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TECHNICAL REPORT

Design method for anchorage of post-installed reinforcing bars (rebars) with improved bond-splitting behavior as compared to EN 1992-1-1

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DESIGN METHOD FOR ANCHORAGE OF POST-INSTALLED REINFORCING BARS (REBARS) WITH IMPROVED BOND-SPLITTING BEHAVIOR AS COMPARED TO EN 1992-1-1

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Contents

1 SCOPE OF THE TECHNICAL REPORT

1.1 Abstract

This Technical Report (TR) provides a method for the design of post-installed reinforcing bars (rebars) in moment resisting connections where structural elements are cast at different times.

This TR is only applicable for post-installed rebar systems that hold European Technical Assessments (ETAs) based on EAD 332402-00-0601 [7], EAD 332402-00-0601-v01 [8] or EAD 332402-00-0601-v02 [9].

The design method included in this TR relies on characteristic resistances and parameters, as well as the intended working life, which are stated in the ETA based on EAD 332402-00-0601 [7], EAD 332402-00-0601-v01 [8] for static and quasi-static loading assuming a working life of 50 or 100 years, respectively, and EAD 332402-00-0601-v02 [9] for seismic actions.

This TR is intended for safety related applications in which the failure of post-installed rebars may result in collapse or partial collapse of the structure, cause risk to human life or lead to significant economic loss. The proof of local transmission of the loads into concrete members is delivered by using the design methods described in this document. Proof of transmission of the loads shall be determined at the ultimate and serviceability limit states in accordance with EN 1992-1-1 [4] for static and quasi-static loading and with EN 1998-1 [5] for seismic action.

This TR does not cover the design of reinforced or unreinforced concrete members part of the moment resisting connection. The design of these members shall be carried out in compliance with the requirements of appropriate and applicable Standards.

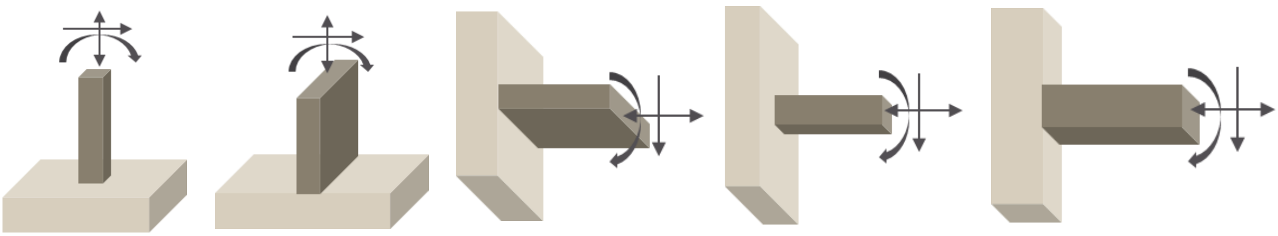
1.2 Relevance

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

1.2.1 Covered applications

The design procedure described in this TR is applicable for moment-resisting connections subjected to static and quasi-static loading and seismic action, as shown in Figure 1.2.1. Fatigue loading, and fire exposure are not covered by this Technical Report.

The design requirements of this TR cover both ultimate and serviceability limit states.



Column to foundation/slab (CFJ) | Wall to foundation/slab (WFJ) | Slab to wall (SWJ) | Beam to wall (BWJ) | Beam to column (BCJ)

Figure 1.2.1: Structural moment resisting connections covered by this TR
(clear grey: existing element; dark grey: new element)

Note: The definition of the structural elements addressed in Figure 1.2.1 (column, wall, slab and beam) is given in EN 1992-1-1, Section 5.3.1.

Note: The shear transfer through shear friction between the existing and the new reinforced concrete elements should be ensured by surface roughening prior to casting new against existing concrete. In cases where the surface layer of existing concrete is carbonated, the carbonated layer should be removed around the areas that are to receive post-installed rebars. A rule of thumb is to remove the carbonated concrete over a circular area given by the diameter of the bar plus 60 mm.

This TR is applicable to post-installed rebar connections with the following dimensions:

- Minimum and maximum rebar size, ϕ and maximum embedment depth, l_b as reported in the relevant ETA.

And where the following conditions are fulfilled:

- Minimum concrete cover, c_{min}, as given in Table 1.2.1 and Table 1.2.2 .
- Minimum clear spacing between two post-installed bars is a = 40 mm ≥ $4 \cdot \phi$.

Table 1.2.1 Minimum concrete cover, c_{min}

Drilling method	Bar diameter ϕ	c_{min}
Hammer drilling or diamond drilling	< 25 mm	max(30 mm + 0,06 l_b; $2 \cdot \phi$)
	≥ 25 mm	max(40 mm + 0,06 l_b; $2 \cdot \phi$)
Compressed air drilling	< 25 mm	max(50 mm + 0,08 l_b; $2 \cdot \phi$)
	≥ 25 mm	max(60 mm + 0,08 l_b; $2 \cdot \phi$)

The factors 0,06 and 0,08 in Table 1.2.1 take into account the possible inherent tolerances of the drilling process. These factors might be smaller if drilling aid devices (see Figure 1.2.2) are used. When using such a drilling aid device the minimum concrete cover may be reduced as given in Table 1.2.2 .

Table 1.2.2 Minimum concrete cover, c_{min}, when using a drilling aid

Drilling method	Bar diameter ϕ	c_{min}
Hammer drilling or diamond drilling	< 25 mm	max(30 mm + 0,02 l_b; $2 \cdot \phi$)
	≥ 25 mm	max(40 mm + 0,02 l_b; $2 \cdot \phi$)
Compressed air drilling	< 25 mm	max(50 mm + 0,02 l_b; $2 \cdot \phi$)
	≥ 25 mm	max(60 mm + 0,02 l_b; $2 \cdot \phi$)

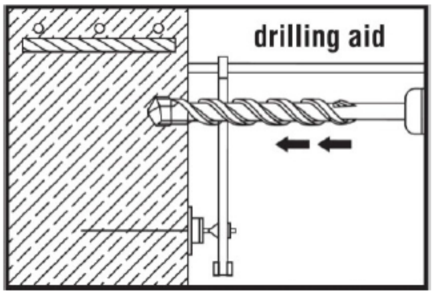


Figure 1.2.2 Example of drilling aid

All reinforcement requirements (e.g., diameters, reinforcement ratio and spacing) as per EN 1992-1-1 [4] shall be taken into account.

1.2.2 Materials

This TR covers post-installed rebar connections in reinforced or unreinforced normal weight, non-carbonated concrete without fibres of class C20/25 to C50/60 according to EN 206 [1] with a system assessed according to EAD 332402-00-0601 [7] or EAD 332402-00-0601-v01 [8] or EAD 332402-00-0601-v02 [9].

The system for post-installed rebar connections is composed of a mortar and an embedded straight deformed reinforcing bar complying with EN 1992-1-1 Annex C [4] for applications under static and quasi-static loading. Under seismic action additional requirements of EN 1998-1 [5] and its National Annexes may apply, e.g., steels of class B and C or C only as per Table C.1 of EN 1992-1-1 [4] shall be used for applications in structures of DCL/DCM or DCH in accordance with EN 1998-1 [5], respectively.

Characteristic values needed for the design of the post-installed rebars are given in the relevant ETA.

The design method is valid for single rebars and group of rebars. If rebars are installed in a group, only rebars with the same type, size, and length shall be used.

2 SPECIFIC TERMS/SYMBOLS USED IN THIS TR

2.1 Abbreviations

BCJ	=	Beam-Column-Joint
BWJ	=	Beam-Wall-Joint
CFJ	=	Column-Foundation-Joint
DCL	=	Ductility Class Low according to EN 1998-1 [5]
DCM	=	Ductility Class Medium according to EN 1998-1 [5]
DCH	=	Ductility Class High according to EN 1998-1 [5]
EAD	=	European Assessment Document
ETA	=	European Technical Assessment
SWJ	=	Slab-Wall-Joint
TR	=	Technical Report
WFJ	=	Wall-Foundation-Joint

2.2 Notation

$A_{c,N}$	=	Actual projected area of the group of tension rebars
$A^0_{c,N}$	=	Reference projected area
A_k	=	Characteristic fitting factor for equation (4.11a) taken from the relevant ETA
A_s	=	Cross sectional area of reinforcement
A_{st}	=	Cross-sectional area of one stirrup leg
c	=	Clear concrete cover / edge distance measured from the centre of the rebar
$c_{cr,N}$	=	Critical edge distance to ensure the characteristic resistance of a single rebar in case of concrete break-out under tension loading (measured from the centre of the rebar)
c_d	=	Minimum between clear concrete cover and half of the clear spacing from the closest neighbouring reinforcing bar
c_{min}	=	Minimum concrete cover

c_{max}	=	Maximum between clear concrete along the rebar layer (splitting plane) cover and half of the clear spacing from the closest neighbouring reinforcing bar
C_d	=	Design limit displacement of corresponding resistance
e_N	=	Eccentricity of the resulting tension load with reference to the centre of gravity of the tension reinforcement
E_d	=	Design action
f_{ck}	=	Nominal cylinder compressive strength of concrete according to EN 206[1]
f_{cm}	=	Mean cylinder compressive strength of concrete according to EN 1992-1-1 [4]
f_{ctm}	=	Mean tensile strength of concrete according to EN 1992-1-1 [4]
f_{yk}	=	Characteristic tensile (yield) strength of reinforcement
h	=	Thickness of the existing member
k_1	=	Factor for resistance to concrete failure
$k_{cr,N}$	=	Factor for resistance to concrete failure in cracked concrete
k_m	=	Factor for the effectiveness of transverse reinforcement
K_{tr}	=	Normalized ratio to consider the amount of transverse reinforcement crossing a potential splitting surface, equation (4.11a) in accordance with fib Model Code 2010 [10]
$k_{ucr,N}$	=	Factor for resistance to concrete failure in uncracked concrete
l_b	=	Embedment length of the post-installed rebar
M	=	Bending moment
n_b	=	Number of anchored or lapped rebars in the potential splitting surface
n_t	=	Number of legs of confining reinforcement crossing a potential splitting surface
$N_{Rd,c}$	=	Design concrete cone break-out resistance of the post-installed rebars
$N_{Rd,sp}$	=	Design bond-splitting resistance of the post-installed rebars
$N_{Rd,y}$	=	Design resistance to yielding of the post-installed rebars
$N_{Rk,c}$	=	Characteristic concrete cone break-out resistance of the post-installed rebars
$N^0_{Rk,c}$	=	Characteristic concrete cone break-out resistance for a single post-installed rebar not influenced by any adjacent post-installed rebar or edge
$N_{Rk,y}$	=	Characteristic resistance corresponding to yielding of the post-installed reinforcement
p_{tr}	=	Transverse pressure in the concrete
R_k	=	Characteristic value of resistance
R_d	=	Design value of resistance
s_b	=	Clear spacing between the confining reinforcement
$s_{cr,N}$	=	Centre to centre spacing to ensure the characteristic resistance of a single rebar

sp1, sp2, sp3, sp4 and *lb1*	=	Curve fitting exponents of equation (4.11a) taken from the relevant ETA
w_k	=	Characteristic crack width (95% quantile)
z	=	Lever arm
$\alpha_{eq,sp}$	=	Reduction factor taking into account the influence of cyclic loading on the splitting resistance taken from the relevant ETA
$\alpha_{eq,p}$	=	Reduction factor taking into account the influence of cyclic loading on the pull-out resistance taken from the relevant ETA
α_{sus}	=	ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions all considered at ultimate limit state
ϕ	=	Nominal diameter of the reinforcing bar
γ	=	Partial factor
γ_c	=	Partial factor for concrete
γ_{inst}	=	Factor accounting for the sensitivity to installation of post-installed rebars
γ_M	=	Partial factor for material
γ_{Mc}	=	Partial factor for concrete cone failure
γ_{Mp}	=	Partial factor for pull-out
γ_{Ms}	=	Partial factor for steel failure
γ_{Msp}	=	Partial factor for bond-splitting failure
γ_{Rd}	=	is the factor accounting for possible steel over-strength due to steel strain hardening according to EN 1998-1 [5]
η_1	=	Coefficient related to the quality of the bond condition and the position of the bar during concreting according to EN 1992-1-1 [4]
$\tau_{Rk,sp}$	=	Characteristic bond-splitting resistance
$\tau_{Rk,ucr}$ (or $\tau_{Rk,ucr,50}$)	=	Characteristic bond resistance in uncracked concrete considering a working life of 50 years
$\tau_{Rk,ucr,100}$	=	Characteristic bond resistance in uncracked concrete considering a working life of 100 years
Ω_{cr} (or $\Omega_{cr,03}$)	=	Factor to account for the influence of cracked concrete on pull-out resistance considering a crack width of 0,3 mm taken from the relevant ETA
$\Omega_{cr,05}$	=	Factor to account for the influence of cracked concrete on pull-out resistance considering a crack width of 0,5 mm taken from the relevant ETA
$\Omega_{cr,08}$	=	Factor to account for the influence of cracked concrete on pull-out resistance considering a crack width of 0,8 mm taken from the relevant ETA
$\Omega_{p,tr}$	=	Factor to account for transverse pressure in concrete

$\psi_{ec,N}$	=	Factor considering the effect of eccentricity between the point of application of the axial force and the centre of gravity of the tensioned rebars (e.g., in the case or more layers of tensioned reinforcement).
$\psi_{M,N}$	=	Factor considering the effect of the compression zone of the cross section of the attached reinforced concrete element in case of bending moments
$\psi_{re,N}$	=	Factor considering the effect of dense reinforcement between which the rebar is installed
$\psi_{s,N}$	=	Factor considering the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of concrete cone failure
ψ_{sus}	=	Factor to account for the effect of sustained loads on the bond strength

2.3 Indices

50	=	Value for 50 years working life
100	=	Value for 100 years working life
b	=	Bond
c	=	Concrete
cr	=	Cracked concrete
d	=	Design value
dur	=	Durability
eq	=	Earthquake / seismic
k	=	Characteristic
M	=	Material
max	=	Maximum
min	=	Minimum
p	=	Pull-out
R	=	Resistance
s	=	Steel
sp	=	Splitting
ucr	=	Uncracked concrete
y	=	Yield

2.4 Definitions

Mortar	=	Bonding material that is part of the post-installed rebar system
Rebar	=	Deformed reinforcing bar

3 DESIGN AND SAFETY CONCEPT

3.1 General

(1) The design procedure is applicable to post-installed rebar systems assessed as per EAD 332402-00-0601 [7] or EAD 332402-00-0601-v01 [8] or EAD 332402-00-0601-v02 [9] and having a valid ETA.

(2) The post installed rebar connection shall resist all actions and influences likely to occur during execution and use within the scope of this TR.

(3) Values for actions shall be obtained from the relevant parts of EN 1991 [3].

(4) The concrete members connected using post-installed rebar systems shall comply to the provisions of EN 1992-1-1 [4] under static and quasi-static loading and EN 1998-1 [5] under seismic action and their National Annexes, as applicable.

3.2 Design format

(1) At ultimate limit state it shall be shown that

$$E_d \leq R_d \tag{3.1}$$

Where

$$R_d = R_k/\gamma_M \tag{3.2}$$

(2) At serviceability limit state it shall be shown that

$$E_d \leq C_d \tag{3.3}$$

3.3 Verification by partial factor method

3.3.1 Partial factors for actions

(1) Partial factors for actions shall be according to EN 1990 [2] and national regulations (e.g., National Annexes of EN 1990 [2]) as applicable.

3.3.2 Partial factors for resistances

(1) Partial factors shall be in accordance with EN 1992-4, EN 1992-1-1 [4], EN 1998-1 [5] or national regulations (e.g., National Annexes) for the resistances under different failure modes. The values provided in Table 3.3.1 are recommended.

(2) The factor γ_{inst}, which is required for the determination of γ_{Mc}, is product dependent and shall be taken from the relevant ETA.

Table 3.3.1: Partial safety factors for different failure modes

Failure Modes	**Partial Factor**
Reinforcement Yielding	γ_{Ms} = 1,15
Concrete cone failure	$\gamma_{Mc} = \gamma_{inst} \cdot \gamma_c$ $\gamma_{inst} \geq$ 1,0 see relevant ETA γ_c = 1,5
Pull-out failure and Bond-splitting failure	$\gamma_{Mp} = \gamma_{Msp} = \gamma_{Mc}$

(3) The recommended values of the partial factors are valid for static and quasi-static loads and shall be applied to the characteristic resistances of the respective failure modes (Table 3.3.1).

(4) The factors listed in Table 3.3.1 apply to seismic actions based on EN 1998-1 [5], Cl. 5.2.4 (2). Additionally, the consideration of over-strength factors to ensure a ductile failure mode as per EN 1998-1 [5] for applications in structures with DCM or DCH might be required.

(5) In the framework of seismic retrofitting of existing buildings, modifications to the safety factors in accordance with EN 1998-3 [6] and/or national regulations may be applicable (e.g., consideration of *Confidence Factors* in combination with the respective *Knowledge Levels*).

3.4 Project Specification

The project specification should typically include the following:

(1) Strength class of concrete used for the existing concrete member and proposed for the new connecting concrete member.

(2) Reinforcement detailing drawings for the existing and new member.

(3) It is recommended to conduct non-destructive or destructive (if feasible) evaluation of the existing concrete strength and reinforcement details (e.g., detection). Provisions of EN 1998-3 [6] and applicable National Annexes shall be followed to reach the desired *Knowledge Level* if *Confidence Factors* according to the same standards are used.

3.5 Installation of Post-installed rebars

The resistance and reliability of the post-installed rebar system is significantly influenced by its installation procedures. The partial factors listed in Section 3.3.2 are valid only when the conditions of installation provided by the relevant ETA are met.

3.6 Determination of concrete condition of the base member

In the region of anchorage of the new connecting member, the concrete may be cracked or non-cracked. The condition of the concrete for the service life of the structural connection shall be determined by the designer.

Cracked concrete shall always be assumed, unless uncracked concrete conditions can be guaranteed (e.g., EN 1992-4, eq. (4.4) [13]).

Under static and quasi-static loading the consideration of a crack width w_k of 0,3 mm over the entire anchorage length (using the factor Ω_{cr} or $\Omega_{cr,03}$ from the relevant ETA) can be conservatively assumed.

Under seismic action the crack width can be significantly larger and is influenced by several factors such as type of connections, design assumptions (i.e., elastic vs. ductile design), deformability of the existing member, capacity design considerations, ratio between anchorage length and height of the existing member, etc. If no detailed information is available, e.g., results of finite element modelling, the recommendations of Table 3.6.1 can be conservatively followed.

Table 3.6.1: Recommended assumptions for maximum design crack widths

Ductility class according to EN 1998-1	**Behaviour factor, *q* according to EN 1998-1**	**l_b / *h* [-]**	**Assumed crack width, w_k [mm]**	**Comment**
DCL	1,0	All	0,3	Static design applies
DCM	1,0 – 1,5	≥ 0,8	0,3	
		< 0,8	0,5	
DCM / DCH	1,5 – 3,0	≥ 0,8	0,5	
		< 0,8	0,8	
DCM / DCH	> 3,0	≥ 0,8	0,8	
		< 0,8	Not covered by this TR	

Note: Concrete of the existing element may be considered uncracked, if ensured by appropriate assessment (e.g., if condition given by EN 1992-4, eq. (4.4) [13] is verified in the seismic design situation)

4 VERIFICATION OF ULTIMATE LIMIT STATE UNDER STATIC AND QUASI STATIC LOADING

4.1 Required verifications

(1) The design resistance (R_d), expressed as the total tension force in the post installed reinforcement used for the moment resisting connection, shall be calculated for each failure mode based on characteristic resistance evaluated as per Sections 4.2 to 4.4.

(2) The decisive design resistance for the anchorage shall be calculated using equation (4.1).

$$R_d = min(N_{Rd,y};\ N_{Rd,c};\ N_{Rd,sp}) \tag{4.1}$$

Where

R_d is equal to R_k / γ_M

$N_{Rd,y}$ is the design resistance to yielding of the post-installed rebars

$N_{Rd,c}$ is the design concrete cone break-out resistance of the post-installed rebars

$N_{Rd,sp}$ is the design bond-splitting resistance of the post-installed rebars

Table 4.1.1 gives an overview and brief description of the required verifications.

(3) Concrete breakout resistance does not need to be verified, when the design relies on supplementary reinforcement following the provisions of EN 1992-4, 7.2.1.2 and 7.2.1.9 [13].

Table 4.1.1: Required verifications and description

Failure mode	**Notation**	**Verification required**		**Comment**
		Tension rebar group	**Most unfavourable tension loading on single rebar**	
Steel yielding resistance	$N_{Rd,y} = N_{Rk,y} / \gamma_{Ms}$	Yes	no	The state of stress in the tension bars is to be averaged based on the position of the centre of gravity of the tension reinforcement
Concrete cone break-out resistance	$N_{Rd,c} = N_{Rk,c} / \gamma_{Mc}$	Yes	no	Eccentricities are taken into account in the calculation of $N_{Rk,c}$ as per Section 4.3
Bond-splitting resistance	$N_{Rd,sp} = N_{Rk,sp} / \gamma_{Msp}$	Yes	yes	The overall resistance of all tension bars must be calculated to compare it with the other relevant failure modes. However, single bars might underlie more severe loading conditions (e.g., eccentric and/or different c_d and/or c_{max} values)

Note: the combined pull-out and concrete break-out resistance as per EN 1992-4 [13] is replaced in this TR by the calculation of bond-splitting resistance to allow geometric parameters not covered in the EN 1992-4 [13], i.e., small edge distances and/or spacing between rebars as well as anchorage length higher than 20ϕ.

4.2 Resistance corresponding to yielding of the reinforcement

Note: It is recommended to pursue this failure mode in the design of post-installed rebar connections.

The characteristic resistance corresponding to yielding of the post-installed reinforcement is given by equation (4.2)

$$N_{Rk,y} = A_s \cdot f_{yk} \tag{4.2}$$

Where

A_s is the cross-sectional area of all tension post-installed rebars within the connection

4.3 Resistance corresponding to concrete cone failure

The design for the concrete cone failure resistance given in this section is based on EN 1992-4 [13].

Note: The limitations of EN 1992-4 Figure 1.2 are not applicable to the design of post-installed rebars in moment resisting connections for the following reasons:

- *Post-installed reinforcement is not designed for shear loading*
- *Unless otherwise assumed or specified, the hypothesis that plane sections remain plane (rigid base plate assumption) is automatically satisfied when designing the reinforced concrete members in accordance with EN 1992-1-1 [4]*

The characteristic resistance for the group of reinforcement under tension resulting from the moment resisting mechanism shall be obtained as given in equation (4.3).

$$N_{Rk,c} = N_{Rk,c}^{0} \cdot \frac{A_{c,N}}{A_{c,N}^{0}} \cdot \psi_{s,N} \cdot \psi_{ec,N} \cdot \psi_{re,N} \cdot \psi_{M,N} \tag{4.3}$$

The different factors in equation (4.3) shall be determined as follows:

(1) The characteristic resistance for a single reinforcement post-installed in the concrete and not influenced by any adjacent reinforcement or edge is given by equation (4.4)

$$N_{Rk,c}^{0} = k_1 \cdot \sqrt{f_{ck}} \cdot l_b^{1,5} \tag{4.4}$$

where:

k_1 = $k_{cr,N}$ for cracked concrete

= $k_{ucr,N}$ for non-cracked concrete

$k_{cr,N}$ and $k_{ucr,N}$ are given in the relevant ETA.

Note 1: l_b = h_{ef}, thus equation (4.3) is equivalent to the concrete cone resistance equation provided in EN 1992-4 [13].

Note 2: Suggested values of $k_{cr,N}$ and $k_{ucr,N}$ are $k_{cr,N}$ = 7,7 and $k_{ucr,N}$= 11,0.

(2) The geometric effect of adjacent tension reinforcement and edge influence is taken into account using the value of $A_{c,N}/A^0_{c,N}$, where:

$A^0_{c,N}$ $= s_{cr,N} \cdot s_{cr,N}$ (4.5)

is the reference projected area as per [13] with h_{ef} replaced by l_b

$A_{c,N}$ is the actual projected area of the group of tensioned rebars, limited by overlapping of projected areas of adjacent bars and presence of edges. Example calculation is shown in [13].

Note: A value of $s_{cr,N} = 2 \cdot c_{cr,N} = 3 \cdot l_b$ *could be used indicatively.* $c_{cr,N}$ *is given in the relevant ETA*.

(3) The factor $\psi_{s,N}$ accounts for the disturbance of the distribution of stresses in the concrete due to the proximity of an edge of the concrete member. This is given by equation (4.6).

$$\psi_{s,N} = 0{,}7 + 0{,}3 \cdot \frac{c}{c_{cr,N}} \leq 1{,}0 \qquad (4.6)$$

where:

c = The edge distance to the closest edge measured from the centre of the rebar

$c_{cr,N}$ is given in the relevant ETA.

(4) The factor $\psi_{ec,N}$ accounts for eccentricity between the point of application of the axial force and the centre of gravity of the tensioned rebars. This is given by equation (4.7).

$$\psi_{ec,N} = \frac{1}{1 + 2 \cdot \frac{e_N}{s_{cr,N}}} \leq 1{,}0 \qquad (4.7)$$

where:

e_N = The eccentricity of the resulting tension load with reference to the centre of gravity of the tension reinforcement

(5) The factor $\psi_{re,N}$ accounts for the reduced strength of rebars with an anchorage length $l_b < 100$ mm inserted in concrete elements with closely spaced reinforcement.

$$\psi_{re,N} = 0{,}5 + \frac{l_b}{200} \leq 1{,}0 \qquad (4.8)$$

The factor $\psi_{re,N}$ may be taken as 1,0 in the following cases:

a) Reinforcement (any diameter) is present at a spacing ≥ 150 mm, or
b) Reinforcement with a diameter of ≤ 10 mm is present at a spacing ≥ 100 mm

The conditions a) and b) shall be fulfilled for both loading directions in case of reinforcement in two directions.

(6) The factor $\psi_{M,N}$ accounts for the effect of compression stresses resulting from the moment resisting actions on the concrete cone capacity. This is given by equation (4.9).

$$\psi_{M,N} = 2{,}0 - \frac{z}{1{,}5 \cdot l_b} \geq 1{,}0 \qquad (4.9)$$

where:

z = The lever arm between the resulting tension and compression force in the cross section of the connecting member due to the applied moment at the location of face of the base member

$\psi_{M,N}$ = 1,0 for the following cases:

- Anchorages with an edge distance $c < 1{,}5\ l_b$
- Anchorages with $c \geq 1{,}5\ l_b$ loaded by a bending moment and a tension force with $C_{Ed}/N_{Ed} < 0{,}8$ where C_{Ed} is the resultant compression force at the interface section between existing and new reinforced concrete member (taken as absolute value) and N_{Ed} is the resultant tension force of the tensioned post-installed rebars of the connection

Note: For the case of rebars in an application with three or more edge distances less than $c_{cr,N}$ from the rebars, the calculation according to Equation (4.3) leads to conservative results. More precise results are obtained if, in the case of single rebars, the value l_b is substituted by l'_b, where l'_b is calculated as h'_{ef} in accordance with provisions of the EN 1992-4 [13].

4.4 Resistance corresponding to pull-out and splitting failure

(1) The resistance corresponding to bond-splitting failure, $\tau_{Rk,sp}$, and its relevant parameters A_k, Ω_{cr} (or $\Omega_{cr,03}$), *sp*1, *sp*2, *sp*3, *sp*4 and *lb*1 are provided in the relevant ETA.

(2) The bond-splitting resistance is expressed as a function of the embedded length, l_b, as per equations (4.10) and (4.11a).

Note: If the load on the tension bars is applied eccentrically and/or the values c_d and c_{max} are different for each tensioned bar, the resistance $N_{Rk,sp}$ shall be calculated separately for each rebar.

(3) The bond-splitting resistance is limited by the value of $\tau_{Rk,ucr}$ as shown in equations (4.11b) and (4.11c)

$$N_{Rk,sp} = \tau_{Rk,sp} \cdot l_b \cdot \phi \cdot \pi \qquad \text{(for each tension bar)} \tag{4.10}$$

$$\tau_{Rk,sp} = \eta_1 \cdot A_k \cdot \left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_d}{\phi}\right)^{sp3} \cdot \left(\frac{c_{max}}{c_d}\right)^{sp4} + k_m \cdot K_{tr}\right] \cdot \left(\frac{7\phi}{l_b}\right)^{lb1} \cdot \Omega_{p,tr} \tag{4.11a}$$

$$\leq \tau_{Rk,ucr} \cdot \Omega_{cr,03}\ (or\ \Omega_{p,tr}) \cdot \psi_{sus} \qquad \text{for } 7\phi \leq l_b \leq 20\phi \tag{4.11b}$$

$$\leq \tau_{Rk,ucr} \cdot \left(\frac{20\,\phi \cdot}{l_b}\right)^{lb1} \cdot \Omega_{cr,03}\ (or\ \Omega_{p,tr}) \cdot \psi_{sus} \qquad \text{for } l_b > 20\phi \tag{4.11c}$$

where:

η_1 is a coefficient related to the quality of the bond condition and the position of the bar during concreting according to EN 1992-1-1 [4]

= 1,0 when “good” conditions are obtained as per EN 1992-1-1, Figure 8.2 [4]

= 0,7 in all other cases

A_k, *sp*1, *sp*2, *sp*3, *sp*4 and *lb*1 are taken from the relevant ETA

In equation (4.11a) the value $\phi \geq 12$ shall be inserted in the factor accounting for the influence of the rebar diameter (i.e., $(25/\phi)^{sp2}$).

c_d = min {c_s/2; c_x; c_y} (see Figure 4.4.1)

c_{max} = max {c_s/2; c_x} (see Figure 4.4.1)

In the calculation, the ratio c_{max} / c_d shall not be larger than 3,5.

k_m is the factor for the effectiveness of transverse reinforcement defined according to fib Model Code 2010 [10] and fib Bulletin 72 [14] (see Figure 4.4.2).

= 12 where rebars are confined inside a bend of links passing round the bar of at least 90°.

= 6 where a rebar is more than 125 mm and more than 5 bar diameters from the nearest vertical leg of a link crossing the splitting plane in an approximately perpendicular direction

= 0 if a splitting crack would not intersect transverse reinforcement, either because the transverse reinforcement is positioned inside the bars, or the clear spacing between anchored or pairs of lapped rebars is less than 4 times the bottom cover, and hence a crack through the plane of the rebars would form without intersecting transverse reinforcement

K_{tr} is the normalized ratio to consider the amount of transverse reinforcement crossing a potential splitting surface defined and calculated according to fib Model Code 2010 [10] as follows:

$$K_{tr} = (n_t \cdot A_{st}) / (n_b \cdot \phi \cdot s_b) \leq 0{,}05 \qquad (4.12)$$

where:

n_t is the number of legs of confining reinforcement crossing a potential splitting surface

A_{st} is the cross-sectional area of one stirrup leg

n_b is the number of anchored or lapped bars in the potential splitting surface

s_b is the spacing between the confining reinforcement

Note: in the case of cracked concrete, in equations (4.11b) and (4.11c) only Ω_{cr} (or $\Omega_{cr,03}$) applies and $\Omega_{p,tr}$ shall not be applied.

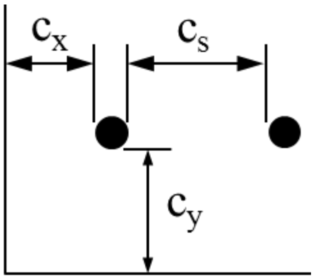
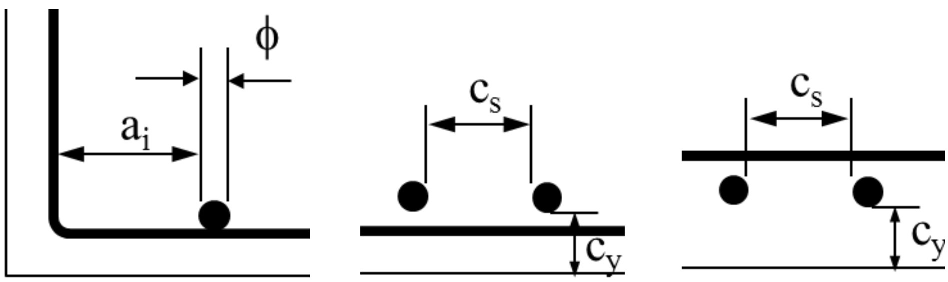


Figure 4.4.1 Notation for bar spacing and cover as per fib Model Code 2010 [10]



$a_i \leq 125$ mm or $a_i \leq 5\phi$: $k_m = 12$
$a_i > 125$ mm and $a_i > 5\phi$: $k_m = 6$

$a_i > 125$ mm and $a_i > 5\phi$ and
$c_s < 4c_y$: $k_m = 0$

$k_m = 0$

Figure 4.4.2 Reduced effectiveness of links as per fib Bulletin 72 [14]

(4) As shown by equation (4.11a,b,c), the pull-out resistance represents an upper limit to the splitting resistance and accounts for: (i) the effect of serviceability cracks in the concrete (using the multiplication factor Ω_{cr}) and (ii) the effect of transverse pressure in the concrete (using the multiplication factor $\Omega_{p,tr}$).

a) $\tau_{Rk,ucr}$ shall be taken from the relevant ETA as $\tau_{Rk,ucr}$ (or $\tau_{Rk,ucr,50}$) or $\tau_{Rk,ucr,100}$ for a working life of 50 or 100 year, respectively.

b) The factor to account for the effects of cracking ($\Omega_{cr,03}$ / $\Omega_{cr,05}$ / $\Omega_{cr,08}$) shall be taken from the relevant ETA.

c) Transverse pressure (p_{tr}) perpendicular to the axis of the post-installed reinforcement should be accounted for using the factor $\Omega_{p,tr}$ as prescribed in fib Model Code 2010 [10] and shown in equation (4.13).

$$\Omega_{p,tr} = 1{,}0 - \frac{0{,}3 \cdot p_{tr}}{f_{ctm}} \qquad \text{for} \quad 0 \le p_{tr} \le f_{ctm} \text{ (tension)}$$

$$\Omega_{p,tr} = 1{,}0 - tanh\left[0{,}2 \cdot \frac{p_{tr}}{0{,}1 \cdot f_{cm}}\right] \quad \text{for} \quad f_{cm} \le p_{tr} \le 0 \quad \text{(compression)} \tag{4.13}$$

Where

f_{cm} and f_{ctm} shall be taken according to EN 1992-1-1 [4] for the concrete strength class under consideration.

p_{tr} is calculated as mean stress in the concrete at ultimate state (orthogonal to the bar axis) averaged over a volume around the bar with a diameter of 3ϕ.

d) The factor to account for the effect of sustained loads as per EN 1992-4 [13] is in accordance with equation (4.14a,b)

$$\psi_{sus} = 1 \qquad \text{for} \qquad \alpha_{sus} \le \psi^0_{sus} \tag{4.14a}$$

$$\psi_{sus} = \psi^0_{sus} + 1 - \alpha_{sus} \qquad \text{for} \qquad \alpha_{sus} > \psi^0_{sus} \tag{4.14b}$$

Where

ψ^0_{sus} is the product dependent factor that takes account of the influence of sustained loads on the bond strength to be taken from the relevant ETA as ψ^0_{sus} (or $\psi^0_{sus,50}$) or $\psi^0_{sus,100}$ for a working life of 50 or 100 years, respectively.

α_{sus} is the ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions all considered at ultimate limit state

If no value is given in the relevant ETA for the product a value ψ^0_{sus} = 0,6, should be used as per EN 1992-4 [13].

4.5 Minimum anchorage length

The anchorage length, l_b, calculated according to the provisions of this TR to resist the design actions shall not be shorter than the minimum required anchorage length, $l_{b,min}$, as per EN 1992-1-1 [4] and the applicable National Annexes.

5 VERIFICATION OF ULTIMATE LIMIT STATE UNDER SEISMIC ACTION

5.1 Required verifications

(1) The design resistance (R_d), expressed as the total tension force in the post installed reinforcement used for the moment resisting connection, shall be calculated for each failure mode based on characteristic resistance evaluated as per Sections 5.2 to 5.4.

(2) The decisive design resistance for the anchorage shall be calculated using equation (5.1).

$$R_{d,eq} = N_{Rd,y,eq} \leq min\left(N_{Rd,c,eq};\ N_{Rd,sp,eq}\right) \tag{5.1}$$

Where:

$R_{d,eq}$ is equal to $R_{k,eq} / \gamma_M$

$N_{Rd,y,eq}$ is the seismic design resistance to yielding of the post-installed rebars

$N_{Rd,c,eq}$ is the seismic design concrete cone break-out resistance of the post-installed rebars

$N_{Rd,sp,eq}$ is the seismic design bond-splitting resistance of the post-installed rebars

Note:

- *Equation (5.1) complies with the capacity design philosophy of EN 1998-1 [5].*
- *$N_{Rd,c,eq}$ or $N_{Rd,sp,eq}$ may be acceptable as decisive failure modes, if the predicted plastic mechanism of the structural system is ductile at a demand level at which the connection with post-installed rebars designed according to this TR is still elastic.*

5.2 Resistance corresponding to yielding of the reinforcement

Section 4.2 applies with the following modification:

(1) Equation (5.3) applies to account for potential over-strength due to steel strain hardening:

$$N_{Rk,y,eq} = \gamma_{Rd} \cdot N_{Rk,y} \tag{5.2}$$

Where

γ_{Rd} ≥ 1,0

Note: The value of the factor γ_{Rd} should be related to level of ductility for which the connection is designed. The values 1,0 and 1,2 for DCM and DCH, respectively, in accordance with the provisions of EN 1998-1, Cl. 5.6.2.2 (anchorage of beams in beam-column joints) [5] can be used.

5.3 Resistance corresponding to concrete cone failure

Section 4.4 applies with the following modifications:

(1) Equation (4.3) is replaced by the following equation:

$$N_{Rk,c,eq} = \alpha_{eq} \cdot N_{Rk,c} \tag{5.3}$$

Where:

α_{eq} = 1,0 if w_k = 0,3 mm

α_{eq} = 0,85 if w_k > 0,3 mm

$N_{Rk,c}$ is calculated according to Section 4.4

Note: The reduction factor α_{eq} = 0,85 is in line with the provisions of EN 1992-4 [13] for single anchors and hence considering only the effect of large crack width (w_k > 0,3 mm). No additional reduction is required for rebar groups, which are usually arranged in layers, because it is highly improbable that the tension rebars experience different crack widths (i.e., the crack run usually along the rebar layer).

5.4 Resistance corresponding to pull-out and splitting failure

Section 4.4 applies with the following modifications:

(1) Equations (4.11a), (4.11b), (4.11c) are replaced by the following equations:

$$\tau_{Rk,sp,eq} = \eta_1 \cdot \alpha_{eq,sp} \cdot A_k \cdot \left(\frac{f_{ck}}{25}\right)^{sp1} \cdot \left(\frac{25}{\phi}\right)^{sp2} \cdot \left[\left(\frac{c_d}{\phi}\right)^{sp3} \cdot \left(\frac{c_{max}}{c_d}\right)^{sp4} + k_m \cdot K_{tr}\right] \cdot \left(\frac{7\phi}{l_b}\right)^{lb1} \qquad (5.4a)$$

$$\leq \tau_{Rk,ucr} \cdot \Omega_{cr,eq} \cdot \alpha_{eq,p} \qquad \text{for } 7\phi \leq l_b \leq 20\phi \qquad (5.4b)$$

$$\leq \tau_{Rk,ucr} \cdot \left(\frac{20\,\phi\cdot}{l_b}\right)^{lb1} \cdot \Omega_{cr,eq} \cdot \alpha_{eq,p} \qquad \text{for } l_b > 20\phi \qquad (5.4c)$$

Where:

$\Omega_{cr,eq} = \Omega_{cr,03}$ or $\Omega_{cr,05}$ or $\Omega_{cr,08}$ depending on the design assumptions (see Section 3.6) taken from the relevant ETA

$\alpha_{eq,sp}$ and $\alpha_{eq,p}$ are the seismic reduction factors for splitting and pull-out, respectively, taken from the relevant ETA

5.5 Additional provisions under seismic conditions

Under specific design conditions the anchorage length, l_b, as calculated in this chapter, should be increased following the provisions on EN 1998-1 [5], e.g.,

- In DCH structures, the anchorage of beams and columns that are expected to plasticize during the seismic event shall be measured from a point on the bar at a distance of 5 rebar diameters inside the face of joint to take into account the yield penetration due to cyclic, post-elastic, deformations (see EN 1998-1, Cl. 5.6.1 (3)P [5]); and
- In columns where the axial force may become tensile, the anchorage length shall be increased by 50% (see EN 1998-1, Cl. 5.6.2.1 (2)P [5]).

5.6 Minimum anchorage length

Section 4.5 applies without modifications.

6 VERIFICATION OF SERVICEABILITY LIMIT STATE

(1) For the existing as well as the connecting reinforced concrete member, the serviceability requirements as per EN 1992-1-1 [4] shall be satisfied.

(2) Displacements given in the product ETA obtained following the requirements of EAD 330499-01-0601 [11] can be used.

(3) The serviceability requirements in terms of concrete cracking for the combined bond and splitting failure modes are accounted for by the product ETA obtained following the requirements of EAD 332402-00-0601 [7].

7 DURABILITY

The durability of the connection with post-installed rebars shall not be less than its intended working life. During this period of use, the mechanical properties of the reinforcing bar should not be adversely affected by environmental influences such as corrosion, oxidation, aging or alkalinity of the concrete. This is ensured by the following:

a) The mortar of a post-installed rebar system with an ETA as per EAD 332402-00-0601 [7] ensures a corrosion protection of the bar not smaller than in the case of a cast-in bar.
b) Concrete clear cover c_{min} = max ($c_{min,dur}$; $c_{min,ETA}$), where $c_{min,dur}$ is the minimum cover required for different exposure classes according to EN 1992-1-1 [4] and $c_{min,ETA}$ is the minimum concrete cover given in the relevant ETA as per EAD 332402-00-0601 [7].

8 ADDITIONAL VERIFICATIONS FOR ENSURING THE CHARACTERISTIC RESISTANCE OF THE EXISTING REINFORCED CONCRETE MEMBER

The transmission of the loads between existing and new concrete members shall be verified in accordance with EN 1992-1-1[4] and should consider all possible failure modes of the connection that are not specifically taken into account by this TR. Additional verifications include, but are not limited to, the verification of the shear resistance of the existing member, or the verification of the shear resistance of the nodal panel.

Among the required design verifications, the local transfer of the forces from the tension post-installed bars to the main reinforcement of the existing element should be verified, e.g., according to EN 1992-4, Annex A [13] or using a strut and tie model.

9 REFERENCE DOCUMENTS

[1]	**EN 206:2013+A1:2016**	Concrete: Specification, performance, production and conformity
[2]	**EN 1990:2002/A1:2005/AC:2010**	Eurocode — Basis of structural design
[3]	**EN 1991:2002**	Eurocode 1: Actions on structures
[4]	**EN 1992-1-1:2004/AC:2010/A1:2014**	Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings
[5]	**EN 1998-1:2004+AC:2009**	Eurocode 8: Design of structures for earthquake resistance – Part 1: General rules, seismic actions and rules for buildings
[6]	**EN 1998-3:2005**	Eurocode 8: Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings
[7]	**EAD 332402-00-0601:12-2018**	Post-Installed Reinforcing Bar (Rebar) Connections with Improved Bond-Splitting Behaviour under Static Loading
[8]	**EAD 332402-00-0601-v01:08-2020**	Post-Installed Reinforcing Bar (Rebar) Connections with Improved Bond-Splitting Behaviour under Static Loading: 100 Years Working Life
[9]	**EAD 332402-00-0601-v02:12-2021**	Post-Installed Reinforcing Bar (Rebar) Connections with Improved Bond-Splitting Behaviour under Seismic action
[10]	**fib Model Code 2010**	fib Model Code for Concrete Structures 2010
[11]	**EAD 330499-01-0601:12-2018**	Bonded Fasteners for Use in Concrete
[12]	**EAD 330087-01-0601:12-2020**	Systems for Post-Installed Rebar Connections with Mortar
[13]	**EN 1992-4:2018**	Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete
[14]	**fib Bulletin 72:2014**	Bond and Anchorage of embedded reinforcement: Background to the fib Model Code for Concrete Structures 2010.