TECHNICAL NOTE

AEFAC
Australian Engineered Fasteners and Anchors Council

AEFAC – TN08

POST-INSTALLED REINFORCING BAR CONNECTIONS

Vol 2: Improved bond-splitting behaviour

Ver. 1.0
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Revision Sheet

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0		Initial release	Sept 2023

1. Scope

This Technical Note is Volume 2 of a suite of AEFAC Technical Notes which provides recommendations on design of post-installed reinforcing bars using adhesives in drilled holes in concrete for tensile load.

The scope of Volume 2 is to provide recommendations specific to moment resisting connections that are supplementary to the recommendations provided in Volume 1. It is a requirement that Volume 2 be used in conjunction with Volume 1.

The design recommendations in Volume 2 of the Technical Note are based on EOTA TR 069. The design method from this Technical Note can only be used with the products pre-qualified in accordance with EAD 332402. The characteristic values necessary for the design of the post-installed reinforcing bars shall be taken from the prequalification report (such as ETA) prepared in accordance with EAD 332402.

This Technical Note covers static and quasi-static loading and does not cover seismic, fatigue and fire actions. It covers post-installed reinforcing bars installed in dry and wet concrete (not in flooded holes).

This Technical Note covers single and a group of reinforcing bars. The reinforcing bars in a group should be of same type, size and length.

The intended application of the post-installed rebar connections to be designed in accordance with this TN should be specified in the prequalification report (such as ETA). The other limitations of the product such as dimensions of the reinforcing bars, installation methods, cover and spacing should be followed from the prequalification report.

The reinforcing bars should be straight deformed bar complying with AS/NZS 4671.

The recommendations provided in this Technical Note are of general nature. For product specific detailed information, advice from the supplier/manufacturer should be sought.

For post-installed rebar connections, the required hole depth may be large and hence the installation quality is extremely important. The installation must be carried out in accordance with the manufacturer's installation instructions (MII). The installation should only be performed by **competent personnel**, either certified by AEFAC [6] or trained by an anchor supplier for this specific application.

Note: The choice for the anchorage system should prioritize the utilization of cast-in reinforcing bars over post-installed alternatives. The use of post-installed reinforcing bars should only be considered when the cast-in reinforcing bars are missing, or their application is deemed infeasible.

2. Terminology

A full list of terminologies is provided in Section 2 of Volume 1.

3. Notation

A list of notations is provided in Section 3 of Volume 1. Below are the notations used in this Volume of the Technical Note.

$A^0_{c,N}$	=	reference projected area of the failure cone of the fastener under tensile loading
$A_{c,N}$	=	actual projected area of the failure cone of the fastener that is limited by adjacent fasteners and edges of the concrete member under tensile loading
A_k	=	Characteristic fitting factor taken from the relevant product pre-qualification report
A_s	=	Cross sectional area of reinforcement
A_{str}	=	Cross-sectional area of one stirrup leg
c	=	edge distance from the centre-line axis of a reinforcing bar
$c_{cr,N}$	=	edge distance of a single reinforcing bar required to ensure the characteristic strength is achieved when loaded in tension
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 cover and half of the Clear spacing from the closest neighbouring reinforcing bar
d_b	=	diameter of reinforcing bar
e_N	=	eccentricity of the resultant tension force acting on a group of reinforcing bars relative to the centroid of the reinforcing bars loaded in tension
f'_c	=	characteristic compressive strength of concrete measured via cylinder tests at 28 days
f_{cm}	=	Mean value of cylinder strength in accordance with AS 3600
f_{ct}	=	Uniaxial tensile strength in accordance with AS 3600
f_{sy}	=	characteristic yield strength of reinforcement

k_1	=	parameter relating to the resistance to concrete cone failure
$k_{cr,N}$	=	parameter relating to cracked concrete loaded in tension
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 in accordance with fib Model Code 2010
$k_{ucr,N}$	=	parameter relating to uncracked concrete loaded in tension
l_b	=	Embedment length of the post-installed rebar
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
$N_{Rk,c}$	=	characteristic tensile strength of a post-installed reinforcing bars to concrete cone failure
$N_{Rk,sp}$	=	characteristic tensile strength of a post-installed reinforcing bars to bond-splitting failure
$N_{Rk,s}$	=	Design resistance to yielding of the post-installed rebars
$N_{Rk,c}$	=	characteristic tensile strength of a post installed reinforcing bar or a group of post-installed reinforcing bars to concrete cone failure
$N^0_{Rk,c}$	=	characteristic tensile strength of a single post installed reinforcing bar not influenced by any adjacent post-installed reinforcing bar or edge
$N_{Rk,s}$	=	Characteristic resistance corresponding to yielding of the post-installed reinforcement
N^*_g	=	design value of resultant tensile load applied to a group of post-installed reinforcing bars
N^*_h	=	design tensile load acting on the most stressed reinforcing bar in the group
p_{tr}	=	transverse pressure in the concrete
s_b	=	Clear spacing between the confining reinforcement
$s_{cr,N}$	=	spacing that is required for a reinforcing bar to develop its characteristic tensile strength
$sp1$, $sp2$, $sp3$, $sp4$	=	Curve fitting exponents taken from the relevant product prequalification report
z	=	Lever arm

α_{sus} = ratio of sustained loads (permanent actions and permanent component of variable actions) to the total value of actions acting on the reinforcing bar at ultimate limit state

ϕ_{Ms} = Capacity reduction factor for reinforcement yielding

ϕ_{Mc} = Capacity reduction factor for concrete cone failure

ϕ_{inst} = Capacity reduction factor for installation

ϕ_{c} = Capacity reduction factor for concrete

ϕ_{Mp} = Capacity reduction factor for pull-out and bond-splitting failure
= $\phi_{Msp} = \phi_{Mc}$

$\tau_{Rk,sp}$ = Characteristic bond-splitting resistance

$\tau_{Rk,ucr}$ = Characteristic bond resistance in uncracked concrete

Ω_{cr} = factor to account for the influence of cracked concrete on resistance to combined pull-out and concrete failure taken from the relevant product prequalification report

$\Omega_{p,tr}$ = factor to account for transverse pressure in concrete

$\psi_{ec,N}$ = parameter accounting for the influence of eccentricity of the resultant load in a group of reinforcing bars on tensile strength

$\psi_{M,N}$ = parameter accounting for the influence of a compression force between connecting members on the tensile strength of a reinforcing bars

$\psi_{re,N}$ = parameter accounting for the effect of dense reinforcement between which the rebar is installed

$\psi_{s,N}$ = parameter related to the distribution of stresses in the concrete due to the proximity of the fastener to an edge

ψ_{sus} = factor accounting for the effects of sustained loading on bond strength

4. General

AS 5216:2021 covers the pre-qualification and design of post-installed reinforcing bar connection. The design method in AS 5216:2021 requires the post-installed reinforcing bar (PIR) system to be prequalified according to EAD 330087. The EAD 330087 sets a “pass/fail” criterion for the chemical bond strength, after which the performance of PIR can be deemed “equal to” that of cast-in bars. Please refer to the Volume 1 of this Technical Note suite. The prequalification and design requirements in AS 5216 and Volume 1 of this Technical Note suite are the same.

The design method in this Technical Note is based on the improved bond-splitting behavior of the post-installed reinforcing bar system. For this design method to be used, the system should be prequalified according to EAD 332402.

Note:

Post-installed reinforcing bar connection utilizing high-strength adhesives can achieve better pull-out resistance compared to cast-in bars in normal strength concrete. Parameters such as the available concrete cover, anchorage length and bar spacing however may limit the performance of bonded bars.

5. Design of Post-installed Rebar Connection

5.1. General

The ultimate strength of the post-installed reinforcing bar system shall be verified in accordance with Equation 3.2.1 in AS 5216 considering different modes of failure.

The design of post-installed reinforcing bars subjected to tensile load shall be performed in accordance with the verification listed in Table 1. The modes of failure producing the lowest design strength shall be adopted.

Table 1: Verification required for PIR

Failure Mode	Ref Clause	Verification Requirement	
		Rebar Group	**Most unfavorable single Rebar**
Steel failure	5.2	$N_g^* = \phi_{Ms} N_{Rk,y}$	
Concrete cone failure	5.3	$N_g^* = \phi_{Mc} N_{Rk,c}$	
Bond-splitting failure	5.4	$N_g^* = \phi_{Msp} N_{Rk,sp}$	$N_h^* = \phi_{Msp} N_{Rk,sp}$

Capacity reduction factors

The capacity reduction factors shall be determined from AS 5216. The recommended values of the factors are shown in Table 2.

Table 2: Capacity reduction factors

Failure modes	Capacity reduction factor
Steel failure	$\phi_{Ms} = \frac{1}{1.15}$
Concrete cone failure	$\phi_{Mc} = \phi_{inst}\,\phi_c$ $\phi_{inst} = \frac{1}{\gamma_{inst}} \leq 1$ γ_{inst} is given in the product pre-qualification report. $\phi_c = \frac{1}{1.5}$
Bond-splitting failure	$\phi_{Mp} = \phi_{Msp} = \phi_{Mc}$

5.2. Steel failure

The characteristic tensile resistance of post-installed reinforcing bars ($N_{Rk,s}$) shall be calculated as follows:

$$N_{Rk,s} = A_s f_{sy}$$

Where,

$N_{Rk,s}$ = Characteristic resistance corresponding to yielding of the post-installed reinforcement

A_s = Cross sectional area of all the post-installed reinforcing bars in tension

f_{sy} = characteristic yield strength of reinforcement

The state of stress in the post-installed rebar in tension shall be averaged based on the position of the center of gravity of the tensioned reinforcing bars.

5.3. Concrete cone failure

The design of post-installed reinforcing bars for concrete cone failure is based on AS 5216.

The characteristic strength of post-installed reinforcing bar(s) to concrete cone failure shall be calculated as follows:

$$N_{Rk,c} = N^0_{Rk,c} \left(\frac{A_{c,N}}{A^0_{c,N}}\right) \psi_{s,N}\, \psi_{re,N}\, \psi_{ec,N}\, \psi_{M,N}$$

Where,

$N^0_{Rk,c}$ = characteristic resistance for a single post-installed reinforcing bar not influenced by adjacent reinforcing bars or edge

$N^0_{Rk,c} = k_1 \sqrt{f'_c}\, l_b^{1.5}$

Where,

k_1 = Parameter related to the characteristic strength of a single PIR to concrete cone failure (k_{crN} for cracked concrete and k_{crN} for uncracked concrete) obtained from product pre-qualification report.

If no values of k_1 is available, $k_{crN} = 7.7$ and $k_{crN} = 11.0$ may be assumed.

l_b = h_{ef}

$\left(\frac{A_{c,N}}{A^0_{c,N}}\right)$ = Geometric effect of adjacent PIR in tension and edge influence.

$A^0_{c,N}$ = Reference projected area calculated according to AS 5216 with h_{ef} replaced with l_b

= $\left(s_{cr,N}\right)^2$

$s_{cr,N} = 2\, c_{cr,N} = 3\, l_b$ can be assumed and the value of $c_{cr,N}$ is given in product prequalification report.

$A_{c,N}$ = Actual projected area of the failure of the PIR that is limited by adjacent reinforcing bars and edges of the concrete

$\psi_{s,N}$ = Factor accounting the disturbance of the distributed stress in the concrete due to the proximity of an edge of concrete member

= $0.7 + 0.3 \left(\frac{c}{c_{cr,N}}\right) \leq 1.0$

Where,

c = Edge distance to the closest edge measured from the center of PIR

$c_{cr,N}$ = Critical edge distance given in product prequalification report.

$\psi_{ec,N}$ = Factor accounting the eccentricity between the center of gravity of tensioned PIR and point of load application

= $\frac{1}{1+2\frac{e_N}{s_{cr,N}}} \leq 1.0$

Where,

e_N = Eccentricity of the resultant tension force acting on a group of PIRs relative to the center of gravity of the tensioned reinforcing bars

$s_{cr,N}$ = Spacing that is required for a reinforcing bar to develop its characteristic tensile strength

$\psi_{re,N}$ = Factor accounting the shorter anchorage length with closely spaced reinforcing bars

= $0.5 + \frac{l_b}{200} \leq 1.0$

The value of $\psi_{re,N}$ may be taken as 1.0 if either of the following conditions apply:

(a) Any reinforcing bar is present at a spacing $\geq$ 150mm
(b) Reinforcing bar of diameter $\leq$ 10mm present at a spacing $\geq$ 100mm

$\psi_{M,N}$ = Factor accounting the effect of a compression stress resulting from the moment resisting actions on the concrete cone capacity

= $2.0 - \frac{z}{1.5\, l_b} \geq 1.0$

Where,

z = 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 the face of the base member

= 1 under any of the following conditions

(a) Anchorages with edge distance $c < 1.5\, l_b$
(b) Anchorages with $c \geq 1.5\, l_b$ loaded by a bending moment and a tension with $N_c^*/N^* < 0.8$ where N_c^* is absolute value of resultant compressive force at the connection interface and N^* is resultant

tension load applied to tensioned post-installed reinforcing bars.

Note:

1. *The concrete cone capacity calculated in this section could be conservative for the case of reinforcing bars if three or more edge distances are less than the characteristic edge distance for concrete cone failure ($c_{cr,N}$). A more precise estimation of strength can be obtained with a modified value of embedment depth (l'_b) for single PIR. The value of l_b is replaced with l'_b where l'_b is calculated as h'_{ef} in accordance with Cl 6.2.3.8 in AS 5216.*
2. *For the design of post-installed reinforcing bars systems for concrete cone failure, limitations of fasteners configurations in Figure 2.1 of AS 5216 are not applicable.*

5.4. Bond-splitting failure

The characteristic strength of each post-installed reinforcing bar to bond-splitting failure shall be calculated as follows:

$$N_{Rk,sp} = \tau_{Rk,sp}\, \pi\, d_b\, l_b$$

Where,

$$\tau_{Rk,sp} = A_k \left(\frac{f'_c}{25}\right)^{sp1} \left(\frac{25}{d_b}\right)^{sp2} \left[\left(\frac{c_d}{d_b}\right)^{sp3} \left(\frac{c_{max}}{c_d}\right)^{sp4} + k_m\, K_{tr}\right] \left(\frac{7d_b}{l_b}\right)^{lb1} \Omega_{p,tr}$$

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

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

Where,

A_k	=	Obtained from pre-qualification report
$sp1$	=	Obtained from pre-qualification report
$sp2$	=	Obtained from pre-qualification report
$sp3$	=	Obtained from pre-qualification report
$sp4$	=	Obtained from pre-qualification report

$lb1$ = Obtained from pre-qualification report

d_b = Diameter of reinforcing bar

= $d_b \geq 12mm$ shall be used in the factor $\left(\frac{25}{d_b}\right)^{sp2}$

c_d = $\min\left(\frac{c_s}{2}; c_x; c_y\right)$

c_{max} = $\max\left(\frac{c_s}{2}; c_x\right)$

$\frac{c_{max}}{c_d}$ ≤ 3.5

k_m = Factor accounting for the effectiveness of transverse reinforcement (refer fib Model Code 2010 and fib Bulletin 72 for further details)

= 12 if reinforcing bars are confined inside a bend of links passing round the bar of at least 90^0

= 6 if a reinforcing bar is more than 125mm 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 pair of lapped reinforcing bars is less than 4 times the bottom cover, and hence a crack through the plane of the reinforcing bars would form without intersecting transverse reinforcement

K_{tr} = Normalized ratio to consider the amount of transverse reinforcement crossing a potential splitting surface defined and calculated in accordance with fib Model Code 2010

= $\frac{n_t A_{st}}{n_b d_b s_b} \leq 0.05$

Where,

n_t = Number of legs of confining reinforcing bars crossing a potential splitting surface

A_{str} = Cross-sectional area of one stirrup leg

n_b = Number of anchored or lapped reinforcing bars in the potential splitting surface

s_b = Spacing between the confined reinforcement

$\tau_{Rk,ucr}$ = Obtained from pre-qualification report

$\Omega_{cr,03}$ = Factor accounting for the effect of cracking and obtained from pre-qualification report

$\Omega_{p,tr}$ = Factor accounting the transverse pressure perpendicular to the axis of post-installed reinforcement and calculated in accordance with fib Model Code 2010.

$= 1 - \frac{0.3\, p_{tr}}{f_{ct}}$ for $0 \le p_{tr} \le f_{ct}$ (tension)

$= 1 - \tanh\left[0.2\, \frac{p_{tr}}{0.1\, f_{cm}}\right]$ for $f_{cm} \le p_{tr} \le 0$ (compression)

Where,

f_{cm} = Mean value of cylinder compressive strength in accordance with AS 3600

f_{ct} = Uniaxial tensile strength in accordance with AS 3600

p_{tr} = Transverse pressure perpendicular to the axis of the post-installed reinforcement. This is calculated as mean stress in the concrete at ultimate state (perpendicular to bar axis) averaged over a volume around the bar with a diameter of $3d_b$

ψ_{sus} = Factor accounting for the effect of sustained loas in accordance with AS 5216 and determined from product pre-qualification report.

Note: While calculating $\tau_{Rk,sp}$ for cracked concrete, only Ω_{cr} (or $\Omega_{cr,03}$) applies and $\Omega_{p,tr}$ does not apply.

5.5. Additional Design Provisions

The minimum anchorage length, l_b, determined according to this Technical Note to resist the design tensile action shall not be shorter than the maximum of following:

(i) 30% of the basic development length ($L_{sy.tb}$) in accordance with AS 3600,
(ii) 10 times the nominal diameter of reinforcing bar and
(iii) 100 mm

6. References

[1] EAD 330499-00-0601 "Bonded fasteners for use in concrete", European Organisation for Technical Assessment, July 2017.

[2] EAD 330087-00-0601 "Systems for post-installed rebar connections with mortar", European Organisation for Technical Assessment, May 2018.

[3] EOTA, "TR 023: Assessment of post-installed rebar connections," European Organization for Technical Approvals, 2006.

[4] Standards Australia, "AS 3600: Concrete structures," Standards Australia, 2018.

[5] Standards Australia, "AS 5216: Design of post-installed and cast-in fastenings in concrete," Standards Australia, Australia, 2021.

[6] AEFAC, "AEFAC Anchor Installer Certification Program," Australian Engineered Fasteners and Anchors Council. www.aefac.org.au.

[7] AEFAC, Technical Note, "AEFAC Anchor Dictionary," Australian Engineered Fasteners and Anchors Council. www.aefac.org.au.

[8] CEN, "BS EN 1992-1 : Design of concrete structures," 2004.

Appendix A. Demonstration of product suitability

Users of this technical note should consider the desirability of selecting fasteners that have a current ETA. ETAs are awarded by European Approval Bodies following a comprehensive test and assessment regime carried out under the relevant European Assessment Document (EAD).

Due to the origin of an ETA some notation requires adaptation to ensure compatibility with this technical note. The required adaptations to ETA notation are listed in Table A.1.

Table A.1 — Adaptations required for an ETA to be compatible with this technical note

Item	Notations in this technical note	Conversion from European notation
Steel failure — fasteners	ϕ_{Ms}	$1/\gamma_{Ms}$
Concrete failure — tension	ϕ_c	$1/\gamma_c$
Installation safety — tension	ϕ_{inst}	$1/\gamma_{inst}$
Concrete splitting failure	ϕ_{Msp}	$1/\gamma_{Msp}$
Pull-out failure and combined pull-out and concrete cone failure	ϕ_{Mp}	$1/\gamma_S$
Characteristic compressive strength of concrete	f'_c = 20 MPa	C20/25 (cylinder/cube)
Reinforcement		
Diameter of reinforcement bar	d_b	ϕ
Characteristic yield strength	f_{sy}	$f_{yk,re}$
Cross-sectional area of one stirrup leg	A_{str}	A_{st}
Resistance		
Characteristic resistance corresponding to yielding of the post-installed reinforcement	$N_{Rk,s}$	$N_{Rk,y}$

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