TECHNICAL REPORT

Design of bonded screw fasteners for use in concrete

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1 SCOPE

This Technical Report provides an amendment to EN 1992-4 [1] for the design of concrete screws in combination with bond material, which are used to transmit actions to the concrete (connection of structural elements and non-structural elements to structural components). The physical models used for the design method are based on a combination of tests and numerical analysis consistent with EN 1990[2], Section 5.2 and EN 1992-4 [1].

2 TERMS, DEFINITIONS AND SYMBOLS

The terms, definitions and symbols used in this Technical Report are given in EAD 332795-01-0601 [3] and EAD 330232-01-0601 [4]. In addition, the following notations are used.

$N_{Rk,p,CS,fi}$ = characteristic pull-out resistance of the concrete screw under fire exposure given in the relevant European Technical Assessment

$N_{Rk,c}$ = characteristic resistance in case of concrete cone failure under tension load

$N_{Rk,p,ucr}$ = combined pull-out and concrete failure resistance in uncracked concrete

$N_{Rk,p,cr}$ = combined pull-out and concrete failure resistance in cracked concrete

$N_{Rk,p,B,ucr}$ = bond material component to the combined pull-out and concrete failure resistance in uncracked concrete

$N_{Rk,p,B,cr}$ = bond material component to the combined pull-out and concrete failure resistance in cracked concrete

$N^0_{Rk,p,B,ucr}$ = characteristic value of contribution of the bond material to the combined pull-out and concrete resistance of a single fastener in uncracked concrete as given in the ETA

$N^0_{Rk,p,B,cr}$ = characteristic value of contribution of the bond material to the combined pull-out and concrete resistance of a single fastener in cracked concrete as given in the ETA

$N^0_{Rk,p,B,C1}$ = characteristic value of contribution of the bond material to the combined pull-out and concrete resistance of a single fastener for seismic category C1 as given in the ETA

$N^0_{Rk,p,B,C2}$ = characteristic value of contribution of the bond material to the combined pull-out and concrete resistance of a single fastener for seismic category C2 as given in the ETA

$N_{Rk,p,CS,ucr}$ = concrete screw component to the combined pull-out and concrete failure resistance in uncracked concrete

$N_{Rk,p,CS,cr}$ = concrete screw component to the combined pull-out and concrete failure resistance in cracked concrete

$N^0_{Rk,p,CS,ucr}$ = characteristic pull-out resistance of a single concrete screw in uncracked concrete as given in the ETA

$N^0_{Rk,p,CS,cr}$ = characteristic pull-out resistance of a single concrete screw in cracked concrete as given in the ETA

$N^0_{Rk,p,CS,C1}$ = characteristic pull-out resistance of a single concrete screw for seismic category C1 as given in the ETA

$N^0_{Rk,p,CS,C2}$ = characteristic pull-out resistance of a single concrete screw for seismic category C2 as given in the ETA

$N_{Rk,c,fi}$ = characteristic resistance in case of concrete cone failure under tension load under fire exposure

d_{nom} = outside diameter of a fastener as defined in the relevant European technical assessment

e_N = eccentricity of resultant tension force of tensioned fasteners in respect to the centre of gravity of the tensioned fasteners (see Figure 6.3 of EN 1992-4 [1])

h_{ef} = effective embedment depth (see Figures 3.1 of EN 1992-4 [1])

n = number of anchors in a group

s = centre to centre spacing of fasteners in a group (see Figure 3.4 of EN 1992-4 [1])

s_1, (s_2) = spacing of fasteners in a group in direction 1 (direction 2), (see Figure 3.4 of EN 1992-4)

$s_{cr,Np}$ = characteristic spacing for the bond material component to ensure the characteristic resistance of the individual fasteners in case of combined pull-out and concrete failure under tension load

$\psi_{ec,N,CS}$ = factor taking into account the group effect when different tension loads are acting on the individual concrete screw of a group for the

$\Psi_{ec,Np}$ = factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of combined pull-out and concrete failure of bonded screw fasteners

$\Psi_{g,Np}$ = factor taking into account a group effect for closely spaced bonded screw fasteners

$\Psi_{re,N}$ = factor taking into account the effect of reinforcement in case of concrete failures in tension

$\Psi_{s,Np}$ = factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of combined pull-out and concrete failure of bonded screw fasteners

Ψ^0_{sus} = factor taking into account the influence of sustained loads at maximum long-term temperature on the bond material component given in the European Technical Assessment

α_{sus} = ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions

3 DESIGN PROCEDURE

3.1 General

In general, the design provisions for bonded fasteners given in EN 1992-4 [1] apply also for bonded screw fasteners, i.e., concrete screws in combination with bonding material, as defined in the scope of EAD 332795-01-0601 [3]. Both components (concrete screw as mechanical component and mortar as bond component) contribute to the functioning of the fastening system. Deviating from EN 1992-4 [1], this design method is valid for a fixed embedment depth. Thus, the characteristic bond resistance τ_{Rk} given in the relevant equations of EN 1992-4 [1] for combined pull-out and concrete failure is replaced by the characteristic resistance $N^0_{Rk,p,B}$ of the bond component. The relevant equations are modified accordingly. All other design provisions given in EN 1992-4 [1] for bonded fasteners remain valid. For the mechanical component $N^0_{Rk,p,CS}$ the design concept is based on the provisions of EN 1992-4 [1] with $N^0_{Rk,p} = N^0_{Rk,p,CS}$.

3.2 Combined pull-out and concrete failure

3.2.1 General

The design equations provided in this Technical Report that are replacing the provisions of EN 1992-4 [1] are listed in Table 1.

Table 1. Replaced equations

Equation no. in EN 1992-4	(7.13)	(7.14a, b)	(7.15)	(7.18)	(7.19)
Replaced by equation no. in this Technical Report for uncracked concrete	(1)	(6,7)	(8)	(10)	(11)
Replaced by equation no. in this Technical Report for cracked concrete	(12)	(17,18)	(8)	(20)	(21)

3.2.2 Uncracked concrete

The characteristic pull-out resistance of a fastener, a group of fasteners and the tensioned fasteners of a group of fasteners in case of combined pull-out and concrete failure in uncracked concrete, $N_{Rk,p,ucr}$, is calculated as follows:

$$N_{Rk,p,ucr} = N_{Rk,p,CS,ucr} + \alpha_b \cdot N_{Rk,p,B,ucr} \quad (1)$$

Where

The component of the concrete screw, $N_{Rk,p,CS,ucr}$, is

$$N_{Rk,p,CS,ucr} = \mathrm{n} \cdot N^0_{Rk,p,CS,ucr} \cdot \psi_{ec,Np,CS} \quad (2)$$

Where

$\psi_{ec,N,CS}$ = factor taking into account the group effect when different tension loads are acting on the individual concrete screw of a group

$= \frac{1}{1+2\cdot(e_N/s)} \leq 1$

$N^0_{Rk,p,CS,ucr}$ characteristic pull-out resistance for a single concrete screw in uncracked concrete considering the increasing factor Ψ_c for concrete strengths above C20/25 from the relevant European Technical Assessment

e_N = according to EN 1992-4 [1]

$$\alpha_b = 1 - \left(1 - \varphi_{b,ucr}\right) \cdot \left(s_{cr,Np} - s\right)/s_{cr,Np} \leq 1 \quad (3)$$

In case of an eccentricity in two directions, $\psi_{ec,Np,CS}$ shall be determined separately for each direction and the product of both factors shall be inserted in Equation (2). In case the anchor spacings in the two main directions s_1 and s_2 are different, this shall be considered in the relative $\psi_{ec,Np,CS}$ factors.

In case the fastener spacings in the two main directions s_1 and s_2 are different, in Equation (3) the mean value shall be considered.

$$\varphi_{b,ucr} = N^0_{Rk,p,B,ucr}/(N^0_{Rk,p,CS,ucr} + N^0_{Rk,p,B,ucr}) \quad (4)$$

The component of the bond material $N_{\mathrm{Rk,p,B,ucr}}$, is

$$N_{Rk,p,B,ucr} = N^0_{Rk,p,B,ucr} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{\mathrm{sus}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np} \quad (5)$$

where

$N^0_{Rk,p,B,ucr}$ characteristic pull-out resistance in uncracked concrete provided by bond material of a single fastener to the combined pull-out and concrete resistance considering the increasing factor Ψ_c for concrete strengths above C20/25 from the relevant European Technical Assessment

$A^0_{p,N} = s_{cr,Np} \cdot s_{cr,Np}$ reference influence area of an individual fastener

$A_{p,N}$ is the actual bond influence area, limited by overlapping areas of adjacent fasteners ($s \le s_{cr,Np}$) as well as by edges of the concrete member ($c \le c_{cr,Np}$) as defined in EN 1992-4 [1], clause 7.2.1.6.

$$\Psi_{\text{sus}} = 1{,}0 \quad for\ \alpha_{sus} \le \Psi^0_{\text{sus}} \tag{6}$$

$$\Psi_{\text{sus}} = (\Psi^0_{\text{sus}} - \alpha_{sus} + \varphi_{b,ucr})/\varphi_{b,ucr} \quad for\ \alpha_{sus} > \Psi^0_{\text{sus}} \tag{7}$$

Ψ^0_{sus} is the product dependent factor that takes account of the influence of sustained load on the bond strength to be taken from the relevant European Technical Assessment as defined in EN 1992-4 [1], clause 7.2.1.6

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 ULS as defined in EN 1992-4 [1], clause 7.2.1.6

The characteristic spacing is

$$s_{cr,Np} = 4{,}1 \cdot \left(\Psi_{sus} \cdot \frac{d_{nom}}{h_{ef}} \cdot (N^0_{Rk,p,CS,ucr} + N^0_{Rk,p,B,ucr}) \right)^{0,5} \le 3h_{ef} \tag{8}$$

Where

h_{ef} to be taken from the relevant European Technical Assessment

d_{nom} = shaft diameter of concrete screw (= nominal diameter)

$N^0_{Rk,p,CS,ucr}$ = characteristic pull-out resistance for a single fastener of the concrete screw in uncracked concrete for concrete strength class C20/25 from the relevant European Technical Assessment

$N^0_{Rk,p,B,ucr}$ = characteristic resistance provided by the component of the bond material of a single fastener to the combined pull-out and concrete resistance in uncracked concrete for concrete strength class C20/25 from the relevant European Technical Assessment

The factor $\Psi_{g,Np}$ takes into account the group effect for closely spaced fasteners.

$$\Psi_{g,Np} = \Psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0,5} \cdot \left(\Psi^0_{g,Np} - 1\right) \ge 1 \tag{9}$$

Where

$$\Psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right) \cdot \left(\frac{N^0_{Rk,p,B,ucr}}{N_{Rk,c}}\right)^{1.5} \ge 1 \tag{10}$$

$$N_{Rk,c} = k_3 \cdot h_{ef}^{1,5} \cdot \sqrt{f_{ck}} \tag{11}$$

k_3 = $k_{ucr,N}$ according to ETA

$N^0_{Rk,p,B,ucr}$ = characteristic resistance provided by the component of the bond material for a single fastener for uncracked concrete for the considered concrete strength, given in the ETA.

$\Psi_{s,Np}$, $\Psi_{re,N}$ and $\Psi_{ec,Np}$ are defined according EN 1992-4 [1], clause 7.2.1.6

3.2.3 Cracked concrete

The characteristic pull-out resistance of a fastener, a group of fasteners and the tensioned fasteners of a group of fasteners in case of combined pull-out and concrete failure in cracked concrete, $N_{Rk,p,cr}$, is calculated as follows:

$$N_{Rk,p,cr} = N_{Rk,p.CS.cr} + \alpha_b \cdot N_{Rk,p,B,cr} \tag{12}$$

where

$$\alpha_b = 1 - \left(1 - \varphi_{b,cr}\right) \cdot \left(s_{cr,Np} - s\right)/s_{cr,Np} \le 1 \tag{13}$$

$$\varphi_{b,cr} = N^0_{Rk,p,B,cr}/(N^0_{Rk,p,CS,cr} + N^0_{Rk,p,B,cr}) \quad (14)$$

The component of the concrete screw, $N_{Rk,p,CS,cr}$, is

$$N_{Rk,p,CS,cr} = n \cdot N^0_{Rk,p,CS,cr} \cdot \psi_{ec,Np,CS} \quad (15)$$

Where

$\psi_{ec,N,CS}$ = factor taking into account the group effect when different tension loads are acting on the individual concrete screw of a group

$= \frac{1}{1+2\cdot(e_N/s)} \leq 1$

$N^0_{Rk,p,CS,cr}$ characteristic pull-out resistance for a single concrete screw in cracked concrete considering the increasing factor Ψ_c for concrete strengths above C20/25 from the relevant European Technical Assessment

e_N = according to EN 1992-4 [1]

α_b defined in section 3.2.2 (Equation (3))

Where there is an eccentricity in two directions, $\psi_{ec,Np,CS}$ shall be determined separately for each direction and the product of both factors shall be inserted in Formula (15). In case the anchor spacings in the two main directions s_1 and s_2 are different, this shall be considered in the relative $\psi_{ec,Np,CS}$ factors.

The component of the bond material $N_{Rk,p,B,cr}$, is

$$N_{Rk,p,B,cr} = N^0_{Rk,p,b,cr} \cdot \frac{A_{p,N}}{A^0_{p,N}} \cdot \Psi_{\text{sus}} \cdot \Psi_{g,Np} \cdot \Psi_{s,Np} \cdot \Psi_{re,N} \cdot \Psi_{ec,Np} \quad (16)$$

where

$N^0_{Rk,p,B,cr}$ characteristic pull-out resistance in cracked concrete provided by bond material of a single fastener to the combined pull-out and concrete resistance considering the increasing factor Ψ_c for concrete strengths above C20/25 from the relevant European Technical Assessment

$$\Psi_{\text{sus}} = 1{,}0 \quad for\ \alpha_{sus} \leq \Psi^0_{\text{sus}} \quad (17)$$

$$\Psi_{\text{sus}} = (\Psi^0_{\text{sus}} - \alpha_{sus} + \varphi_{b,cr})/\varphi_{b,cr} \quad for\ \alpha_{sus} > \Psi^0_{\text{sus}} \quad (18)$$

The characteristic spacing is calculated according to clause 3.2.2 of this report.

The factor $\Psi_{g,Np}$ takes into account the group effect for closely spaced fasteners.

$$\Psi_{g,Np} = \Psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0,5} \cdot \left(\Psi^0_{g,Np} - 1\right) \geq 1 \quad (19)$$

Where

$$\Psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right) \cdot \left(\frac{N^0_{Rk,p,B,cr}}{N_{Rk,c}}\right)^{1,5} \geq 1 \quad (20)$$

$$N_{Rk,c} = k_3 \cdot h_{ef}^{1,5} \cdot \sqrt{f_{ck}} \quad (21)$$

k_3 = $k_{cr,N}$ according to ETA

$N^0_{Rk,p,B,cr}$ = characteristic resistance provided by the component of the bond material for a single fastener for cracked concrete for the considered concrete strength, given in the ETA.

$\Psi_{s,Np}$, $\Psi_{re,N}$ and $\Psi_{ec,Np}$ are defined according EN 1992-4 [1], clause 7.2.1.6

3.3 Concrete pry-out failure

The characteristic pry-out resistance $V_{Rk,cp}$ shall be calculated with the equation according to EN 1992-4 [1], 7.2.2.4 (3) for mechanical post-installed fasteners.

3.4 Seismic loading

The design method for post-installed fasteners under seismic loading provided in Annex C of EN 1992-4 [1] applies. For combined pull-out and concrete failure, in case of post-installed bonded screw fasteners, R_{eq}^0 shall be determined according to 7.2.1.6 of EN 1992-4 [1] and clause 3.2.3 of this Technical Report as follow:

- $N_{Rk,p,CS,cr}^0$ shall be substituted by $N_{Rk,p,CS,C1}^0$ *or* $N_{Rk,p,CS,C2}^0$
- $N_{Rk,p,\mathrm{B},cr}^0$ shall be substituted by $N_{Rk,p,\mathrm{B},C1}^0$ *or* $N_{Rk,p,\mathrm{B},C2}^0$

  where

  $N_{Rk,p,\mathrm{CS},C1}^0$; $N_{Rk,p,\mathrm{CS},C2}^0$ characteristic pull-out resistance of the concrete screw for seismic category C1 or C2 of to the combined pull-out and concrete resistance from the relevant European Technical Assessment

  $N_{Rk,p,\mathrm{B},C1}^0$; $N_{Rk,p,\mathrm{B},C2}^0$ characteristic value of contribution of the bond material for seismic category C1 or C2 of to the combined pull-out and concrete resistance from the relevant European Technical Assessment

3.5 Fire resistance

The design method for post-installed fasteners under fire exposure provided in Annex D of EN 1992-4 [1] applies. For fire resistance only the concrete screw capacity (without the contribution of the bond material) is considered. Therefore, the design is performed as for post-installed mechanical fasteners EN 1992-4 [1], D.4.2 with the following specifications.

3.5.1 Steel failures in tension and shear

Steel failure in tension is verified according to EN1992-4 [1], D.4.2.1 and steel failure in shear according to D.4.3.1.

3.5.2 Concrete cone failure

The design method for post-installed fasteners under fire exposure provided in section D.4.2.2 of EN 1992-4 [1] applies.

For determination of $N_{Rk,c,fi}$ the effective anchorage depth shall be determined in accordance with EAD 330232-01-0601, Figure 1.14 ($h_{ef}=0{,}85(h_{nom}-0{,}5h_t-h_s)\leq 8d_0$).

3.5.3 Pull-out failure

In case of bonded screw fasteners under tension, as only the concrete screw contribution is considered, instead of the combined pull-out and concrete failure a pull-out verification according section 7.2.1.5 of EN 1992-4 [1] as for mechanical anchors should be performed. The characteristic pull-out resistance of the concrete screw (without bond material) under fire exposure $N_{Rk,p,CS,fi}$ shall be taken from the relevant European Technical Assessment.

4 REFERENCE DOCUMENTS

[1] EN 1992-4:2018, Eurocode 2 – Design of concrete structures – Part 4: Design of fastenings for use in concrete.

[2] EN 1990:2002, Eurocode – Basis of structural design.

[3] EAD 332795-01-0601, Bonded Screw Fasteners for Use in Concrete

[4] EAD 330232-01-0601, Mechanical fasteners for use in concrete