]} \quad (2.2.5.2)$$

with:

| | | | |
|---|---|---|---|
| $V_{Rk,c,l,bcj}$ | = | Resistance to local concrete blow-out failure in accordance with Equation (2.2.5.3) | [N] |
| $V_{Rk,c,bcj}$ | = | Resistance to concrete edge failure in accordance with Equation (2.2.5.4) | [N] |
| $V_{Rk,s,b,bcj}$ | = | Resistance to steel failure of the screws in accordance with Equation (2.2.5.5) | [N] |
| $V_{Rk,s,socket,bcj}$ | = | Resistance to steel failure of the stud connector sockets in accordance with Equation (2.2.5.6) | [N] |
| $V_{Rk,s,sc,bcj}$ | = | Resistance to steel failure of the stud connector reinforcing bars in accordance with Equation (2.2.5.7) | [N] |

$$V_{Rk,c,l,bcj} = n_{sc} \cdot k_8 \cdot {d_{socket}}^2 \cdot \sqrt{f_{c,cyl} \cdot R_{p,0,2}} \cdot 1/\left(1 - a_c/z_0 \cdot \mu_{inf}\right) \quad \text{[N]} \quad (2.2.5.3)$$

with:

| | | | |
|---|---|---|---|
| $n_{sc}$ | = | Total number of stud connectors | [-] |
| $k_8$ | = | Coefficient for accounting the local concrete shear resistance related to the category of connection shear performance in accordance with Table 2.2.5.1 | [-] |
| $d_{socket}$ | = | Outer diameter of stud connector socket attached on the stud connector bar with diameter $d_a$ | [mm] |
| $f_{c,cyl}$ | = | concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |

| | | | |
|---|---|---|---|
| $R_{p,0.2}$ | = | Yield strength of the stud connector socket steel | [MPa] |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |
| $z_0$ | = | Lever arm of internal forces<br>= 0,9 · d | [mm] |
| d | = | Effective depth | [mm] |
| $\mu_{inf}$ | = | Coefficient of friction with favourable effect in accordance with Clause 1.2.1, Figure 1.2.1.5 | [-] |

$$V_{Rk,c,bcj} = 2 \cdot k_9 \cdot b_{plate} \cdot l_{socket} \cdot 0{,}85 \cdot {f_{c,cyl}}^{0,25} \cdot 1/\left(1 + a_c/z_0 \cdot \mu_{sup}\right) \quad \text{[N]} \quad (2.2.5.4)$$

with:

| | | | |
|---|---|---|---|
| $k_9$ | = | Coefficient for accounting the effective shear resistance on concrete edge related to the category of joint shear performance in accordance with Table 2.2.5.1 | [-] |
| $b_{plate}$ | = | Width of the fixture end-plate | [mm] |
| $l_{socket}$ | = | Length of stud connector socket | [mm] |
| $f_{c,cyl}$ | = | concrete compressive strength measured on cylinders with a diameter of 15 cm and a height of 30 cm | [MPa] |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |
| $z_0$ | = | Lever arm of internal forces<br>0,9 · d | [mm] |
| d | = | Effective depth | [mm] |
| $\mu_{sup}$ | = | Coefficient of friction with unfavourable effect in accordance with Clause 1.2.1, Figure 1.2.1.5 | [-] |

$$V_{Rk,s,b,bcj} = min\begin{cases} n_{sc} \cdot F_{v,Rk} \cdot 1/\left(1 - a_c/z_0 \cdot \mu_{inf}\right) \\ n_{sc,T} \cdot F_{t,Rk} \cdot \dfrac{z_0}{a_c} \\ \sqrt{\dfrac{1}{\left(\dfrac{a_c/z_0}{n_{sc,T} \cdot F_{t,Rk}}\right)^2 + \left(\dfrac{1 - a_c/z_0 \cdot \mu_{inf}}{n_{sc} \cdot F_{v,Rk}}\right)^2}} \end{cases} \quad \text{[N]} \quad (2.2.5.5)$$

with:

| | | | |
|---|---|---|---|
| $n_{sc}$ | = | Total number of stud connectors | |
| $F_{v,Rk}$ | = | Shear resistance per screw in accordance with EN 1993-1-8, Table 3.4 | [N] |
| $n_{sc,T}$ | = | Number of stud connectors in the tension chord | |

| | | | |
|---|---|---|---|
| $F_{t,Rk}$ | = | Tension resistance per screw according to EN 1993-1-8, Table 3.4 | [N] |
| $z_0$ | = | Lever arm of internal forces | [mm] |
| | = | 0,9 · d | |
| d | = | Effective depth | [mm] |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |
| $\mu_{inf}$ | = | Coefficient of friction with favourable effect in accordance with Clause 1.2.1, Figure 1.2.1.5 | |

$$V_{Rk,s,socket,bcj} = min \begin{cases} n_{sc} \cdot V_{Rk,socket} \\ n_{sc,T} \cdot N_{Rk,socket} \cdot \frac{z_0}{a_c} \\ N_{Rk,socket} - V_{Rk,Socket}\ interaction^* \end{cases} \quad [N] \quad (2.2.5.6)$$

with:

| | | | |
|---|---|---|---|
| $n_{sc}$ | = | Total number of stud connectors | [-] |
| $V_{Rk,socket}$ | = | Shear resistance per stud connector socket | [N] |
| $n_{sc,T}$ | = | Number of stud connectors in the tension chord | [-] |
| $N_{Rk,socket}$ | = | Tension resistance per stud connector socket | [N] |
| $z_0$ | = | Lever arm of internal forces | [mm] |
| | = | 0,9 · d | |
| d | = | Effective depth | [mm] |
| $a_c$ | = | Distance from column edge to the vertical load | [mm] |
| * | | N-V interaction shall be addressed for the resistance to steel failure of the stud connector socket, in case of combined normal and shear force. Sufficient load-bearing capacity of interaction condition shall be verified on the basis of the experimental values. | |

$$V_{Rk,s,sc,bcj} = A_{s,sc,T} \cdot R_{e,act} \cdot \frac{z_0}{a_c} \quad [N] \quad (2.2.5.7)$$

with:

| | | | |
|---|---|---|---|
| $A_{s,sc,T}$ | = | Area of stud connector reinforcement in the tension chord | [mm²] |
| $R_{e,act}$ | = | Actual yield strength of the stud connector reinforcing bar | [MPa] |
| $z_0$ | = | Lever arm of internal forces | [mm] |
| | = | 0,9 · d | |
| d | = | Effective depth | [mm] |

$a_c$ = Distance from column edge to the vertical load [mm]

For calculation of $R_{calc,i}$ the characteristic compressive cylinder strength $f_{ck}$ shall be determined as follows:

$$f_{c,cyl} = f_{cm} - 4 \text{ [MPa]} \quad \text{[MPa]} \quad (2.2.5.8)$$

with:

$f_{cm}$ = measured value of concrete cylinder compressive strength of an exterior beam-column joint test according to EN 206

**Table 2.2.5.1 Category of connection shear performance**

| Category of connection shear performance | B1 | B2 | B3 |
|---|---|---|---|
| $k_8$ | 1,44 | 1,22 | 1,0 |
| $k_9$ | 15,0 | 12 | 10 |

### 2.2.6 Characteristic resistance under fatigue loading

For the determination of characteristic fatigue strength, testing in accordance with Table 2.2.6.1 (minimum one of the characteristics No. 1 or 2) shall be performed. The characteristic applied shall be stated in the ETA.

**Table 2.2.6.1 Characteristic resistance under fatigue loading**

| No | Characteristic | Number of specimens per type of stud connector | Test method and assessment | Expression of performance to be stated in the ETA |
|---|---|---|---|---|
| 1 | Fatigue strength for N = $2 \cdot 10^6$ load cycles | ≥ 3 for min $d_a$<br>≥ 3 for medium $d_a$<br>(where $\Delta d_a$> 10mm)<br>≥ 3 for max $d_a$ | Annex B, Clause B.1.3 | Level:<br>$\Delta\sigma_{Rsk,n=2 \cdot 10^6}$ [MPa] |
| 2 | Fatigue strength for S-N curve with specific $k_1$ [-] and $k_2$ [-] | ≥ 24 with most unfavourable $d_a$ | Annex B, Clause B.1.4 | Level:<br>$\Delta\sigma_{Rsk}$ [MPa];<br>$k_1$ [-] and $k_2$ [-] |

### 2.2.7 Reaction to fire

The stud connectors are considered to satisfy the requirements of class A1 of the reaction-to-fire performance in accordance with the Commission Decision 96/603/EC, as amended by Commission Decisions 2000/605/EC and 2003/424/EC, without the need for testing on the basis of it fulfilling the conditions set out in that Decision and its intended use being covered by that Decision.

Therefore, when the conditions referred to above are fulfilled, the performance of the product is class A1 which shall be stated in the ETA.

# 3 ASSESSMENT AND VERIFICATION OF CONSTANCY OF PERFORMANCE

## 3.1 System(s) of assessment and verification of constancy of performance to be applied

For the products covered by this EAD the applicable European legal act is Commission Decision 2000/606/EC.

The system is 1+.

## 3.2 Tasks of the manufacturer

The cornerstones of the actions to be undertaken by the manufacturer of the product in the procedure of assessment and verification of constancy of performance are laid down in Table 3.2.1.

**Table 3.2.1 Control plan for the manufacturer; cornerstones**

| No | Subject/type of control | Test or control method | Criteria | Minimum number of samples | Minimum frequency of control |
|---|---|---|---|---|---|
| **Factory production control (FPC) [including testing of samples taken at the factory in accordance with a prescribed test plan]** | | | | | |
| Raw material | | | | | |
| 1 | Mechanical characteristics (inspection certificates) | 3.4.1 | According to Control plan | all | Every heat of material |
| Tests after production steps | | | | | |
| 2 | Socket - dimensions and tolerances; coating (where relevant) | 3.4.2 | According to Control plan | 1 per size [1)] | Every 500 pieces of each batch or per each batch [2)] |
| 3 | Anchor head - dimensions and tolerances | 3.4.2 | | 1 per size [1)] | Every batch or once per production week [2)] |
| 4 | Socket – material properties, e.g., tensile strength or hardness, elastic limit, elongation on rupture (where relevant) | 3.4.3 | | 1 per size [1)] | Every 2500 [3)] pieces of each batch or per each batch [2)] |
| 5 | Anchor head – material properties, e.g., tensile strength or elastic limit, elongation on rupture | 3.4.3 | | 1 per size [1)] | Every batch or once per production week [2)] |

1) Each type of material or size
2) Whichever criterion is the more rigorous
3) After successful results of continuous testing during the first year of production, the test frequency may be reduced to one every 5000.

## 3.3 Tasks of the notified body

The cornerstones of the actions to be undertaken by the notified body in the procedure of assessment and verification of constancy of performance for the stud connectors are laid down in Table 3.3.1.

**Table 3.3.1 Control plan for the notified body; cornerstones**

| No | Subject/type of control | Test or control method | Criteria, if any | Minimum number of samples | Minimum frequency of control |
|---|---|---|---|---|---|
| **Initial inspection of the manufacturing plant and of factory production control** | | | | | |
| 1 | Notified Body will ascertain that the factory production control with the staff and equipment are suitable to ensure a continuous and orderly manufacturing of the stud connector. | Verification of the complete FPC as described in the control plan agreed between the TAB and the manufacturer | According to Control plan | According to Control plan | When starting the production or a new line |
| **Continuous surveillance, assessment and evaluation of factory production control** | | | | | |
| 2 | The Notified Body will ascertain that the system of factory production control and the specified manufacturing process are maintained taking account of the control plan. | Verification of the controls carried out by the manufacturer as described in the control plan agreed between the TAB and the manufacturer with reference to the raw materials, to the process and to the product as indicated in Table 3.2.1 | According to Control plan | According to Control plan | 1 per year |
| **Audit-testing of samples taken by the notified product certification body at the manufacturing plant or at the manufacturer's storage facilities** | | | | | |
| 3 | Metal part/component - dimensions and tolerances | 3.4.2 | According to Control plan | 3 for one size per type [1)] | 1 per year |
| 4 | Final product – mechanical characteristics | 3.4.3 | | | 1 per year |
| 5 | Final product: type 1 stud connector – fatigue strength | 3.4.4 | | 5 per smallest and largest size | Once per 5 production years |
| 6 | Final product: type 2 stud connector – fatigue strength | 3.4.4 | | 3 for one size per type [1)] | 1 per year |

1) all sizes shall be tested within a period of 5 years

## 3.4 Special methods of control and testing used for the assessment and verification of constancy of performance

### 3.4.1 Raw material

The raw materials shall be subject to control by the manufacturer before acceptance. Check of raw materials shall include control of the inspection documents presented by the supplier of the initial materials (comparison with nominal values).

The raw material shall be checked using the following documents:

- Reinforcing bars: Material and material properties to be proven by an inspection certificate 3.1 in accordance with EN 10204 or equivalent;
- Sockets: Material and material properties to be proven by an inspection certificate 3.1 in accordance with EN 10204 or equivalent;
- Ancillary components: Dimensions and material properties to be proven by a test report 2.2 in accordance with EN 10204 or equivalent.

### 3.4.2 Geometrical characteristics

The geometrical characteristics in accordance with Table 3.4.2.1 shall be determined by means of measuring. Possible tolerances as specified by the manufacturer shall be considered.

**Table 3.4.2.1 Determination of geometrical characteristics**

| No | Characteristic | Test method and evaluation | Expression of result |
|---|---|---|---|
| 1 | Socket outer diameter | Measuring and comparing with manufacturer's technical file | Ød$_{Socket}$ [mm] |
| 2 | Socket length | | $l_{Socket}$ [mm] |
| 3 | Thread diameter | | Ød$_{th}$ [mm] |
| 4 | Thread length | | $l_{th}$ [mm] |
| 5 | Pitch for thread | | p [mm] |
| 6 | Zinc coating thickness of socket, where relevant | | t [µm] |
| 7 | Diameter of the stud connector bar | | $d_a$ [mm] |
| 8 | Head length | | $l_{SC}$ [mm] |
| 9 | Head width | | $b_{SC}$ [mm] |
| 10 | Head thickness | | $h_{SC}$ [mm] |

### 3.4.3 Mechanical characteristics

The mechanical characteristics in accordance with Table 3.4.3.1 shall be determined by means of testing. Possible tolerances as specified by the manufacturer shall be considered. The tests shall be performed in accordance with the methods given in Table 3.4.3.1.

**Table 3.4.3.1 Determination of geometrical characteristics**

| No | Characteristic | Test method and evaluation | Expression of result |
|---|---|---|---|
| 1 | Characteristic yield strength | See following description | $f_{yk} \geq 500$ [MPa] |
| 2 | Characteristic ratio tensile strength / yield strength | | $(f_u/f_y)_k \geq 1{,}05$ [-] |
| 3 | Characteristic strain at maximum force | | $\varepsilon_{uk} \geq 2{,}5$ [%] |

The test setups shall correspond to Annex A, Clause A.3 and tests shall be performed in accordance with Annex A, Clause A.3.

The characteristic yield strength $f_{yk}$ shall be determined as 5 %-fractile (in accordance with A.8) of the test results $f_y$.

The characteristic strain at maximum force $\varepsilon_{uk}$ shall be determined as 5 %-fractile (in accordance with A.8) of the test results $\varepsilon_u$.

The characteristic ratio of tensile strength/yield strength $(f_u/f_y)_k$ shall be determined as 5 %-fractile (in accordance with A.8) of the ratio $f_u/f_y$.

### 3.4.4 Fatigue resistance

The test setups shall correspond to Annex B, Clause B.1 and tests shall be performed in accordance with Annex B, Clause B.1. The characteristic specified in the ETA (see Clause 2.2.6, Table 2.2.6.1).

# 4 REFERENCE DOCUMENTS

| | |
|---|---|
| EN 206:2013+A2:2021 | Concrete - Specification, performance, production and conformity |
| EN 1990:2023 | Eurocode - Basis of structural and geotechnical design |
| EN 1992-1-1:2023 | Eurocode 2 - Design of concrete structures – Part 1-1: General rules and rules for buildings, bridges and civil engineering structures |
| EN 1993-1-1:2022 | Eurocode 3 - Design of steel structures - Part 1-1: General rules and rules for buildings |
| EN 1993-1-8:2024 | Eurocode 3 - Design of steel structures - Part 1-8: Joints |
| EN 10080:2005 | Steel for the reinforcement of concrete - Weldable reinforcing steel – General |
| EN 10088-3:2023 | Stainless steels - Part 3: Technical delivery conditions for semi-finished products, bars, rods, wire, sections and bright products of corrosion resisting steels for general purposes |
| EN 10088-4:2009 | Stainless steels - Part 4: Technical delivery conditions for sheet/plate and strip of corrosion resisting steels for construction purposes |
| EN 10088-5:2009 | Stainless steels - Part 5: Technical delivery conditions for bars, rods, wire, sections and bright products of corrosion resisting steels for construction purposes |
| EN 10204:2004 | Metallic products - Types of inspection documents |
| EN ISO 683-1:2018 | Heat-treatable steels, alloy steels and free-cutting steels - Part 1: Non-alloy steels for quenching and tempering (ISO 683-1:2016) |
| EN ISO 683-7:2024 | Heat-treatable steels, alloy steels and free-cutting steels - Part 7: Bright products of non-alloy and alloy steels (ISO 683-7:2023) |
| EN ISO 1461:2022 | Hot dip galvanized coatings on fabricated iron and steel articles - Specifications and test methods (ISO 1461:2022) |
| 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 (ISO 3506-1:2020) |
| EN ISO 4014:2022 | Fasteners - Hexagon head bolts - Product grades A and B (ISO 4014:2022) |
| EN ISO 4016:2022 | Fasteners - Hexagon head bolts - Product grade C (ISO 4016:2022) |
| EN ISO 4017:2022 | Fasteners - Hexagon head screws - Product grades A and B (ISO 4017:2022) |
| EN ISO 4018:2022 | Fasteners - Hexagon head screws - Product grade C (ISO 4018:2022) |
| EN ISO 4042:2022 | Fasteners - Electroplated coating systems (ISO 4042:2022) |
| EN ISO 4762:2004 | Hexagon socket head cap screws (ISO 4762:2004) |
| EN ISO 10684:2004 + AC:2009 | Fasteners - Hot dip galvanized coatings (ISO 10684:2004+Cor1:2008) |
| EN ISO 15630-1:2019 | Steel for the reinforcement and prestressing of concrete - Test methods - Part 1: Reinforcing bars, rods and wire (ISO 15630-1:2019) |
| EAD 160129-00-0301 | Couplers for mechanical splices of reinforcing steel bars |
| TR 081:2022-06 | Design methods for verification of load-bearing capacity of stud connectors for anchoring in reinforced concrete members |

# ANNEX A RESISTANCE UNDER STATIC OR QUASI-STATIC LOADING – GENERAL ASPECTS OF TESTS AND ASSESSMENT

## A.1 Test specimens

The specimen shall contain those components and bursting reinforcement that will be embedded in the structural concrete, and their arrangement shall conform to the intended application and with the specification given in clause 1.2.1.

Manufacturer's product installation instructions shall be followed when preparing test specimens. The stud connectors shall be fixed on the formwork or auxiliary constructions in a way that no movement or deformation will occur during the time of laying the reinforcement and of placing and compacting the concrete. The concrete shall properly be compacted close to the stud connector particularly at the reinforcement bar, the optional anchor head or the attached socket and supplementary reinforcement without significant voids. The stud connector threaded socket shall be protected against ingress of concrete or corrosion until fixing the structural steel member.

In general, a flexural reinforcement with a yield strength of $f_{yk}$ = 500 MPa shall be used in the tests.

The concrete of the test specimen shall correspond to normal concrete used for concrete structures with respect to materials, composition, compaction and its compressive strength. The composition of the concrete used for the load transfer test specimen shall be given in the test records. The test specimen shall be concreted in a horizontal position. After casting, the test specimen shall be removed from the mould after one day and left to cure in a moist environment until testing. The test cylinders or cubes cast for determination of compressive strength of concrete shall be cured the same way.

At least the following material properties shall be determined:

- Mean value of cylindrical concrete compressive strength at the day of testing,
- Mean value of yielding strength of used flexural reinforcement of at least 3 specimens or taken from a 3.1 certificate in accordance with EN 10204,
- Mean value of yielding strength of used stud connector reinforcement of at least 3 specimens or taken from a 3.1 certificate in accordance with EN 10204,
- Yielding strength of screws.

## A.2 Test procedure

The purpose of the full-scale tests is to establish whether a stud connector is capable of safe, effective behaviour in service including consideration of adverse conditions both during site installation and in service.

Testing shall be performed with a compression testing machine or in a calibrated test rig. Force-displacement-plots shall be recorded throughout the test. The load shall be applied to the specimen on an area that simulates the loading condition in a complete anchorage.

Following measurements shall be taken in general:

- applied load in all load points,
- corresponding deformations to assess the ductility of failure,
- axial strain in the stud connector bar (see Figures A.4.2.2, A.5.2.2, A.6.2.2 and A.7.2.3) to assess the load transfer into concrete,
- the anchorage-slip of stud connector anchor head,
- the formation of cracks and crack widths.

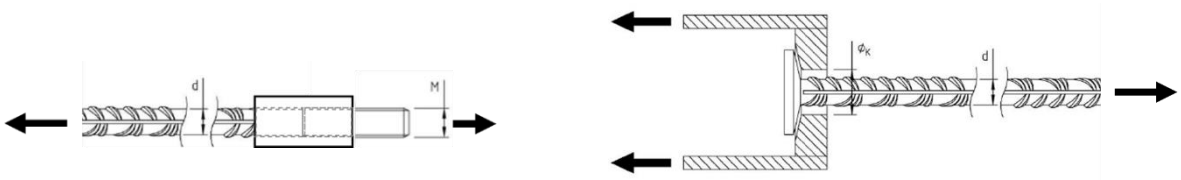
Note: The axial strain of the stud connectors shall be measured at the side of the bar to avoid any bending influence on the measurement results. Furthermore, the strain shall be measured 1 to 4 cm in front of the anchor head and in the transition area between the column and the beam or column and corbel (see Figures A.4.2.2, A.5.2.2 and A.6.2.2). For steel-reinforced concrete connections in accordance with A.7, the strains shall be measured 1 to 4cm behind the socket (see Figure A.7.2.3).

## A.3 Steel tests

The steel tests of stud connectors shall be carried out in accordance with EN ISO 15630-1, Clause 5. The test setups are shown in Figure A.3.1.

The bar ends of the stud connector shall be gripped in such a way that the load is transmitted axially and as much possible free of bending moment on the whole length. If a specimen with anchor head at one end is tested the rectangular anchor head shall be born with a bearing plate with a hole (see Figure A.3.1b). The shape of the bearing plate needs to correspond with the shape of the anchor head that point or line contacts shall be avoided. The dimensions of the bearing plate shall be in accordance with Figure A.3.2.

In addition, for failure modes b) and c) the rupture elongation $A_{gt,act}$ shall be measured in accordance with EN ISO 15630-1 [21] at the part of the reinforcing steel bar which is ruptured outside the socket. If this is not possible, $A_{gt,act}$ may be measured on a separate bar of the same heat at the same load level as the stud connector bar and from the same length which was used in the coupled assembly.




a) Test setup for type 2 stud connector

b) Test setup for type 1 stud connector with anchor head and bearing plate at one end

**Figure A.3.1: Sectional view of test setups for steel tests**

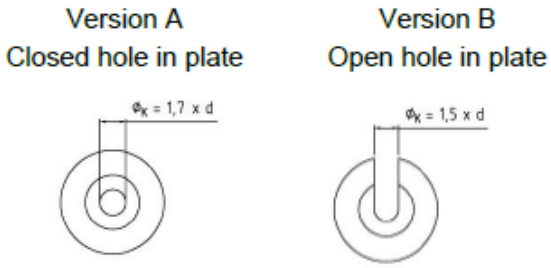



**Figure A.3.2: Top view of bearing plate for stud connector anchor head with two possible versions (stud connector not shown)**

## A.4 Shear resistance of exterior beam-column joint

### A.4.1 General

The provisions in accordance with Clauses A.1 and A.2 apply.

Test specimens shall be designed to exhibit shear failure in joint while at the same time the stud connectors reach their yield strength and cause the maximum anchoring force in the node.

- The following boundary conditions shall be observed: Concrete compressive cylinder strength: $f_{cm}$ = 25 – 50 MPa;
- Column thickness: $h_{col} \geq$ 200 mm;
- Column width: $b_{col} \geq$ 160 mm;
- Shear slenderness: $h_{beam}/h_{col}$ = 1,5 – 2,0;
- Column longitudinal reinforcement ratio at half column section in which the stud connector anchor head is positioned (outer column side) in accordance with Clause 1.2.1, Figure 1.2.1.2, with $\rho_{s1,col} = A_{s1,col} / (b_{col} \cdot h_{col}) \cdot 100\%$: $\rho_{s1,col}$ = 0,5 – 2,0%. The column longitudinal reinforcement shall be

arranged in such a way that no bending failure in the column and no anchorage failure within the joint occurs;
- Axial column compression load $N_{col}$ = 100 – 750 kN;
- Diameter of headed stud connector used as flexural tensile reinforcement in the beam: $d_a$ = 16 – 25 mm;
- Concrete cover of reinforcement: $c_{min} \geq$ 20 mm.

The arrangement of type 1 stud connectors in the concrete specimen shall comply with the provisions in accordance with Figure 1.2.1.2 of Clause 1.2.1.

Each test specimen shall have a unique set of the aforementioned parameters. At least one specimen shall be tested for every configuration according to Table A.4.1.1. To ensure comparability of the results, the boundary conditions for at least 5 tests are defined in more detail in Table A.4.1.1. Further tests can be carried out within limits specified above.

**Table A.4.1.1 Full scale tests for exterior beam-column joints**

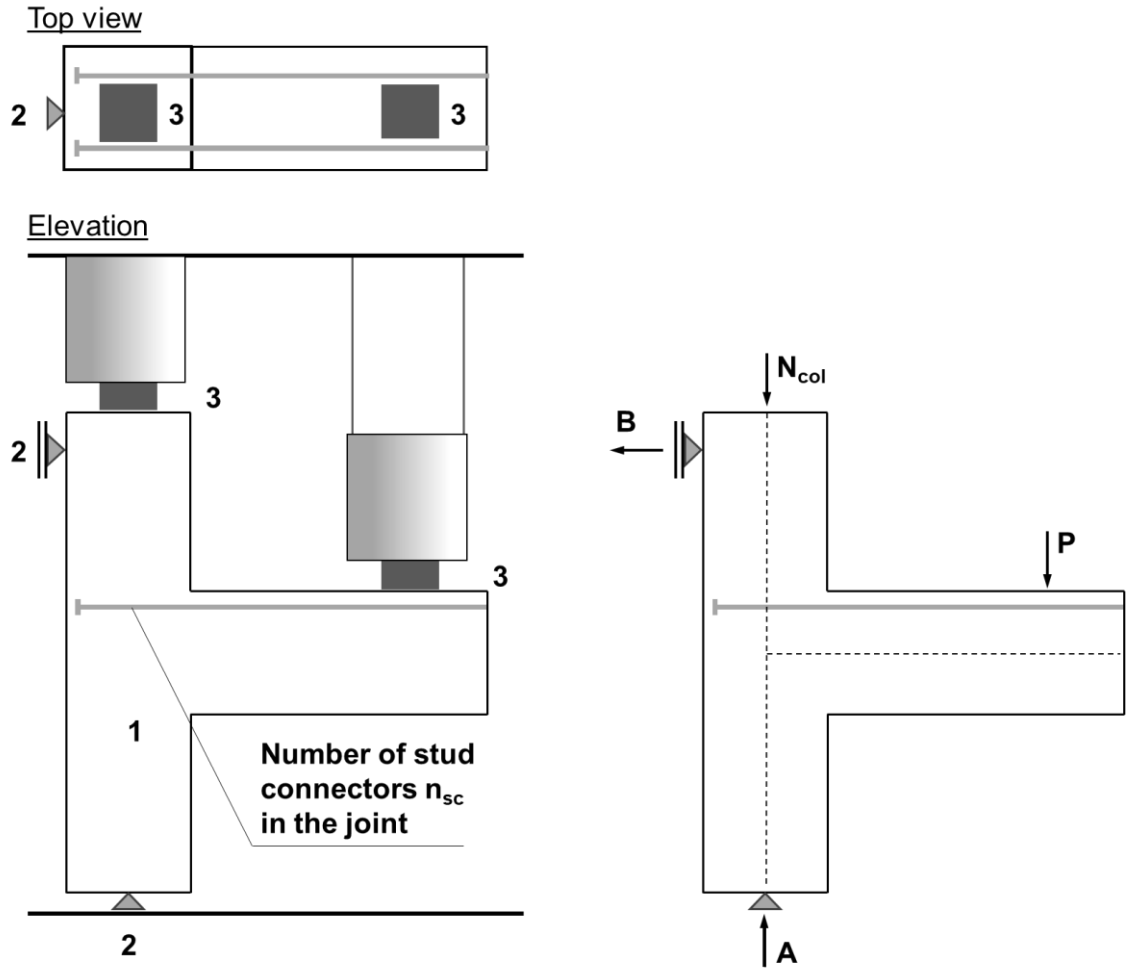
| | | **Test 1** | **Test 2** | **Test 3** | **Test 4** | **Test 5** |
|---|---|---|---|---|---|---|
| $h_{beam}/h_{col}$ | [-] | 1,5 | 1,5 | 1,5 | 2 | 1,5 |
| $f_{cm,cyl}$ | [MPa | 36±4 | 36±4 | 25 | 36±4 | 50 |
| $d_a$ | [mm] | 20 | 20 | 14±2 | 20 | 25 |
| $N_{col}$ | [kN] | 100 | 625±125 | 500 | 500 | 500 |

## A.4.2 Test setup

The scheme of a test setup is shown in Figure A.4.2.1. The measurement set-up is shown in Figure A.4.2.2.

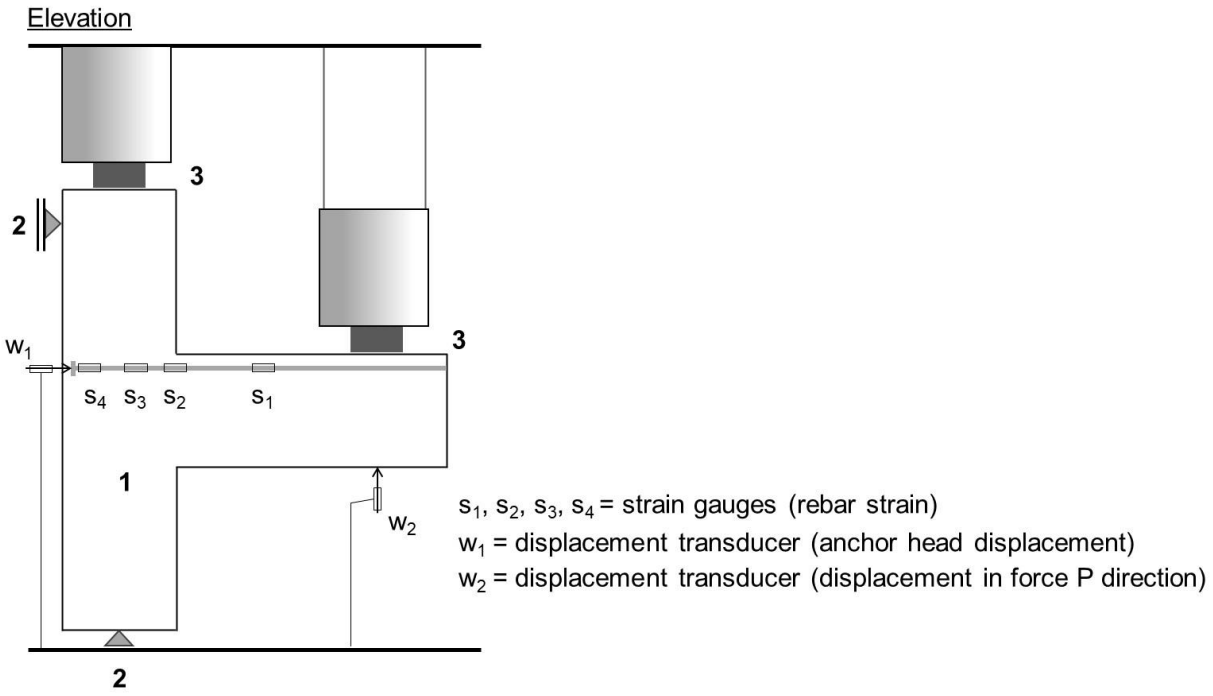
The tests shall be performed with a constant axial compression column load $N_{col}$ and an incrementally increasing vertical point load P on the beam. The bearings of load applications and/or supports shall be allowed freedom of movement (no friction). To achieve this, elastomeric bearings and spherical bearings for the load applications points and supports shall be used.

The failure load $R_{test}$ of the exterior beam-column joint test correspond with the shear force in the upper column section.




Legend: 1 = test specimen (exterior beam-column joint), 2 = bearing support, 3 = load application point

**Figure A.4.2.1: Test setup for type 1 stud connectors in exterior beam-column joints**




Legend: 1 = test specimen (exterior beam-column joint), 2 = bearing support, 3 = load application point

**Figure A.4.2.2: Strain and displacement measurement**

### A.4.3 Test procedure

First the constant compression load $N_{col}$ shall be applied to the column section. Then the load P at the beam shall be increased incrementally such that the peak load or failure occurs after 1 to 10 min from commencement. Loads and displacements shall be recorded either continuously or at least in about 100 to 300 intervals. The tests may be carried out with load or displacement control. In case of displacement control, then the test shall be continued up to at least 75 % of the maximum load to be measured (to allow the drop of the load/displacement curve).

The failure load $R_{test,i}$ of the test refers to the maximum shear force in the upper column section, which shall be calculated from the maximum load P which causes specimen failure using the corresponding lever arms.

The anchor head displacement and axial strain along the stud connector bar shall be measured continuously (see Figure A.4.2.2). Significant non-proportional displacement may indicate the beginning of concrete crushing in the head bearing zone, i.e., when the force-displacement curve indicates a significant loss of stiffness.

The test requirement for anchoring of type 1 stud connectors in exterior beam-column joint shall be considered fulfilled if the anchor head displacement is less than 0,10 mm, or if the specimen is cut through and no indication of concrete crushing is observed.

If concrete crushing is observed at the anchor head the test cannot be used for the evaluation.

## A.5 Shear resistance of corbels

### A.5.1 General

The provisions in accordance with Clauses A.1 and A.2 apply.

When testing the test specimens, shear failure of the inclined compression strut of the corbel shall occur while at the same time the stud connectors reach their yield strength and the maximum anchoring force in column and corbel is reached.

Local concrete crushing or splitting at the anchor head in the corbel shall be avoided with an adequate transverse reinforcement.

- The following boundary conditions shall be observed: Concrete compressive cylinder strength: $f_{cm}$ = 25 – 40 MPa,
- Corbel length: $l_c$ = 200 – 360 mm,
- Corbel height: $h_c$ = 300 – 500 mm,
- Corbel width: $b_c$ = 200 – 300 mm,
- Ratio between distance from column edge to vertical load and corbel height: $a_c/h_c \leq 1{,}0$,
- Positioning of stud connectors in the corbel, which are arranged in one- or two layers,
- Diameter of headed stud connector in the corbel: $d_a$ = 16 – 25 mm,
- Concrete cover of reinforcement: $c_{min} \geq 20$ mm.

The arrangement of the type 1 stud connectors in the concrete specimen shall comply with the provisions in accordance with Figure 1.2.1.3 of Clause 1.2.1.

Each test specimen shall have a unique set of the aforementioned parameters. At least one specimen shall be tested for every configuration as per table A.5.1.1. To ensure comparability of the results, the boundary conditions for at least 5 tests are defined in more detail in Table A.5.1.1. Further tests can be carried out within limits specified above.

**Table A.5.1.1 Full scale tests for corbels**

| | | **Test 1** | **Test 2** | **Test 3** | **Test 4** | **Test 5** |
|---|---|---|---|---|---|---|
| $a_c/h_c$ | [-] | 0,55±0,05 | 0,55±0,05 | 0,55±0,05 | 0,55±0,05 | 0,55±0,05 |
| $f_{cm,cyl}$ | [MPa] | 25 | 40 | 25 | 30 | 30 |
| $d_a$ | [mm] | 25 | 25 | 14±2 | 14±2 | 14±2 |
| $l_c$ | [mm] | 300 | 300 | 300 | 200 | 360 |
| $h_c$ | [mm] | 300 | 300 | 300 | 200 | 500 |
| $b_c$ | [mm] | 300 | 300 | 300 | 200 | 200 |
| Layers of type 2 stud connectors | [-] | 1 | 1 | 1 | 1 | 2 |

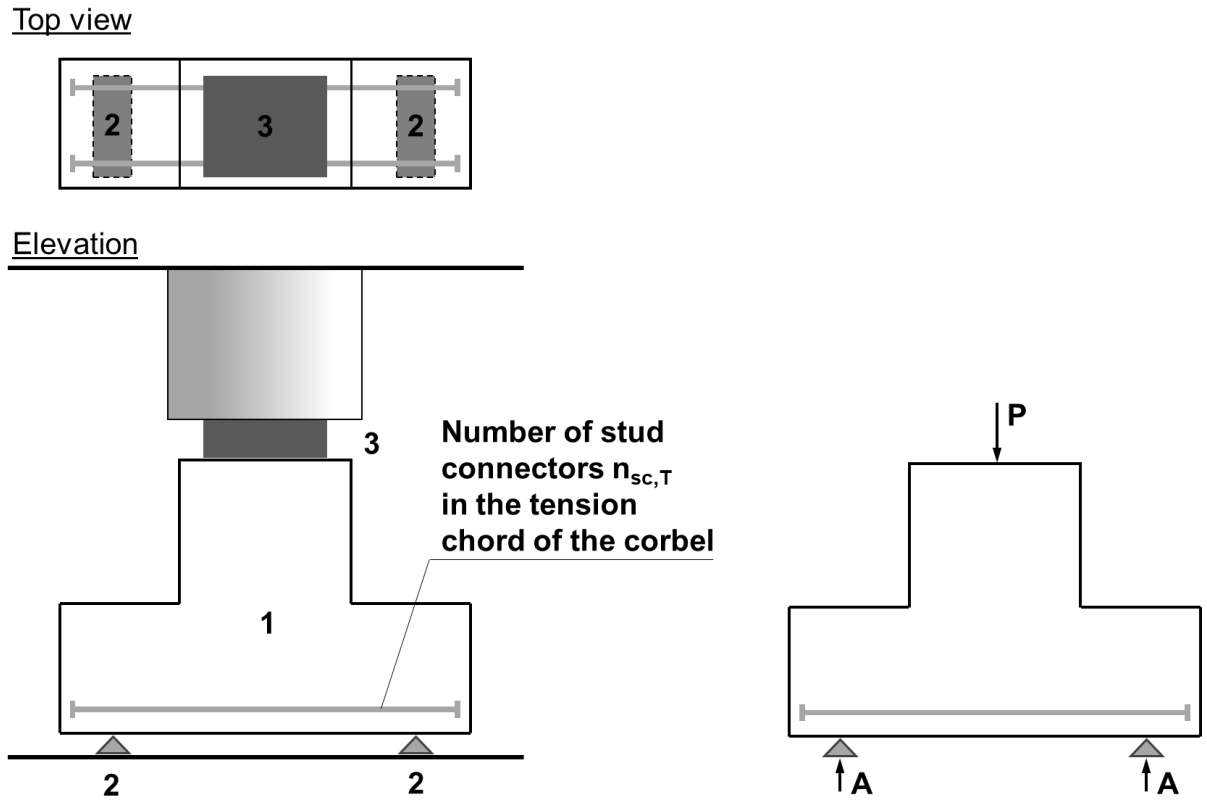
## A.5.2 Test setup

The scheme of a test setup is shown in Figure A.5.2.1. The measurement set-up is shown in Figure A.5.2.2.

The tests shall be performed with a direct loading of the column section with a vertical force P. The bearings of load application and/or supports shall allow freedom of movement (no friction). To allow freedom of movement elastomeric bearings and spherical bearings for the load applications points and supports shall be used.

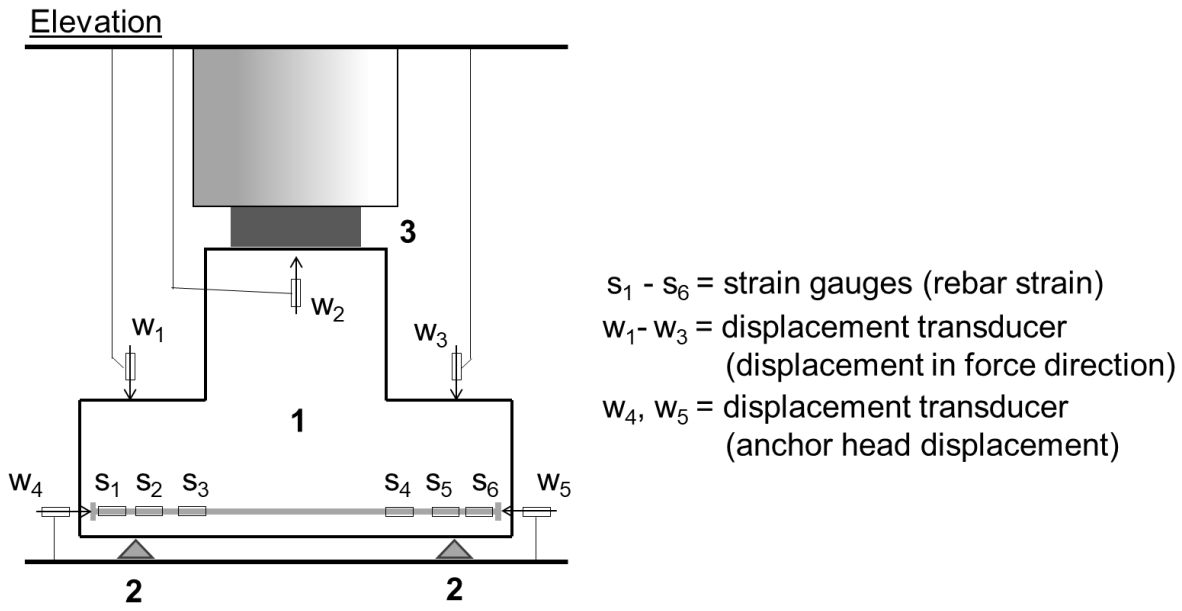
The dimension of the loading plate shall be chosen so that the load reaction causes a compression in the stud connector tensile reinforcement. (

The failure load $R_{test}$ of the corbel test correspond with the force A in the supports of the specimen.




Legend: 1 = test specimen (monolithic column/corbel connection), 2 = loading plate of corbels, 3 = load application point

**Figure A.5.2.1: Test setup for type 1 stud connectors in corbels, double-sided configuration**




Legend: 1 = test specimen (monolithic column/corbel connection), 2 = loading plate of corbels, 3 = load application point

**Figure A.5.2.2: Strain and displacement measurement**

### A.5.3 Test procedure

The load P shall be increased incrementally up to twice (2 corbels shall be tested as shown in the Figure A.5.2.1) of 70% of the calculated failure load $R_{calc}$ of one corbel in accordance with equation **Fehler! Verweisquelle konnte nicht gefunden werden.**. After attaining this load level at least 5 slow cycles shall be performed, with a force range of twice the $0{,}7 \cdot R_{calc}$ and of $0{,}15 \cdot R_{calc}$ being the upper and the lower force respectively. The necessary number of loading cycles depends upon stabilisation of strain readings and crack widths. Following cyclic loading, the specimen shall be loaded continuously to failure.

During cyclic loading measurement shall be taken at the upper and lower loads to decide whether stabilisation of strains and crack widths is being attained. Cracks widths and longitudinal strains shall be considered to have stabilised if the increase under the upper load has stopped. Measurement shall be performed at least at 3 points (see Figure A.5.2.2). Cracks widths shall be upon last attainment of lower load of ≤ 0,50 mm.

The failure load $R_{test,i}$ of the test refers to the maximum vertical force at the support of the corbel.

Cracks widths shall be upon last attainment of upper load of ≤ 1,00 mm.

The anchor head displacement shall be measured continuously. Significant non-proportional displacement may indicate the beginning of concrete crushing in the head bearing zone, i.e., when the force-displacement curve indicates a significant loss of stiffness.

The test requirement for anchoring of type 1 stud connectors in concrete corbels shall be considered fulfilled if the anchor head displacement is less than 0,10 mm, or if the specimen is cut through and no indication of concrete crushing is observed.

## A.6 Shear resistance at interface of concrete corbels cast at later time to supporting reinforced concrete members

### A.6.1 General

The provisions in accordance with Clauses A.1 and A.2 apply.

When testing the test specimen, shear failure at interface of concrete corbel cast at later times to the column or shear failure of the inclined compression strut of the corbel shall occur.

Local concrete crushing or splitting at the anchor head in the corbel shall be avoided with an adequate transverse reinforcement.

The following boundary condition shall be observed:

- Concrete compressive cylinder strength: $f_{cm}$ = 30 – 45 MPa,
- Corbel length: $l_c$ = 200 – 360 mm,
- Corbel height: $h_c$ = 200 – 500 mm,
- Corbel width: $b_c$ = 200 – 250 mm,
- Type of construction joint,
- Ratio between distance from column edge to vertical load and corbel height: $0{,}2 \leq a_c/h_c \leq 0{,}6$,
- Positioning of stud connectors in the corbel, which are arranged in one or two layers,
- Diameter of headed stud connector in the corbel: $d_a$ = 16 – 20 mm,
- Concrete cover of reinforcement: $c_{min} \geq 20$ mm.

The arrangement of the type 1 stud connectors in the concrete specimen shall comply with the provisions in accordance with Figure 1.2.1.3 of Clause 1.2.1. The interface surface of the construction joint shall be designed in accordance with Figure 1.2.1.4 of Clause 1.2.1.

Each test specimen shall have a unique set of the aforementioned parameters. At least one specimen shall be tested for every configuration according to Table A.6.1.1. To ensure comparability of the results, the boundary conditions for at least 4 tests are defined in more detail in Table A.6.1.1. Further tests can be carried out within limits specified above.

**Table A.6.1.1 Full scale tests for corbels casted at later time to the column**

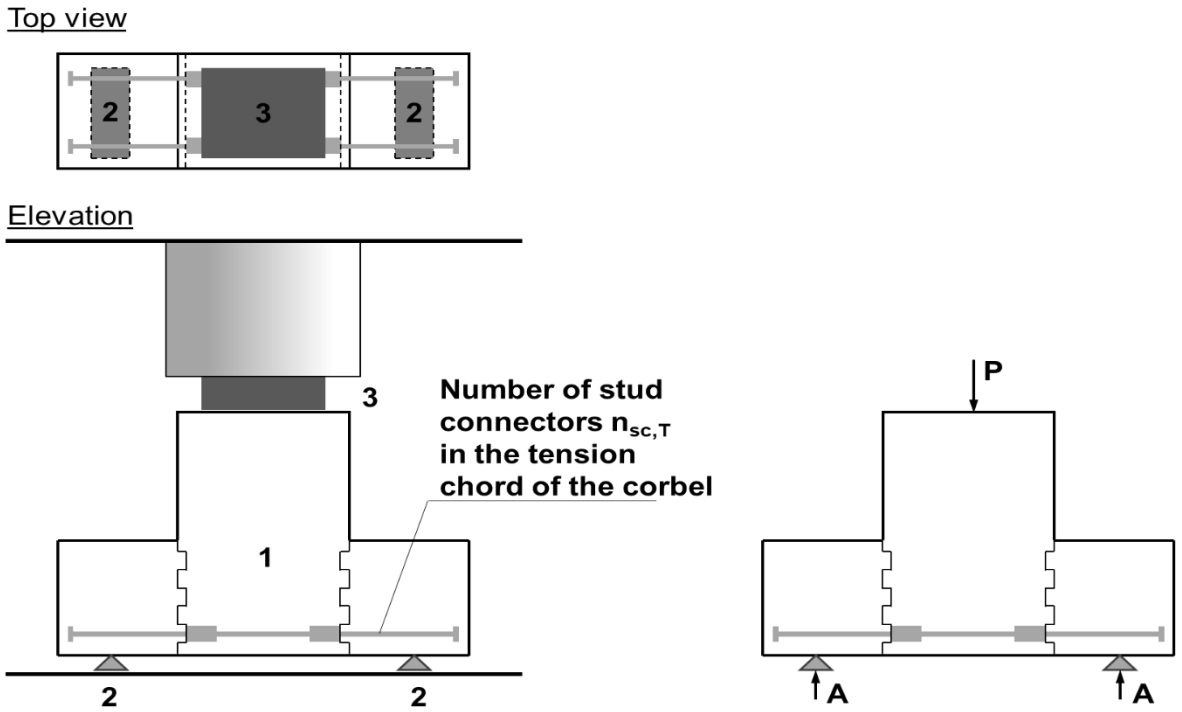
| | | Test 1 | Test 2 | Test 3 | Test 4 |
|---|---|---|---|---|---|
| $a_c/h_c$ | [-] | 0,25±0,05 | 0,55±0,05 | 0,25±0,05 | 0,55±0,05 |
| $f_{cm,cyl}$ | [MPa] | 30 | 30 | 45 | 30 |
| $d_a$ | [mm] | 20 | 14±2 | 20 | 14±2 |
| $l_c$ | [mm] | 200 | 200 | 200 | 360 |
| $h_c$ | [mm] | 500 | 200 | 500 | 500 |
| $b_c$ | [mm] | 300 | 200 | 200 | 200 |
| Layers of type 2 stud connectors | [-] | 1 | 1 | 1 | 2 |

## A.6.2 Test setup

The scheme of a test setup is shown in Figure A.6.2.1. The measurement set-up is shown in Figure A.6.2.2.

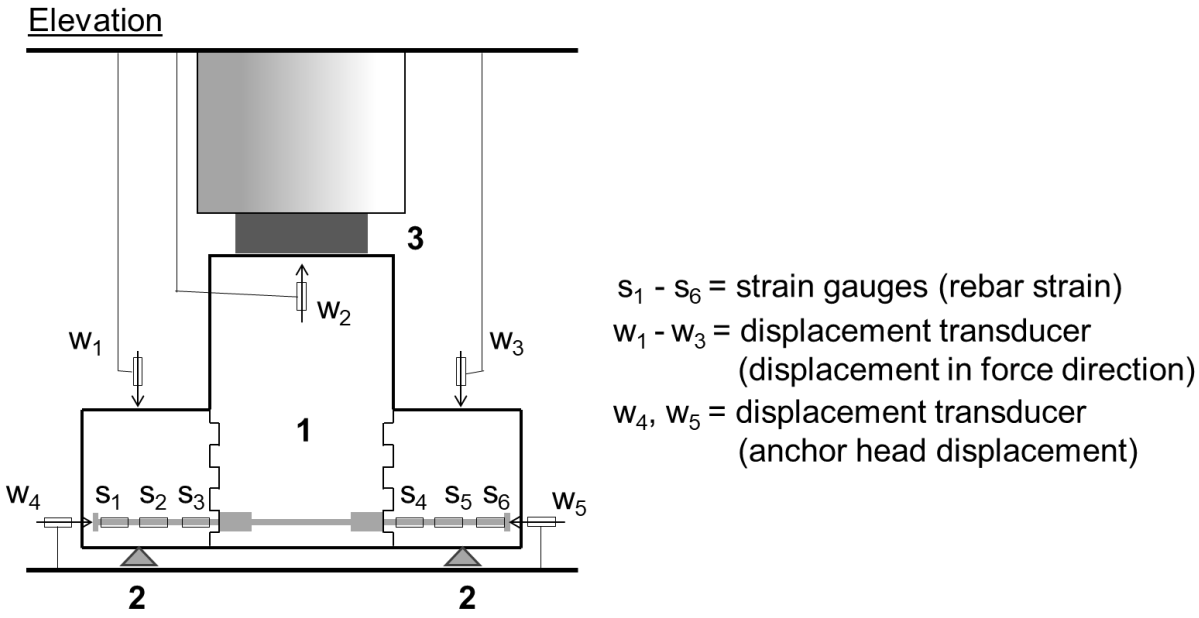
The tests shall be performed with a direct loading of the column with a vertical force P. The bearings of load application and/or supports shall allow freedom of movement (no friction). To allow freedom of movement elastomeric bearings and spherical bearings for the load applications points and supports shall be used.

The dimensions of the loading plate shall be chosen such that the load reaction caused a compression in the stud connector tensile reinforcement.




Legend: 1 = test specimen (column/corbel connection, construction joint with indented interface surfaces, coupler for mechanical splice of stud connector reinforcing bars), 2 = loading plate of corbel, 3 = load application point

**Figure A.6.2.1: Test setup for type 1 stud connectors in corbels cast at later time to the supporting column, double-sided configuration**




Legend: 1 = test specimen (column/corbel connection, construction joint with indented interface surfaces, coupler for mechanical splice of stud connector reinforcing bars), 2 = loading plate of corbel, 3 = load application point

**Figure A.6.2.2: Strain and displacement measurement**

## A.6.3 Test procedure

The load P shall be increased incrementally up to twice (2 corbels shall be tested as shown in the Figure A.6.2.1) of 70% of the calculated failure load $R_{calc}$ of one corbel in accordance with equation **Fehler! Verweisquelle konnte nicht gefunden werden.**. After attaining this load level at least 5 slow cycles shall be performed, with a force range of twice the $0{,}7 \cdot R_{calc}$ and of $0{,}15 \cdot R_{calc}$ being the upper and the lower force respectively. The necessary number of loading cycles depends upon stabilisation of strain readings and crack widths. Following cyclic loading, the specimen shall be loaded continuously to failure.

During cyclic loading measurement shall be taken at the upper and lower loads to decide whether stabilisation of strains and crack widths is being attained. Cracks widths and longitudinal strains shall be considered to have stabilised if the increase under the upper load has stopped. Measurement shall be performed at least at 3 points (see Figure A.6.2.2).

The failure load $R_{test,i}$ of the test refers to the maximum vertical force at the support of the corbel.

Cracks widths shall be upon last attainment of lower load of ≤ 0,50 mm.

Cracks widths shall be upon last attainment of upper load of ≤ 1,00 mm.

The anchor head displacement shall be measured continuously. Significant non-proportional displacement may indicate the beginning of concrete crushing in the head bearing zone, i.e., when the force-displacement curve indicates a significant loss of stiffness.

The test requirement for anchoring of type 1 stud connectors in concrete corbels shall be considered fulfilled if the anchor head displacement is less than 0,10 mm, or if the specimen is cut through and no indication of concrete crushing is observed.

## A.7 Shear resistance to failure of connection between steel member and supporting reinforced concrete member

### A.7.1 General

The provisions in accordance with Clauses A.1 and A.2 apply.

When testing the test specimens, steel failure of the stud connectors shall occur.

The testing parameter shall be within the following boundaries:

- Concrete compressive cylinder strength: $f_{cm}$ = 30 – 45 MPa,
- Distance from column edge to vertical load: $a_c$ = 0 – 100 mm,
- Ratio between distance from column edge to vertical load and fixture end-plate height: $a_c/h_{plate}$ = 0 – 0,50,
- Column thickness: $h_{col}$ = 240 – 400 mm,
- Column width: $b_{col}$ = 240 – 400 mm,
- Column length: $l_{col}$ = 700 – 450 mm,
- Fixture end-plate height: $h_{plate}$ = 200 – 320 mm,
- Fixture end-plate width: $b_{plate}$ = 200 – 400 mm,
- Positioning of stud connectors in the column such that be arranged in one layer or multi layers,
- Diameter of stud connector: $d_a$ = 16 – 25 mm,
- Strength class of the screws: 8.8 – 12.9.

The arrangement of the type 2 stud connectors in the concrete specimen shall comply with the provisions in accordance with Figure 1.2.1.5 of Clause 1.2.1.

Each test specimen shall have a unique set of the aforementioned parameters. At least one specimen shall be tested for every configuration according to Table A.7.1.1. To ensure comparability of the results, the boundary conditions for at least 7 tests are defined in more detail in Table A.7.1.1. Further tests can be carried out within limits specified above.

**Table A.7.1.1 Full scale tests for connection and load transfer into concrete**

| | | **Test 1** | **Test 2** | **Test 3** | **Test 4** | **Test 5** | **Test 6** | **Test 7** |
|---|---|---|---|---|---|---|---|---|
| $a_c/h_{plate}$ | [-] | 0,45±0,05 | 0,45±0,05 | 0,25±0,05 | 0,45±0,05 | 0,25±0,1 | 0 | 0 |
| $f_{cm,cyl}$ | [MPa] | 30 | 30 | 30 | 30 | 45 | 30 | 30 |
| $d_a$ | [mm] | 20 | 14±2 | 25 | 20 | 25 | 14±2 | 25 |

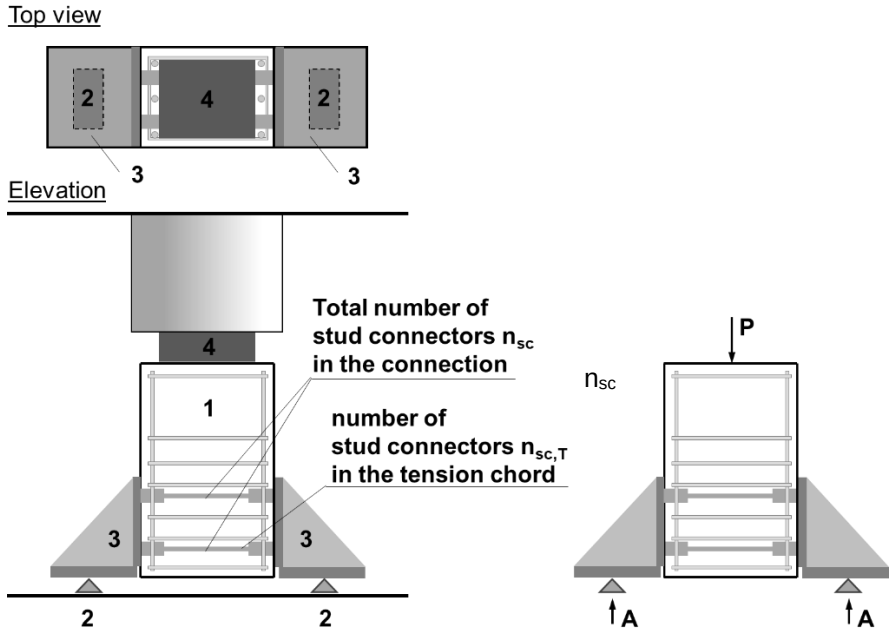
### A.7.2 Test setups

The test setups for steel to concrete connections are shown in Figure A.7.2.1 for tests with a structural steelwork corbel and in Figure A.7.2.2 for tests with a structural steel plate. The measurement set-up is shown in Figure A.7.2.3.

For the tests the load device shall have suitable measures to avoid load transfer by friction, e.g., by using a low friction plastic foil.

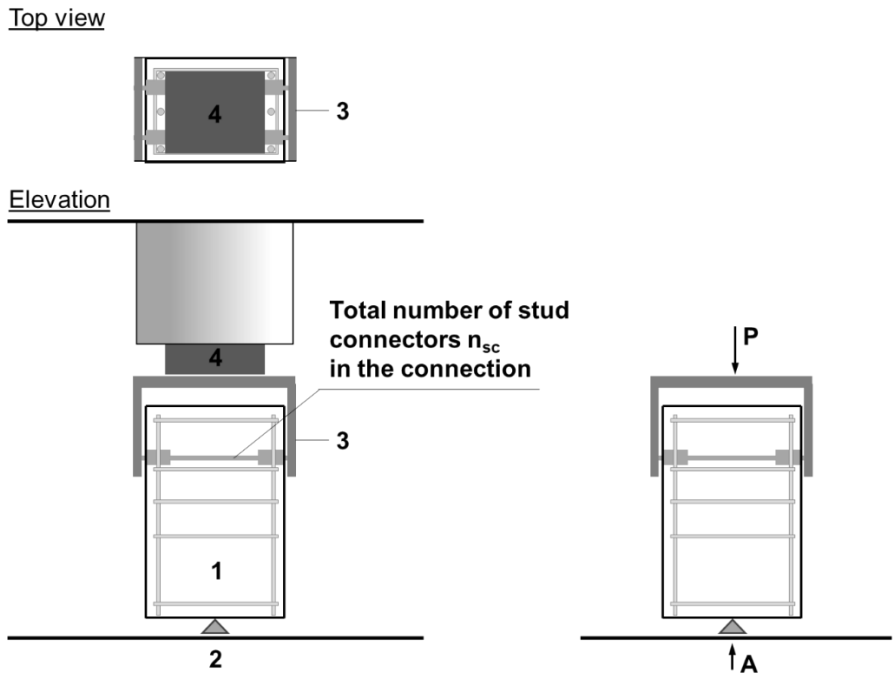
The tests shall be performed with a direct loading of the column with a vertical force P. The bearings of load application and/or supports shall allow freedom of movement (no friction). To allow freedom of movement elastomeric bearings and spherical bearings for the load applications points and supports shall be used.

The failure load $R_{test}$ of the corbel or the load device test correspond with the force A in the supports of the specimen.



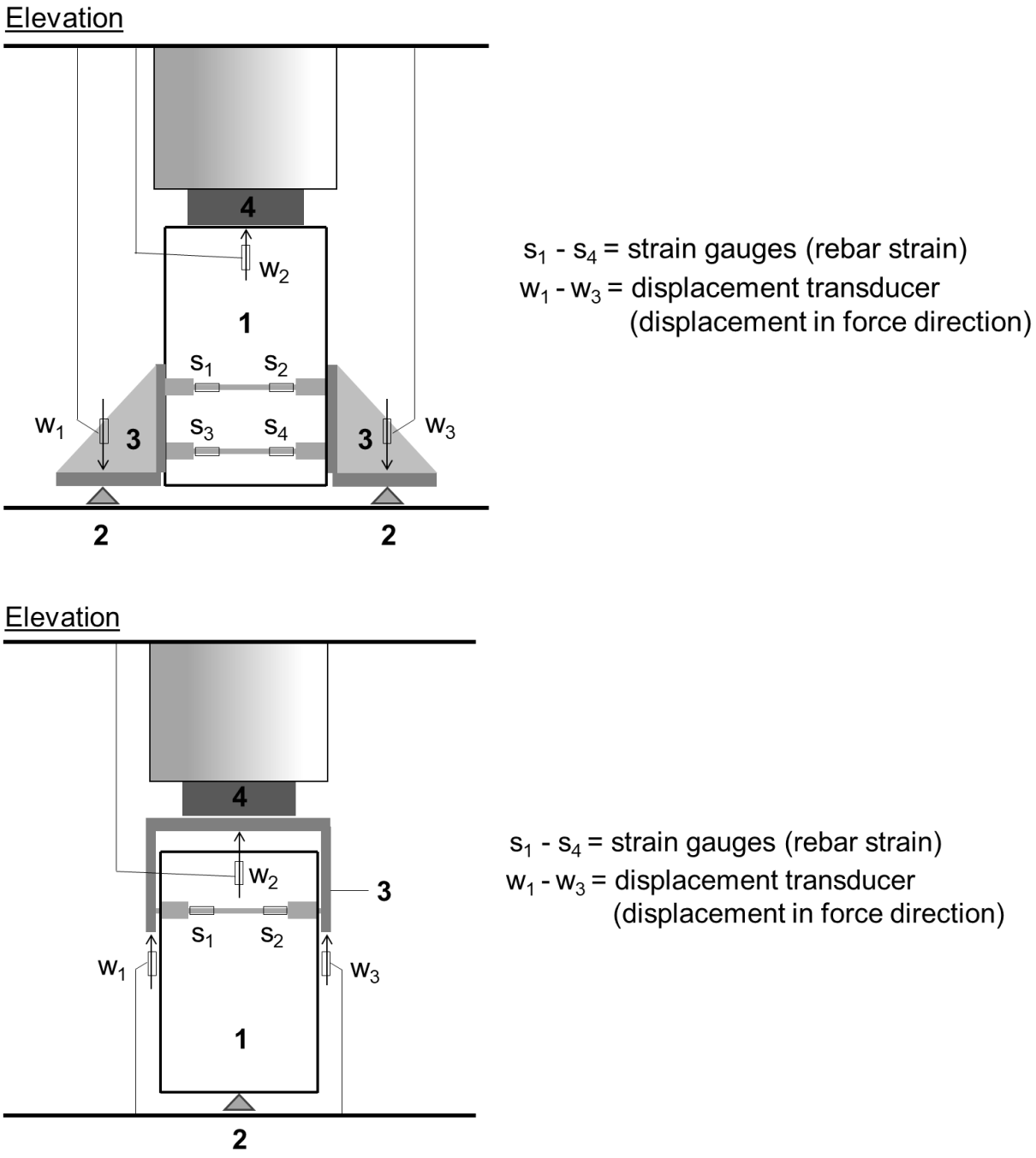

Legend: 1 = test specimen (column with type 2 stud connectors), 2 = bearing support, 3 = fixture, 4 = load application point

**Figure A.7.2.1: Test setup for a combined moment and shear loading of a connection to type 2 stud connectors embedded in supporting reinforced concrete members, double-sided joint configuration**




Legend: 1 = test specimen (column with type 2 stud connector), 2 = support, 3 = fixture, 4 = load application point

**Figure A.7.2.2: Shear test setup for connections to type 2 stud connectors embedded in supporting reinforced concrete members, double-sided joint configuration**




Legend: 1 = test specimen (column with type 2 stud connectors), 2 = bearing support, 3 = fixture, 4 = load application point

**Figure A.7.2.3: Strain and displacement measurement**

## A.7.3 Test procedure

The load P shall be increased incrementally up to twice (2 corbels shall be tested as shown in the Figure A.7.2.1) of 70% of the calculated failure load $R_{calc}$ of one corbel in accordance with equation **Fehler! Verweisquelle konnte nicht gefunden werden.**. After attaining this load level at least 5 slow cycles shall be performed, with a force range of twice the $0{,}7 \cdot R_{calc}$ and of $0{,}15 \cdot R_{calc}$ being the upper and the lower force respectively. The necessary number of loading cycles depends upon stabilisation of strain readings and

crack widths. Following cyclic loading, the specimen shall be loaded continuously to failure. During the cyclic loading measurement shall be taken at the upper and lower loads to decide whether stabilisation of strains and crack widths is being attained. Cracks widths and longitudinal strains shall be considered to have stabilised if the increase under the upper load has stopped. Measurement shall be performed at least at 3 points (see Figure A.7.2.3).

The failure load $R_{test,i}$ of the combined shear and moment loading test refers to the maximum vertical force at the support of the steel fixture. The failure load $R_{test,i}$ of the shear test refers to the maximum shear force at the connection of the fixture to the type 2 stud connector.

Cracks widths shall be upon last attainment of lower load of ≤ 0,50 mm.

Cracks widths shall be upon last attainment of upper load of ≤ 1,00 mm.

## A.8 Assessment method

The 5 %-fractile of $X_i$ shall be calculated for a confidence level of 75 % in accordance with statistical procedures of EN 1990, Annex D. If a precise verification does not take place, a normal or log-normal distribution and an unknown standard deviation of the population shall be assumed:

$$X_{i,5\%-Fractile} = X_m \cdot (1 - k_n \cdot \mathrm{COV}) \quad \text{(A.8.4)}$$

with:

$X_m$ = Mean value of $X_i$

COV = Coefficient of variation taken from the tests

$k_n$ = Fractile factor in accordance with EN 1990, Table D.1, for an unknown standard deviation of the population

# ANNEX B RESISTANCE UNDER HIGH-CYCLE FATIGUE LOADING – GENERAL ASPECTS OF TESTS AND ASSESSMENT

## B.1 Test method

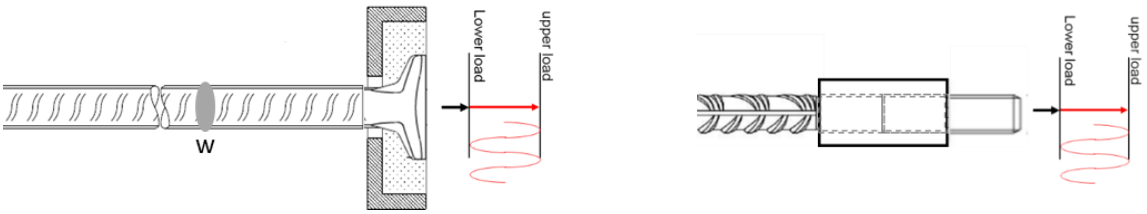
### B.1.1 General

The load cycle tests of type 1 stud connectors shall be performed with consideration of the following:

- The tests shall be performed with an upper stress level of $\sigma_{up} = 0{,}6 \cdot R_{e,nom}$.
- The frequency of load cycles shall be maintained constant during the test and also during the test series. The testing frequency shall be between 20 Hz and 200 Hz. In this range, the influence of the test frequency on the results is very small. The frequency can be selected according to the existing conditions. The stress range shall be observed within ± 5% of the specified value.
- The testing procedure is applicable for both testing of the anchor head in air and for optional testing embedded in concrete.
- For heads in air, the stud connector shall be placed vertically with a head bearing area on the bearing plate. The bearing plate shall conform to Figure B.1.2. In this case the effort for the tests can be reduced, but the test results are more conservative (on the safe side).
- For heads embedded in concrete, the head bearing area is cast in concrete without any bond force in accordance with Figure B.1.1.1a. The concrete strength shall be chosen that no crushing occurs in the bearing area. The anchor head displacement shall be measured continuously, or at least, the concrete test specimen shall be cut through the middle plane at the end of the test, in order to identify any concrete crushing in the head bearing zone. If a concrete failure occurs, the test shall be repeated with a higher concrete strength.
-

The tests of type 2 stud connectors shall be carried out in accordance with Clause 8 of EN ISO 15630-1, with the following modifications:

- The tests shall be performed with an upper stress level of $\sigma_{up}$ = of $0{,}6 \cdot R_{e,nom}$.
- The frequency of load cycles shall be maintained constant during the test and also during the test series. The stress range shall be observed within ± 5% of the specified value.
- If the specimen fails in the grips of the testing machine or within a distance of $2 \cdot d_a$ of the grips and the socket is still intact, the test may be continued after re-gripping the specimen with the same stress range, if the minimum free length is still available.
- The socket shall be positioned in the middle of the test piece (see Figure B.1.1.1b).




Legend: w = flash but welding, if applicable

a) Test setup for type 1 stud connector with anchor head cast in concrete

b) Test setup for type 2 stud connector

**Figure B.1.1.1: Sectional view of test setups for fatigue loading**

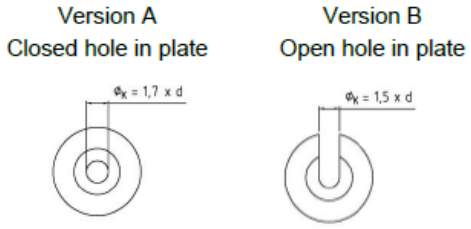



**Figure B.1.1.2: Top view of bearing plate for stud connector anchor head with two possible versions (stud connector anchor head not shown)**

## B.1.2 Characteristic resistance to quasi-static loading

Load cycle tests with diameters in accordance with Clause 2.2.1, Table 2.2.1.1, row 3 shall be performed with a certain stress range of $\Delta\sigma_s = 2\cdot\sigma_a = 60$ MPa based on the nominal cross section of the stud connector bar and at least $N = 2\cdot10^6$ load cycles (resistance to quasi-static loading).

All steel qualities/properties specified by the manufacturer shall be tested. Steels of the same grade but different ductility class do not need to be tested both.

If no failure occurs up to $N = 2\cdot10^6$ load cycles the performance for quasi-static loading shall be specified in the ETA. Otherwise, in the ETA only the characteristic of static loading shall be specified.

## B.1.3 Characteristic resistance to fatigue loading for $N = 2\cdot10^6$ load cycles

Load cycle tests with diameters in accordance with Clause 2.2.6, Table 2.2.6.1, shall be performed with a certain stress range of $2\cdot\sigma_a$ [MPa] and at least $N = 2\cdot10^6$ load cycles.

All steel qualities/properties specified by the manufacturer shall be tested. Steels of the same grade but different ductility class do not need to be tested both.

The stress range shall be $2\cdot\sigma_a = 90$ MPa.

If no failure occurs up to $N = 2\cdot10^6$ load cycles the characteristic fatigue strength $\Delta\sigma_{Rsk,n=2\cdot10^6}$ shall be determined as follows:

$\Delta\sigma_{Rsk,n=2\cdot10^6} = 0{,}78\cdot(2\cdot\sigma_a)$ [MPa]

If a failure occurs before reaching $N = 2\cdot10^6$ load cycles the test series shall be repeated with a smaller value $2\cdot\sigma_a$ [MPa].

If no failure occurs in 3 further tests on a reduced stress level, the characteristic fatigue strength $\Delta\sigma_{Rsk,n=2\cdot10^6}$ shall be determined as shown before.

## B.1.4 Characteristic resistance to fatigue loading for S-N curve with specific $k_1$ [-] and $k_2$ [-]

For the most unfavourable diameter (largest bar diameter) at least 24 tests shall be performed in order to determine a complete S-N curve in accordance with EN 1992-1-1, Annex E.4.

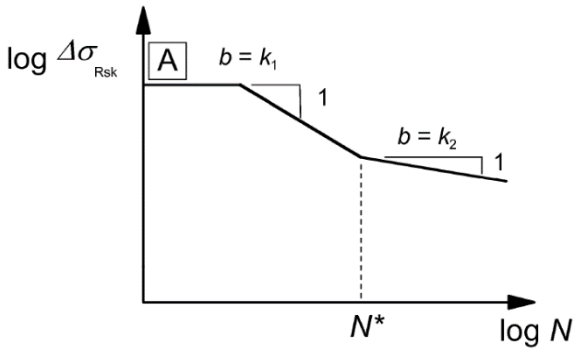



**Figure B.1.4.1: S-N curve**

Reference method:

All tests shall be carried out until the fracture of the specimen or until 10 million load cycles are reached. Another possibility is to test only until 2 million load cycles are reached and to estimate the following stress exponents to get a complete S-N curve in accordance with Figure B.1.4.1:

a) If the determined stress exponent $k_1$ is less than the exponent in accordance with EN 1992-1-1, Table 6.3N (type of reinforcement: coupler), then the stress exponent $k_1$ determined in the tests shall be applied in the range from 2 million to 10 million load cycles. The stress exponent $k_2$ (see Figure B.1.4.1) shall be determined using the following equation: $k_2 = 2 \cdot k_1 - 1$.
b) If the determined stress exponent $k_1$ is greater than the exponent in accordance with EN 1992 1-1, Table 6.3N (type of reinforcement: coupler), then the stress exponent $k_1$ in accordance with EN 1992-1-1, Table 6.3N (type of reinforcement: coupler), shall be applied in the range from 2 million to 10 million load cycles, followed by the stress exponent $k_2$ in accordance with EN 1992-1-1, Table 6.3N (line for coupler).

The S-N curve shall be determined with respect to the following restrictions:

The individual results of the fatigue tests (Number of load cycles N achieved with stress range $2 \cdot \sigma_a$) shall be evaluated in a diagram (double logarithmic, log N/log $\Delta\sigma_{Rsk}$, see Figure B.1.4.1).
A regression line shall be determined for all test values so that the squared distances between the data points and the regression line are minimized.
The 5-% and the 95-% quantile of the determined regression line (S-N curve) shall be evaluated at a confidence level of 75 %, in accordance with EN 1990, Table D.1, with unknown population standard deviation.
The 5 % quantile of the S-N curve ($\Delta\sigma_{Rsk}$ at N*; $k_1$, $k_2$) shall be given in the ETA.