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

TR 069
October 2019
Amended June 2021
EOTA Technical Reports are developed as supporting reference documents to EOTA publications such as European Technical Approval Guidelines (ETAG) and European Assessment Documents (EAD), or other harmonised technical specifications. They can be used for technical assessments of construction products, notably when conducted by Technical Assessment Bodies (TAB) designated by European Members States in accordance to Regulation (EU) 305/2011 for issuing European Technical Assessments (ETA).

EOTA Technical Reports detail aspects relevant for construction products such as design, execution and evaluation of tests, and express the common understanding of existing knowledge and experience of the Technical Assessment Bodies in EOTA at a particular point in time. They may give recommendations for product packaging, transport, storage, maintenance, replacement and repair.

Where knowledge and experience is developing, especially through assessment work, such reports can be amended. Amendments of EOTA Technical Reports supersede the previous one. The reference title and language for this TR is English. The applicable rules of copyright refer to the document elaborated in and published by EOTA.

This EOTA Technical Report has been adopted by the EOTA Technical Board and has been elaborated by:

EOTA WG “No + title” convened by TAB (Acronym/Name)
Contents

1 Scope of the Technical Report..............................................................4
  1.1 Abstract 4
  1.2 Relevance 4
    1.2.1 Covered applications..........................................................4
    1.2.2 Materials...........................................................................5

2 Specific terms/symbols used in this TR..............................................6
  2.1 Abbreviations 6
  2.2 Notation 6
  2.3 Indices 9
  2.4 Definitions 9

3 Design and safety concept..................................................................10
  3.1 General 10
  3.2 Design format 10
  3.3 Verification by partial factor method 10
    3.3.1 Partial factors for actions...................................................10
    3.3.2 Partial factors for resistances.............................................10
  3.4 Project Specification 11
  3.5 Installation of Post-installed rebars 11
  3.6 Determination of concrete condition of the base member 11

4 Verification of ultimate limit state under static and quasi static loading ........12
  4.1 Required verifications 12
  4.2 Resistance corresponding to yielding of the reinforcement 13
  4.3 Resistance corresponding to concrete cone failure 13
  4.4 Resistance corresponding to pull-out and splitting failure 15
  4.5 Minimum anchorage length 17

5 Verification of ultimate limit state under seismic action........................18
  5.1 Required verifications 18
  5.2 Resistance corresponding to yielding of the reinforcement 18
  5.3 Resistance corresponding to concrete cone failure 18
  5.4 Resistance corresponding to pull-out and splitting failure 19
  5.5 Additional provisions under seismic conditions 19
  5.6 Minimum anchorage length 19

6 Verification of serviceability limit state..............................................19

7 Durability ............................................................................................20

8 Additional verifications for ensuring the characteristic resistance of the existing reinforced concrete member ..............................20

9 Reference documents............................................................................21
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.

![Figure 1.2.1: Structural moment resisting connections covered by this TR](Image)

*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·φ.

### Table 1.2.1 Minimum concrete cover, c_min

<table>
<thead>
<tr>
<th>Drilling method</th>
<th>Bar diameter φ</th>
<th>c_min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer drilling or diamond</td>
<td>&lt; 25 mm</td>
<td>max(30 mm + 0.06 l_b; 2·φ)</td>
</tr>
<tr>
<td>drilling</td>
<td>≥ 25 mm</td>
<td>max(40 mm + 0.06 l_b; 2·φ)</td>
</tr>
<tr>
<td>Compressed air drilling</td>
<td>&lt; 25 mm</td>
<td>max(50 mm + 0.08 l_b; 2·φ)</td>
</tr>
<tr>
<td></td>
<td>≥ 25 mm</td>
<td>max(60 mm + 0.08 l_b; 2·φ)</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Drilling method</th>
<th>Bar diameter φ</th>
<th>c_min</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hammer drilling or diamond</td>
<td>&lt; 25 mm</td>
<td>max(30 mm + 0.02 l_b; 2·φ)</td>
</tr>
<tr>
<td>drilling</td>
<td>≥ 25 mm</td>
<td>max(40 mm + 0.02 l_b; 2·φ)</td>
</tr>
<tr>
<td>Compressed air drilling</td>
<td>&lt; 25 mm</td>
<td>max(50 mm + 0.02 l_b; 2·φ)</td>
</tr>
<tr>
<td></td>
<td>≥ 25 mm</td>
<td>max(60 mm + 0.02 l_b; 2·φ)</td>
</tr>
</tbody>
</table>

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

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

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BCJ</td>
<td>Beam-Column-Joint</td>
</tr>
<tr>
<td>BWJ</td>
<td>Beam-Wall-Joint</td>
</tr>
<tr>
<td>CFJ</td>
<td>Column-Foundation-Joint</td>
</tr>
<tr>
<td>DCL</td>
<td>Ductility Class Low according to EN 1998-1 [5]</td>
</tr>
<tr>
<td>DCM</td>
<td>Ductility Class Medium according to EN 1998-1 [5]</td>
</tr>
<tr>
<td>DCH</td>
<td>Ductility Class High according to EN 1998-1 [5]</td>
</tr>
<tr>
<td>EAD</td>
<td>European Assessment Document</td>
</tr>
<tr>
<td>ETA</td>
<td>European Technical Assessment</td>
</tr>
<tr>
<td>SWJ</td>
<td>Slab-Wall-Joint</td>
</tr>
<tr>
<td>TR</td>
<td>Technical Report</td>
</tr>
<tr>
<td>WFJ</td>
<td>Wall-Foundation-Joint</td>
</tr>
</tbody>
</table>

2.2 Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_{c,N} )</td>
<td>Actual projected area of the group of tension rebars</td>
</tr>
<tr>
<td>( A^0_{c,N} )</td>
<td>Reference projected area</td>
</tr>
<tr>
<td>( A_k )</td>
<td>Characteristic fitting factor for equation (4.11a) taken from the relevant ETA</td>
</tr>
<tr>
<td>( A_s )</td>
<td>Cross sectional area of reinforcement</td>
</tr>
<tr>
<td>( A_{st} )</td>
<td>Cross-sectional area of one stirrup leg</td>
</tr>
<tr>
<td>( c )</td>
<td>Clear concrete cover / edge distance measured from the centre of the rebar</td>
</tr>
<tr>
<td>( c_{cr,N} )</td>
<td>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)</td>
</tr>
<tr>
<td>( c_d )</td>
<td>Minimum between clear concrete cover and half of the clear spacing from the closest neighbouring reinforcing bar</td>
</tr>
<tr>
<td>( c_{\text{min}} )</td>
<td>Minimum concrete cover</td>
</tr>
</tbody>
</table>
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_{ucc,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_{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
DESIGN METHOD FOR ANCHORAGE OF POST-INSTALLED REINFORCING BARS (REBARS) WITH IMPROVED BOND-SPLITTING BEHAVIOR AS COMPARED TO EN 1992-1-1

- $sp1, sp2, sp3, sp4$ 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
- $\alpha_{sus}$: 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
- $\phi$: Nominal diameter of the reinforcing bar
- $\gamma$: Partial factor
- $\gamma_c$: Partial factor for concrete
- $\gamma_{inst}$: Factor accounting for the sensitivity to installation of post-installed rebars
- $\gamma_M$: Partial factor for material
- $\gamma_{Mc}$: Partial factor for concrete cone failure
- $\gamma_{Mp}$: Partial factor for pull-out
- $\gamma_{Ms}$: Partial factor for steel failure
- $\gamma_{Msp}$: Partial factor for bond-splitting failure
- $\gamma_{Rd}$: is the factor accounting for possible steel over-strength due to steel strain hardening according to EN 1998-1 [5]
- $\eta_1$: 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
- $\Omega_{cr}$ (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
- $\Omega_{sp,lr}$: Factor to account for transverse pressure in concrete
DESIGN METHOD FOR ANCHORAGE OF POST-INSTALLED REINFORCING BARS (REBARS) WITH IMPROVED BOND-SPLITTING BEHAVIOR AS COMPARED TO EN 1992-1-1

\[ \psi_{ec,N} = \text{Factor considering the effect of eccentricity between the point of application of the axial force and the centre of gravity of the tensioned rebars (e.g., in the case or more layers of tensioned reinforcement).} \]

\[ \psi_{M,N} = \text{Factor considering the effect of the compression zone of the cross section of the attached reinforced concrete element in case of bending moments} \]

\[ \psi_{re,N} = \text{Factor considering the effect of dense reinforcement between which the rebar is installed} \]

\[ \psi_{s,N} = \text{Factor considering the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of concrete cone failure} \]

\[ \psi_{sus} = \text{Factor to account for the effect of sustained loads on the bond strength} \]

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].


3.2  Design format

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

\[ E_d \leq R_d \]  

Where

\[ R_d = R_k / \gamma_M \]  

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

\[ E_d \leq C_d \]  

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 \( \gamma_{\text{inst}} \), which is required for the determination of \( \gamma_{\text{Mc}} \), is product dependent and shall be taken from the relevant ETA.

Table 3.3.1: Partial safety factors for different failure modes

<table>
<thead>
<tr>
<th>Failure Modes</th>
<th>Partial Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reinforcement Yielding</td>
<td>( \gamma_{Ms} = 1,15 )</td>
</tr>
<tr>
<td>Concrete cone failure</td>
<td>( \gamma_{Mc} = \gamma_{\text{inst}} \cdot \gamma_c )</td>
</tr>
<tr>
<td></td>
<td>( \gamma_{\text{inst}} \geq 1,0 ) see relevant ETA</td>
</tr>
<tr>
<td></td>
<td>( \gamma_c = 1,5 )</td>
</tr>
<tr>
<td>Pull-out failure and Bond-splitting failure</td>
<td>( \gamma_{Mp} = \gamma_{\text{Mbp}} = \gamma_{Mc} )</td>
</tr>
</tbody>
</table>
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 \(w_c\) of 0.3 mm over the entire anchorage length (using the factor \(\Omega_{cr}\) 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**

<table>
<thead>
<tr>
<th>Ductility class according to EN 1998-1</th>
<th>Behaviour factor, (q) according to EN 1998-1</th>
<th>(b / h [-])</th>
<th>Assumed crack width, (w_c) [mm]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>DCL</td>
<td>1,0</td>
<td>All</td>
<td>0.3</td>
<td>Static design applies</td>
</tr>
<tr>
<td>DCM</td>
<td>1,0 – 1,5</td>
<td>(\geq 0.8)</td>
<td>0.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt; 0.8)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>DCM / DCH</td>
<td>(1,5 – 3,0)</td>
<td>(\geq 0.8)</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt; 0.8)</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>DCM / DCH</td>
<td>(&gt; 3,0)</td>
<td>(\geq 0.8)</td>
<td>0.8</td>
<td>Not covered by this TR</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(&lt; 0.8)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*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).

\[
R_d = \min (N_{Rd,y}; N_{Rd,c}; N_{Rd,sp})
\]

Where

- \( R_d \) is equal to \( R_k / \gamma_M \)
- \( N_{Rd,y} \) 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

<table>
<thead>
<tr>
<th>Failure mode</th>
<th>Notation</th>
<th>Verification required</th>
<th>Most unfavourable tension loading on single rebar</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel yielding resistance</td>
<td>( N_{Rd,y} = N_{Rk,y} / \gamma_M )</td>
<td>Yes</td>
<td>no</td>
<td>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</td>
</tr>
<tr>
<td>Concrete cone break-out resistance</td>
<td>( N_{Rd,c} = N_{Rk,c} / \gamma_Mc )</td>
<td>Yes</td>
<td>no</td>
<td>Eccentricities are taken into account in the calculation of ( N_{Rk,c} ) as per Section 4.3</td>
</tr>
<tr>
<td>Bond-splitting resistance</td>
<td>( N_{Rd,sp} = N_{Rk,sp} / \gamma_{Map} )</td>
<td>Yes</td>
<td>yes</td>
<td>The overall resistance of all tension bars must be calculated to compare it with the other relevant failure modes. However, single bars might undergo more severe loading conditions (e.g., eccentric and/or different ( c_0 ) and/or ( c_{max} ) values)</td>
</tr>
</tbody>
</table>

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 20\( \phi \).
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)

\[ N_{Rk,y} = A_s \cdot f_{yk} \]  

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).

\[ N_{Rk,c} = N_{Rk,c}^0 \cdot \frac{A_{c,N}}{A_{c,N}^0} \cdot \psi_{s,N} \cdot \psi_{ec,N} \cdot \psi_{te,N} \cdot \psi_{M,N} \]  

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)

\[ N_{Rk,c}^0 = k_1 \cdot \sqrt{f_{ck}} \cdot I_b^{1.5} \]  

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: \( I_b = h_{ef} \), 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 $A_{c,N}/A_{c,N}^0$, where:

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

is the reference projected area as per [13] with $h_{nr}$ 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).

$$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} \leq 1.0 \quad (4.6)$$

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).

$$\psi_{ec,N} = \frac{1}{1 + 2 \cdot \frac{e_N}{s_{cr,N}}} \leq 1.0 \quad (4.7)$$

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.

$$\psi_{re,N} = 0.5 + \frac{l_b}{200} \leq 1.0 \quad (4.8)$$

The factor $\psi_{re,N}$ may be taken as 1.0 in the following cases:

a) Reinforcement (any diameter) is present at a spacing $\geq 150$ mm, or
b) Reinforcement with a diameter of $\leq 10$ mm is present at a spacing $\geq 100$ mm

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

(6) The factor $\psi_{MN}$ 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).

$$\psi_{MN} = 2.0 - \frac{z}{1.5 \cdot l_b} \geq 1.0 \quad (4.9)$$

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

$\psi_{MN} = 1.0$ for the following cases:
Anchorages with an edge distance \( c < 1.5b \)

Anchorages with \( c \geq 1.5b \) loaded by a bending moment and a tension force with \( C_{cd}/N_{Ed} < 0.8 \) where \( C_{cd} \) 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.

\[
\tau(b, d, \eta, \kappa \cdot \Psi) = \Psi A \cdot \frac{\tau_{cr}}{\tau_{fr}} \cdot \frac{\phi}{\tau_{fr}} = \Psi A \cdot \frac{\tau_{cr}}{\tau_{fr}} \cdot \frac{\phi}{\tau_{fr}}
\]

\( \tau_{fr} \) 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 \( h'_{re} \) 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, \( \tau_{fr,sp} \), and its relevant parameters \( A_k \), \( \Omega \), (or \( \Omega_{cr,03} \), \( sp1 \), \( sp2 \), \( sp3 \), \( sp4 \) and \( lb1 \) 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).

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

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 \( N_{fr,sp} \) shall be calculated separately for each rebar.

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

\[
N_{fr,sp} = \tau_{fr,sp} \cdot l_b \cdot \phi \cdot \pi \quad \text{(for each tension bar)} 
\]

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

\[
\leq \tau_{fr,cr} \cdot \Omega_{cr,03} \cdot \Omega_{p,cr,03} \cdot \psi_{sus} \quad \text{for } 7\phi \leq l_b \leq 20\phi
\]

\[
\leq \tau_{fr,cr} \cdot \left( \frac{20}{l_b} \right)^{lb1} \cdot \Omega_{cr,03} \cdot \Omega_{p,cr} \cdot \psi_{sus} \quad \text{for } l_b > 20\phi
\]

where:

\( \eta_1 \) 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]

\( A_k, sp1, sp2, sp3, sp4 \) and \( lb1 \) 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., \( (25/\phi)^{sp2} \)).

\( c_d = \min \{ c_{d2}; c_i; c_d \} \) (see Figure 4.4.1)

\( c_{max} = \max \{ c_{d2}; c_i \} \) (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).

\( k_m = 12 \) 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:

\[
K_{tr} = \frac{n_{t} \cdot A_{st}}{n_{b} \cdot \phi \cdot s_{b}} \leq 0.05
\]

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 \( \Omega_{cr} \) (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]](image)

![Figure 4.4.2 Reduced effectiveness of links as per fib Bulletin 72 [14]](image)

(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 \( \Omega_{cr} \)) and (ii) the effect of transverse pressure in the concrete (using the multiplication factor \( \Omega_{p,tr} \)).

a) \( t_{Rk,ucr} \) shall be taken from the relevant ETA as \( t_{Rk,ucr} \) (or \( t_{Rk,ucr,50} \) or \( t_{Rk,ucr,100} \) for a working life of 50 or 100 year, respectively.)
b) The factor to account for the effects of cracking ($\Omega_{cr,03} / \Omega_{cr,06} / \Omega_{cr,08}$) 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).

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

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

(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 $3\phi$.

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)

$$\psi_{sus} = 1 \quad \text{for} \quad \alpha_{sus} \leq \psi_{sus}'$$

$$\psi_{sus} = \psi_{sus}' + 1 - \alpha_{sus} \quad \text{for} \quad \alpha_{sus} > \psi_{sus}'$$

(4.14a)

(4.14b)

Where

$\psi_{sus}'$ 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 $\psi_{sus}'$ (or $\psi_{sus,50}'$ or $\psi_{sus,100}'$) for a working life of 50 or 100 years, respectively.

$\alpha_{sus}$ 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 $\psi_{sus}' = 0,6$, 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.

\[
R_{d,eq} = \min(N_{Rd,y,eq}; N_{Rd,c,eq}; N_{Rd,sp,eq})
\]  
   (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:

\[
N_{Rk,y,eq} = \gamma_{Rd} \cdot N_{Rk,y}
\]  
   (5.2)

Where
\( \gamma_{Rd} \geq 1,0 \)

Note: The value of the factor \( \gamma_{Rd} \) 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:

\[
N_{Rk,c,eq} = \alpha_{eq} \cdot N_{Rk,c}
\]  
   (5.3)

Where:
\( \alpha_{eq} = 1,0 \) if \( w_k = 0,3 \) mm
\( \alpha_{eq} = 0,85 \) if \( w_k > 0,3 \) mm

\( N_{Rk,c} \) is calculated according to Section 4.4

Note: The reduction factor \( \alpha_{eq} = 0,85 \) 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:

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

\[
\leq \tau_{Rk,acr} \cdot e_{cr,eq} \cdot \alpha_{eq,p}
\]

for \( 7\phi \leq l_b \leq 20\phi \) \hspace{1cm} (5.4b)

\[
\leq \tau_{Rk,acr} \cdot \left( \frac{20\phi}{l_b} \right)^{lb1} \cdot e_{cr,eq} \cdot \alpha_{eq,p}
\]

for \( l_b > 20\phi \) \hspace{1cm} (5.4c)

Where:

\( e_{cr,eq} = e_{cr,03} \) or \( e_{cr,05} \) or \( e_{cr,08} \) 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].

©EOTA 2022
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 \(c_{\min} = \max(c_{\min,\text{dur}}, c_{\min,\text{ETA}})\), where \(c_{\min,\text{dur}}\) is the minimum cover required for different exposure classes according to EN 1992-1-1 [4] and \(c_{\min,\text{ETA}}\) 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

[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
[12] EAD 330087-01-0601:12-2020 Systems for Post-Installed Rebar Connections with Mortar