DESIGN GUIDELINES FOR CAST-IN AND POST-INSTALLED ANCHORS IN AUSTRALIA

David J. Heath¹, Emad F. Gad²

ABSTRACT: The Australian anchor industry is rapidly growing, however, guidance for the design of post-installed and cast-in anchors for safety-critical applications in Australian codes of practice is minimal. The current level of guidance has resulted in a lack of consistency for product assessment and limited guidance for design. This paper summarises a design procedure for cast-in and post-installed anchors that has been endorsed by the Australian Engineered Fasteners and Anchors Council (AEFAC) for adoption in Australia. The design procedure is based on design guidelines that are intended to become a harmonised European Standard. The design guidelines are an imperative part of a framework being developed by AEFAC to enhance quality and safety standards in the Australian fastener industry.

KEYWORDS: Post-installed, cast-in, anchor, fastener, design guidelines

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1 INTRODUCTION

Structural fasteners used in safety-critical applications involving metal inserts into a concrete or masonry substrate should be designed and detailed by a competent structural engineer. Applications are defined as ‘safety-critical’ when their failure may cause risk to human life and/or considerable economic loss. Fasteners must be fit for purpose; durable, robust, and possess sufficient integrity for all design actions [1]. Structural fasteners in anchors or masonry are commonly referred to as anchors and form the focus of this paper.

In concrete, anchors may be grouped according to their installation method into cast-in-place and post-installed. Post-installed anchors may be further classified into two groups; direct installation (power actuated) fasteners and a much larger ensemble being drill installation fasteners which covers chemical bonded anchors and mechanical anchors (such as expansion and screw anchors).

The Australian Engineered Fasteners and Anchors Council (AEFAC, www.aefac.org.au) is an industry initiative that was formed in 2012 to introduce governance to the industry with support and guidance to be provided for design engineers, contractors, suppliers, installers and field engineers. AEFAC has reviewed international best practice and resolved that the specification and design provisions outlined by the European Organisation for Technical Assessment (EOTA) are the most appropriate for Australian practice. These design provisions are underpinned by the Concrete Capacity (CC) Method and are currently being developed into industry guidelines for use in Australia. This paper outlines the design provisions for cast-in and post-installed anchors for adoption in Australia.

2 DESIGN PROVISIONS FOR CAST-IN AND POST-INSTALLED ANCHORS

At present, guidelines for the design and evaluation of anchors in Australia are minimal, with the anchor industry relying on suppliers for information and performance data. AS 3600 [2] states shallow anchorage failure should be investigated but provides no further guidance. AS 3850.1 [3] provides guidance on testing and design of brace inserts for precast construction. In New Zealand, NZS 3101:2006 [4] is a partial reproduction of U.S. design guidelines ACI 318-11 [5] and purports to provide design provisions for cast-in and post-installed anchors. However, the design provisions are incomplete and the calculations for basic concrete breakout strength for tension failure and shear failure are non-conservative for post-installed anchors. The absence of suitable guidelines for anchors in safety-critical applications overseas has contributed to catastrophic failures [6, 7, 8]. Implementing proper design guidelines for anchors is paramount to lifting quality and safety standards.

2.1 CONCRETE CAPACITY METHOD

The Concrete Capacity (CC) Method is a mathematical procedure that has been adopted in Europe and the United States for the design of cast-in and post-installed anchors [9, 5]. In many cases the anchor is designed for unreinforced concrete, however, improved performance may be achieved by including supplementary reinforcement. The procedure estimates the strength of an anchor set in concrete to tension forces, shear forces, as well as combined tension and shear forces. This paper summarises the design procedure endorsed by AEFAC for use in Australia and published in the draft European Standard for anchor design which has evolved to include design for fatigue and seismic actions [9]. This endorsement is consistent with the technical specification set by the Australian Technical Infrastructure Committee (ATIC) for the use of anchors in concrete [10]. The principles behind the design procedure have been described extensively elsewhere [1, 11]. The design provisions presented in this paper cover the following types of anchors:

- Cast-in: headed inserts and anchor channel
- Post-installed: mechanical (concrete screw anchors, expansion anchors, undercut anchors) and bonded (bonded anchors, bonded expansion anchors, bonded undercut anchors)

An anchor must have been awarded a European Technical Assessment (ETA, formerly European Technical Approval) or equivalent, to demonstrate its suitability for its intended use and to be compatible with the design guidelines outlined below. An ETA requires the product undergo a sophisticated and application-dependent test regime, demonstrate traceability, include factory auditing, and be independently verified.

The design of an anchor includes the design tension action, \( N_{Ed} \) (refer Section 3), the design shear action, \( V_{Ed} \) (refer Section 4), and simultaneous tension and shear (refer Section 5). European design provisions adopt partial safety factors, \( \gamma \), that are the inverse of the capacity reduction factor, \( \phi \), adopted in Australian design practice such that:

\[
\phi = \frac{1}{\gamma}
\]  

Partial safety factors for anchors are product-specific and are published in the ETA for a product. The conversion from partial safety factor to capacity reduction factor for the respective failure mode is simple.

A summary is provided in Table 1 of the design verifications required for tension failure modes and shear failure modes. Figure 1 illustrates an anchor in concrete with diameter, \( d \), anchor head diameter, \( d_a \), and effective embedment depth, \( h_{ef} \). Figure 2 illustrates groups of anchors including edge distance, \( c \), spacing, \( s \), and member thickness, \( h \). A full list of the adopted notation may be found in the Appendix.

![Figure 1: Effective embedment depth of a headed fastener.](image-url)
2.2 PREQUALIFICATION

Anchor products currently used in the market come from various suppliers. EOTA oversees the awarding of ETAs for trade within the European Union. An ETA is a certification that a product has been rigorously tested and independently confirmed to satisfy the requirements of European Technical Assessment Guideline 001 (ETAG) and demonstrated to be fit for its intended purpose [12]. There are 12 different Options for which a product may be tested against depending on the application for which it is intended. The CC Method outlined in this paper for anchor design relies on an anchor having an ETA. If an anchor product has not been awarded an ETA, its quality cannot be guaranteed by EOTA and it is not eligible to be designed for using the CC Method outlined below. A more comprehensive summary is provided in [13].

Table 1: Design verifications for cast-in and post-installed anchors under tension or shear loading.

<table>
<thead>
<tr>
<th>Mode of failure</th>
<th>Tension</th>
<th>Shear</th>
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<tbody>
<tr>
<td></td>
<td>Design verification</td>
<td>Cast-in</td>
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<tr>
<td>Steel failure of anchor</td>
<td>Refer to AS 4100 where appropriate</td>
<td>√</td>
</tr>
<tr>
<td>Connection between channel and anchor</td>
<td>$N_{Ed}^s \leq \phi_{M,s}N_{Rk,s,c}$</td>
<td>√</td>
</tr>
<tr>
<td>Local flexure of channel lip</td>
<td>$N_{Ed} \leq \phi_{M,j}N_{Rk,s,l}$</td>
<td>√</td>
</tr>
<tr>
<td>Flexure of channel</td>
<td>$M_{Ed} \leq \phi_{M,flex}M_{Rk,s,flex}$</td>
<td>√</td>
</tr>
<tr>
<td>Pull-out failure$^d$</td>
<td>$N_{Ed} \leq \phi_{M,p}N_{Rk,p}$</td>
<td>√</td>
</tr>
<tr>
<td>Combined pull-out and concrete failure$^e$</td>
<td>$N_{Ed} \leq \phi_{M,c}N_{Rk,c}$</td>
<td>√</td>
</tr>
<tr>
<td>Concrete cone failure</td>
<td>$N_{Ed} \leq \phi_{M,c}N_{Rk,c}$</td>
<td>√</td>
</tr>
<tr>
<td>Splitting failure</td>
<td>$N_{Ed} \leq \phi_{M,sp}N_{Rk,sp}$</td>
<td>√</td>
</tr>
<tr>
<td>Blow-out failure$^f$</td>
<td>$N_{Ed} \leq \phi_{M,b}N_{Rk,b}$</td>
<td>√</td>
</tr>
<tr>
<td>Concrete edge failure</td>
<td>$V_{Ed} \leq \phi_{M,V}V_{Rk,c}$</td>
<td>√</td>
</tr>
<tr>
<td>Concrete pry-out failure</td>
<td>$V_{Ed} \leq \phi_{M,V}V_{Rk,c,p}$</td>
<td>√</td>
</tr>
<tr>
<td>Supplementary reinforcement failure$^g$</td>
<td>Refer to AS 3600 where appropriate</td>
<td>√</td>
</tr>
</tbody>
</table>

$^a$ Verification for most loaded channel bolt or anchor, considering effects of edge distance and spacing.

$^b$ Includes concrete screw anchors, expansion anchors and undercut anchors.

$^c$ Includes bonded anchors, bonded expansion anchors and bonded undercut anchors.

$^d$ Not required for post-installed chemical anchors.

$^e$ Not required for headed and post-installed mechanical anchors.

$^f$ Required for headed anchors (including channel) and post-installed mechanical undercut anchors where $c \leq 0.5h_c$.

$^g$ Only relevant where component reinforcement for the fastener is present.
3 DESIGN GUIDELINES FOR TENSION

The design tensile force acting on an anchor, \( N_{Ed} \), must be less than the design tensile resistance, \( N_{Rd} \), such that:
\[
N_{Ed} < N_{Rd} = \phi N_{Rk}
\]  
(2)

The characteristic tensile strength, \( N_{Rk} \), and capacity reduction factor, \( \phi \), are dependent on failure mode and should be checked according to Table 1. Tensile failure modes are illustrated in Figure 3(a) and additional anchor channel failure modes in Figure 3(b). The concrete is unreinforced unless otherwise noted.

3.1 STEEL FAILURE OF FASTENER

Verification of the resistance of the anchor bolt or rod against steel failure under tension (\( N_{Rk,s} \)) should be carried out in accordance with AS 4100:1998 [14] or where this does not apply, EN 1992-1-1:2005 [15] may be used. Calculation of characteristic resistance for anchor channel is required since this data is published in the ETA including the following failure modes: channel bolt (\( N_{Rk,s,a} \)), connection failure between anchor and channel (\( N_{Rk,s,c} \)), local flexural failure of channel lips (\( N_{Rk,s,l} \)), failure of the channel bolt (\( N_{Rk,s} \)) and failure by flexure of the channel (\( M_{Rk,flex} \)). Verification may be performed using the design verification listed in Table 1.

3.2 PULL-OUT FAILURE OF FASTENER

The characteristic resistance to pull-out failure, \( N_{Rk,p} \), is given in the ETA. It is not presently possible to calculate the pull-out resistance for post-installed mechanical anchors. For headed fasteners, \( N_{Rk,p} \) is limited by the pressure under the fastener head:
\[
N_{Rk,p} = k_1 A_h f_{ck}
\]  
(3)

where
\[
A_h = \left( \pi/4 \right) d_h^2 - d^2
\]  
(4)

\[
k_1 = \begin{cases} 7.5 & \text{for fasteners in cracked concrete} \\ 10.5 & \text{for fasteners in non-cracked concrete} \end{cases}
\]

3.3 COMBINED PULL-OUT AND CONCRETE FAILURE

The characteristic resistance of an individual or group of bonded fasteners to combined pull-out and concrete failure, \( N_{Rk,p} \) is determined as follows:
\[
N_{Rk,p} = N_{Rk,p}^0 \left( A_{p,N}/A_{p,N}^0 \right) \psi_{g,Np} \psi_{s,Np} \psi_{ec,Np}
\]  
(5)

The characteristic resistance of a single bonded fastener, \( N_{Rk,p}^0 \) not influenced by adjacent bonded fasteners, may be determined as follows:
\[
N_{Rk,p}^0 = \tau_{Rk,p} d_h f_{ck}
\]  
(6)

where
\[
\tau_{Rk} = \begin{cases} \tau_{Rk,cr} & \text{for cracked concrete} \\ \tau_{Rk,ucr} & \text{for non-cracked concrete} \end{cases}
\]

The group effect is accounted for by \( \psi_{g,Np} \) as follows:
\[
\psi_{g,Np} = \psi_{g,Np}^0 - \left( s/s_{cr,Np} \right)^0.5 \left( \psi_{g,Np} \right) > 1
\]  
(10)

where
\[
\psi_{g,Np}^0 = \sqrt{n} - \left( \sqrt{n} - 1 \right)^0.5 \frac{\tau_{Rk,c}}{\tau_{Rk,c}} \geq 1
\]  
(11)

\[
\tau_{Rk,c} = \left( k_8 / \pi d_h \right) f_{ck}
\]  
(12)

\[
k_8 = \begin{cases} 7.7 & \text{for cracked concrete} \\ 11.0 & \text{for non-cracked concrete} \end{cases}
\]

Disturbance to the distribution of stresses due to close proximity of a concrete edge is accounted for by \( \psi_{s,Np} \) as follows:
\[
\psi_{s,Np} = 0.7 + 0.3 \left( s/e_{cr,Np} \right) \leq 1
\]  
(13)
Where a layer of dense reinforcement exists, the shell spalling factor $\psi_{re,N}$ applies when $h_{ef} < 100$ mm:

$$\psi_{re,N} = 0.5 + \left(\frac{h_{ef}}{200}\right) \leq 1$$ (14)

However, $\psi_{re,N}$ may be taken as 1.0 when reinforcement is at a spacing greater than 150 mm, or when reinforcement with a diameter of 10 mm or less as a spacing of at least 100 mm.

When an eccentricity in loading exists on a group of fasteners, the eccentricity factor, $\psi_{ec,Np}$, accounts for the effect on the characteristic resistance:

$$\psi_{ec,Np} = \frac{1}{1 + 2e_N / s_{cr,Np}} \leq 1$$ (15)

Where fasteners are present in a narrow member with three or more edges affecting the failure surface the above calculations are conservative. Refinements may be made to the effective depth ($h_{ef}$), characteristic edge distance ($c_{cr,N}$) and characteristic spacing for the determination of the $A_{p,N}/A_{0,N}$ ratio.

### 3.4 CONCRETE CONE FAILURE

The characteristic resistance of an individual or group of fasteners to concrete cone failure, $N_{Rk,c}$, is calculated as follows:

$$N_{Rk,c} = N^0_{Rk,c} \left( A_{c,N} / A^0_{c,N} \right) \psi_{s,N} \psi_{re,N} \psi_{ec,N} \psi_{M,N}$$ (16)

The characteristic resistance of a single fastener remote from the effects of spacing and edge distance, $N^0_{Rk,c}$, is determined:

$$N^0_{Rk,c} = k_g \sqrt{s_{ck} h_{ef}^{1.5}}$$ (17)

with

- $k_g = k_{cr,N}$ for cracked concrete
- $k_g = k_{ucr,N}$ for non-cracked concrete
- $k_{cr,N} = 7.7$ for post-installed fasteners and 8.9 for cast-in headed fasteners based on current experience. The value for cast-in channel is dependent on channel shape.
- $k_{ucr,N} = 11.0$ for post-installed fasteners and 12.7 for cast-in headed fasteners based on current experience. The value for cast-in channel is dependent on channel shape.

The effect of spacing and edge distance on the resistance to concrete cone failure is dependent on the ratio $A_{c,N}/A^0_{c,N}$, where:

- $A_{c,N}$ = actual projected area limited by overlapping concrete breakout bodies of adjacent fasteners ($s \leq s_{cr,N}$) and the concrete edges ($c \leq c_{cr,N}$).
- $A^0_{c,N} = s_{cr,N}^2$ as shown in Figure 4

$$N_{Rk,c} = N^0_{Rk,c} \psi_{ch,c,N} \psi_{ch,c,N} \psi_{re,N} \psi_{ec,N}$$ (21)

$$N^0_{Rk,c} = \text{calculated according to Equation (17)}$$

The disturbance to the distribution of stresses on the concrete cone failure due to the nearest edge is established via the factor $\psi_{s,N}$, where:

$$\psi_{s,N} = 0.7 + 0.3(c/c_{cr,N}) \leq 1$$ (19)

The determination of the shell spalling factor, $\psi_{re,N}$ is determined in accordance with Section 3.3.

When a group of fasteners exists with an eccentric resultant loading, the factor $\psi_{ec,N}$ may be used to modify the characteristic resistance as follows:

$$\psi_{ec,N} = \frac{1}{1 + 2e_N / s_{cr,Np}} \leq 1$$ (20)

The influence of a compression force between the concrete and fixture on the characteristic resistance to concrete cone failure is represented by $\psi_{M,N}$, where:

$$\psi_{M,N} = 1 \text{ for fastenings close to edge } (c < 1.5h_{ef}),$$

$$\psi_{M,N} = 2 - 0.67z/h_{ef} \geq 1 \text{ for other fastenings loaded by a bending moment and tension force.}$$

Where bending is present in two directions, $z$ is determined for the resultant direction.

The above calculations are conservative for fasteners in narrow members where three or more edges influence the failure area. More precise calculations exist in [9].

For cast-in channel, the characteristic resistance of one anchor in the channel to concrete cone failure, $N_{Rk,c}$, is calculated according to:

$$N_{Rk,c} = N^0_{Rk,c} \psi_{ch,c,N} \psi_{ch,c,N} \psi_{re,N} \psi_{ec,N}$$ (21)

$$N^0_{Rk,c} = \text{calculated according to Equation (17)}$$
The factor, $\psi_{ch,s,N}$ accounts for the effects of neighbouring anchors on concrete cone failure as follows:

$$
\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch}} \left(1 - \frac{s_i}{s_{cr,N}}\right)^{5/2} \left(N_i / N_0\right)} \leq 1
$$

(22)

where

- $s_i = \text{distance to neighbouring anchors} \ (s_i \leq s_{cr,N})$
- $s_{cr,N} = 2(2.8 - 1.3h_{ef}/180)h_{ef} \geq 3h_{ef}$
- $N_i = \text{tension force in the influencing anchor}$
- $N_0 = \text{tension force in anchor under consideration}$
- $n_{ch} = \text{number of anchors within a distance, } s_{cr,N}$

The influence of a concrete edge on the resistance of the channels is represented by $\psi_{ch,e,N}$ as follows:

$$
\psi_{ch,e,N} = \sqrt{c_1 / c_{cr,N}} \leq 1
$$

(24)

where

- $c_1 = \text{edge distance of anchor}$
- $c_{cr,N} = 0.5s_{cr,N}$

(25)

Where multiple edges exist, the minimum edge distance should be used in Equation (24).

The influence of a corner on the concrete cone resistance of a channel is accounted for by $\psi_{ch,c,N}$ as follows:

$$
\psi_{ch,c,N} = \sqrt{c_2 / c_{cr,N}} \leq 1
$$

(26)

where

- $c_2 = \text{corner distance of the anchor being considered.}$

If two corners influence the anchor, $\psi_{ch,c,N}$ should be calculated for both and the product of these two values inserted into Equation (21). The shell spalling factor, $\psi_{re,N}$ is calculated according to Equation (14). Equation (21) yields a conservative estimate of the resistance of a channel to cone failure in a narrow member with the influence of neighbouring anchors, an edge and corners within a distance of $s_{cr,N}$. More precise calculations may be found in [10].

### 3.5 SPLITTING FAILURE

Splitting failure during installation may be avoided for all anchor types by observing requirements published in the ETA, including minimum edge distances, $c_{min}$, minimum spacing, $s_{min}$, and minimum member thickness, $h_{min}$.

Splitting failure during loading may be avoided if one of the following conditions exists –

- a) Edge distance in all directions is $c \geq c_{cr,sp}$ for single fasteners, $c \geq 1.2c_{cr,sp}$ for fastener groups, and $h \geq h_{min}$ for member depth.
- b) The calculation of characteristic resistance to concrete cone failure and pull-out failure is performed for cracked concrete, reinforcement resists splitting failure and limits cracks to a width of 0.3 mm. Determination of the required reinforcement is performed in accordance with [9].

If the above conditions are not met, the characteristic resistance to splitting failure, $N_{Rk,sp}$ is determined as follows:

$$
N_{Rk,sp} = N_{Rk,sp}^0 A_{c,N} A_{e,N} A_{h,N} \psi_{s,N} \psi_{re,N} \psi_{ec,N} \psi_{h,sp}
$$

(27)

where

- $N_{Rk,sp}^0 = \text{given in the ETA}$
- $\psi_{s,N}, \psi_{re,N}, \psi_{ec,N}$ as per Section 3.3

The influence of member thickness on the splitting resistance is taken into account via $\psi_{h,sp}$ as follows:

$$
\psi_{h,sp} = \left(\frac{h}{h_{min}}\right)^{2/3}
$$

(28)

The above provisions exist to avoid splitting failure for anchor channels, except Equation (27) is replaced by Equation (29) to determine the resistance to splitting, $N_{Rk,sp}$, as follows:

$$
N_{Rk,sp} = N_{Rk,sp}^0 A_{c,N} A_{e,N} A_{h,N} \psi_{s,N} \psi_{ch,c,N} \psi_{ch,e,N} \psi_{ch,s,N} \psi_{h,sp}
$$

(29)

where

- $N_{Rk,sp}^0 = \text{min}(N_{Rk,sp}^0, N_{Rk,c})$
- $N_{Rk,c} = \text{calculated according to Equation (3)}$
- $N_{Rk,c}, \psi_{ch,c,N}, \psi_{ch,e,N}, \psi_{ch,s,N}$ according to Section (3.3).
- $\psi_{h,sp}$ according to Equation (28).

### 3.6 BLOW-OUT FAILURE

A check on the characteristic resistance to blow-out failure, $N_{Rk,cb}$ should be performed for headed fasteners and for post-installed mechanical undercut fasteners acting as headed fasteners if one edge distance, $c$, is less than or equal to $0.5h_{ef}$. The characteristic resistance to blow-out failure, $N_{Rk,cb}$, becomes:

$$
N_{Rk,cb} = N_{Rk,cb}^0 A_{cb,N} A_{cb,Nhcb} \psi_{s,N} \psi_{re,N} \psi_{ec,N}
$$

(31)

Where spacing or edge effects are not present, the characteristic resistance of a single fastener to blow-out failure, $N_{Rk,cb}^0$ becomes:

$$
N_{Rk,cb}^0 = k_d c_1 \sqrt{A_h} \sqrt{A_c}
$$

(32)

Where

- $k_d = 8.7 $ for cracked concrete
- $A_h = 12.2 $ for non-cracked concrete
- $A_c = \text{as per Equation (4) or ETA}$

The effects of fastener spacing and edge distance are accounted for by the ratio $A_{cb,N}/A_{cb,Nhcb}$, where:
\[ A^0_{c,\text{Nb}} = (4c_1)^2 \text{ as show in Figure 5} \]  

\[ A_{c,\text{Nb}} = \text{actual projected area limited by overlapping concrete breakout bodies of adjacent fasteners (} s \leq 4c_1, \text{ concrete edges (} c_2 \leq 2c_1) \text{ or member thickness.} \]

The disturbance to the distribution of stresses due to a nearby edge is accounted for by \( \psi_{s,\text{Nb}} \) as follows:

\[ \psi_{s,\text{Nb}} = 0.7 + 0.3(2c_2/2c_1) \leq 1 \]  

The group effect for \( n \) fasteners in a row parallel to an edge is accounted for by \( \psi_{g,\text{Nb}} \) as follows:

\[ \psi_{g,\text{Nb}} = \sqrt{n} + \left(1 - \sqrt{n}\right)s_1/4c_1 \geq 1 \]

\[ s_1 \leq 4c_1 \]  

The effect of an eccentricity due to different loads in an anchor group is accounted for by \( \psi_{e,\text{Nb}} \) as follows:

\[ \psi_{e,\text{Nb}} = \frac{1}{1+2c_N/(4c_1)} \]

The influence of member thickness on the resistance to blow-out failure is accounted for via \( \psi_{h,\text{Nh},\text{Nb}} \) as follows:

\[ \psi_{h,\text{Nh},\text{Nb}} = \left(h_{ef} + f\right)/4c_1 \leq (2c_1 + f)/4c_1 \leq 1 \]

\[ f = \text{distance between anchor head and lower surface of concrete member.} \]

3.7 STEEL REINFORCEMENT FAILURE

Supplementary reinforcement is intended to tie a potential concrete breakout body to the concrete member and to ensure a ductile failure mode. The supplementary reinforcement should be appropriately detailed in accordance with AS 3600:2009. Failure modes including steel yielding and loss of reinforcement anchorage should be assessed. A detailed presentation of the topic is beyond the scope of this paper.

4 DESIGN GUIDELINES FOR SHEAR

The design shear force applied to the anchor, \( V_{\text{Ed}} \), should be less than the anchor design shear resistance:

\[ V_{\text{Ed}} \leq V_{\text{Rd}} = \phi V_{\text{Rk}} \]

The characteristic shear strength, \( V_{\text{Rk}} \), as well as the capacity reduction factor, \( \phi \), is dependent on the failure mode and should be checked in accordance with Table 1. Shear failure modes are illustrated in Figure 6(a) with additional failure modes specific to anchor channels illustrated in Figure 6(b).

4.1 STEEL FAILURE

Verification of the resistance of the anchor bolt or rod against steel failure under shear should be carried out in accordance with AS 4100:1998 [14] or where this does not apply, EN 1992-1-1:2005 [15] may be used. The characteristic resistance of a single fastener to steel failure, \( V_{\text{Rk,s}} \), is given in the ETA. For anchor channel, the ETA includes the following characteristic resistances: channel bolt (\( V_{\text{Rk,s,b}} \)), anchor failure (\( V_{\text{Rk,s,a}} \)), connection failure between anchor and channel (\( V_{\text{Rk,s,c}} \)) and flexural failure of channel lips (\( V_{\text{Rk,s,l}} \)).

The characteristic resistance of a single anchor, \( A_{\text{k},\text{Nh}} \), is determined in Equation (32). The factor, \( \psi_{h,\text{Nh},\text{Nb}} \) accounts for the effects of neighbouring anchors and may be determined according to Equation (22) with \( s_{r,N} = 4c_1 \) instead of \( s_{r,N} \).

The influence of a corner on the resistance to blow-out is determined by the factor \( \psi_{h,c,\text{Nh}} \) as follows:

\[ \psi_{h,c,\text{Nh}} = \frac{c_2}{c_{cr,N}} \leq 1 \]

\[ c_2 = \text{corner distance of anchor} \]

\[ c_{cr,N} = s_{cr,N}/2 \]

Where two corners influence the resistance to blow-out failure, \( \psi_{h,c,\text{Nh}} \) is calculated for both directions and the product inserted into Equation (38).
Consideration should be given to bending failure of the anchor where limited restraint exists above the surface of the concrete member, including an assessment of restraint to rotation provided to the anchor. The ETA identifies the characteristic bending resistance and details of the verification are provided in [9].

4.2 CONCRETE EDGE FAILURE

The resistance to concrete edge failure should be investigated if edge effects are likely; viz: if \( c < \max(10h_{ef}, 60d) \). If more than one edge exists, the resistance for all edges should be calculated individually.

The characteristic resistance of an individual or group of fasteners to concrete edge failure is calculated as:

\[
V_{Rk,e} = V_{Rk,c}^0 A_{c,V}^0 \frac{A_{c,V}^0}{A_{c,V}^0} \psi_{s,V} \psi_{h,V} \psi_{ec,V} \psi_{re,V} \beta \tag{43}
\]

The characteristic resistance of an individual fastener loaded perpendicular to an edge becomes:

\[
V_{Rk,e} = k_5 d_{nom}^0 \frac{\beta}{f} \sqrt{f_{ct}} c_1^{1.5} \tag{44}
\]

with

\[
k_5 = 1.7 \text{ for cracked concrete}
= 2.4 \text{ for non-cracked concrete}
\]

\[
\alpha = 0.1 \left( \frac{l_f}{c_1} \right)^{0.5} \tag{45}
\]

\[
\beta = 0.1 \left( \frac{d_{nom}}{c_1} \right)^{0.2} \tag{46}
\]

where

\[
h_{ef} = \text{case of a uniform diameter of the shank of the headed fastener and a uniform diameter of the post-installed fastener.} \\
\leq 12d_{nom} \text{ in case of } d_{nom} \leq 24 \text{ mm} \\
\leq \max(8d_{nom}, 300 \text{ mm}) \text{ where } d_{nom} > 24 \text{ mm} \\
d_{nom} \leq 60 \text{ mm}
\]

The effects of edge distance and spacing, as well as member thickness for concrete edge failure are accounted for by the ratio \( A_{c,V} / A_{c,V}^0 \), where:

\[
A_{c,V}^0 = 4.5c_1^2 \text{ as per Figure 7.} \tag{47}
\]

\[
A_{c,V} = \text{idealised break-out body, limited by adjacent fasteners (s \leq 3c_1) and edges parallel to assumed loading direction (c_2 \leq 1.5c_1) and member thickness (h < 1.5c_1)}
\]

When a torsion moment acts on two fasteners such that each fastener is loaded in shear in opposite directions and both close to an edge, an additional check is required for two break-out bodies overlapping.

The disturbance to the distribution of stresses due to additional nearby edges including multiple edges in a narrow member is addressed by \( \psi_{re,V} \) as follows:

\[
\psi_{s,V} = 0.7 + 0.3(c_2/1.5c_1) \leq 1 \tag{48}
\]

Since the resistance to concrete edge failure does not increase proportionately to member thickness, the factor \( \psi_{h,V} \) is imposed:

\[
\psi_{h,V} = \sqrt{1.5c_1/h} \geq 1 \tag{49}
\]

The effect of an eccentricity introduced by different shear loads acting on different fasteners in a group is accounted for by the factor \( \psi_{re,V} \) as follows:

\[
\psi_{re,V} = \frac{1}{1 + 2e_V/(3c_1)} \leq 1 \tag{50}
\]

\[
e_V = \text{eccentricity between resulting shear load acting on the group of fasteners relative to their centre of gravity.}
\]

The effect of a shear load acting at an angle to the free edge is accounted for by the factor \( \psi_{re,V} \) as follows:

\[
\psi_{re,V} = 1.0 \text{ for non-cracked concrete without edge reinforcement}
= 1.4 \text{ for cracked concrete with edge reinforcement including closely spaced stirrups or wire mesh with a spacing a \leq 100 mm and z \leq 2c_1}}. \text{ This condition is relevant where } h_{ef} \text{ is at least 2.5 times member depth.}
\]

When the applied shear load is directed towards an edge the 0.5 factor in Equation (51) should be replaced by a factor equal to 1.0 to check against the break-out body developing in the corner.

The effect of reinforcement on the resistance to concrete break-out is determined via the factor \( \psi_{re,V} \) as follows:

\[
\psi_{re,V} = \begin{cases} 
0.7, & \text{if } e_V \leq 5 \text{ and } a \leq 100 \\
0.5, & \text{if } e_V > 5 \text{ or } a > 100
\end{cases}
\]

\[
\psi_{re,V} = 0.7 + 0.3(c_2/1.5c_1) \leq 1 \tag{48}
\]

\[
\psi_{re,V} = 1.0 \text{ for non-cracked concrete without edge reinforcement}
= 1.4 \text{ for cracked concrete with edge reinforcement including closely spaced stirrups or wire mesh with a spacing a \leq 100 mm and z \leq 2c_1}}. \text{ This condition is relevant where } h_{ef} \text{ is at least 2.5 times member depth.}
\]

When the fastener is in a thin and narrow member, refinements may be made to spacing and edge distance to more precisely determine the resistance to concrete edge break-out failure [9].

**Figure 7: Idealised surface of edge break-out failure.**

For anchor channels, a check on resistance to concrete edge failure may be omitted if \( c \geq \max(10h_{ef}, 60d) \) where \( d \) = diameter of channel bolt. Otherwise, the
characteristic resistance to concrete edge failure for anchor channels is determined as follows:

\[ V_{Rk,\text{c}} = V_{Rk,\text{c},Y}^0 \psi_{ch,\text{c,V}} \psi_{ch,\text{c,Y}} \psi_{ch,90^{\circ},\text{Y}} \psi_{re,\text{V}} \]  \hspace{1cm} (52)

The basic characteristic resistance to edge failure, \( V_{Rk,\text{c}}^0 \), where one anchor is loaded perpendicular to the edge and not influenced by neighbouring anchors, member thickness or corner effects becomes:

\[ V_{Rk,\text{c}}^0 = k_{10} \sqrt{f_{ck}} c_1^{1.5} \]  \hspace{1cm} (53)

\[ k_{10} = \begin{cases} 2.5 & \text{for cracked concrete} \\ 3.5 & \text{for non-cracked concrete} \end{cases} \]

The influence of neighbouring anchors is accounted for via the factor, \( \psi_{ch,\text{c,V}} \), as follows:

\[ \psi_{ch,\text{c,V}} = \frac{1}{1 + \sum_{i=1}^{n} \left[ (1 - s_i / s_{cr,V}) \frac{s_{cr,V}}{V_i / V_0} \right]^5} \]  \hspace{1cm} (54)

\[ s_i = \text{distance to neighbouring anchors (refer to Figure 2)} \]

\[ s_{cr,V} = 4c_1 + 2h_h \]  \hspace{1cm} (55)

\[ V_i = \text{shear force of an influencing anchor} \]

\[ V_0 = \text{shear force of the anchor being considered} \]

\[ n = \text{number of anchors within a distance equal to } s_{cr,V}. \]

The factor, \( \psi_{ch,\text{c,V}} \), takes into account the effect of a corner on the characteristic edge distance as follows:

\[ \psi_{ch,\text{c,V}} = \sqrt{c_2 / c_{cr,V}} \leq 1 \]  \hspace{1cm} (56)

\[ c_{cr,V} = 0.5 s_{cr,V} \]  \hspace{1cm} (57)

Where multiple corners influence the anchor, \( \psi_{ch,\text{c,V}} \) is calculated for each corner and the product of the two values is used in Equation (52).

The influence of member thickness is accounted for via the factor, \( \psi_{ch,\text{h,V}} \), as follows:

\[ \psi_{ch,\text{h,V}} = \sqrt{h / h_{cr,V}} \leq 1 \]  \hspace{1cm} (58)

\[ h_{cr,V} = 2c_1 + 2h_h \]  \hspace{1cm} (59)

The presence of loads acting parallel to the edge is taken into account via the factor, \( \psi_{ch,90^{\circ},\text{Y}} \), applicable to the anchor closest to the edge, as follows:

\[ \psi_{ch,90^{\circ},\text{Y}} = 2.5 \]

The factor \( \psi_{re,\text{V}} \) is calculated according to the provisions outlined above in this Section. Where edge reinforcement and cracked concrete applications exist, \( \psi_{re,\text{V}} > 1 \) only if the anchor channel height, \( h_h \geq 40 \text{ mm} \).

If the anchor channel is in a thin and narrow member then refinements may be made to the edge distance \( c_1 \) for more accurate results [9].

4.3 CONCRETE PRY-OUT FAILURE

The resistance of an individual anchor to concrete pry-out failure, \( V_{Rk,\text{cp}} \), is given by:

\[ V_{Rk,\text{cp}} = k_3 N_{Rk,\text{c}} \]  \hspace{1cm} (60)

\[ k_3 = \text{Given in the ETA, equal to 0.75 where supplementary reinforcement exists} \]

\[ N_{Rk,\text{c}} = \text{Calculated according to Equation (16).} \]

For anchor groups with shear forces the most unfavourable anchor should be verified. It should be assumed that a virtual edge exists in the direction of the neighbouring anchor(s) such that \( c = 0.5s \).

4.4 SUPPLEMENTARY REINFORCEMENT FAILURE

If the design is to include supplementary reinforcement, consideration should be given to:

1) Steel failure of reinforcement, and
2) Anchorage failure of reinforcement

Checks of the above considerations and the contribution of the reinforcement to design may be performed in accordance with AS 3600:2009.

5 DESIGN GUIDELINES FOR COMBINED LOADING

Under combined tension and shear loading, verification of resistance is required for each failure mode independently. Verification of fastenings with supplementary reinforcement should also be performed. Further details are given in [9].

5.1 STEEL FAILURE OF FASTENER

The resistance to steel failure of the fastener under combined loading is assessed as follows:

\[ \left( \frac{N_{Ed}}{N_{Rd,i}} \right)^{a_i} + \left( \frac{V_{Ed}}{V_{Rd,i}} \right)^{a_i} \leq 1 \]  \hspace{1cm} (61)

with

\[ N_{Ed} / N_{Rd,i} \leq 1 \text{ and } V_{Ed} / V_{Rd,i} \leq 1 \]

\[ N_{Rd,i} = N_{Rd,i} \text{ for steel failure of fastener and channel bolt} \]

\[ a_i = 2 \text{ for tensile failure of anchor bolt} \]

For other anchor channel steel failure modes –

\[ a_i = 2 \text{ for } V_{Rd,i} \leq N_{Rd,i} \]

\[ = \text{Given in the ETA, corresponding with } N_{Rd,i} \text{, } N_{Rd,i} \text{ and } V_{Rd,i} \text{, } V_{Rd,i} \text{, } V_{Rd,i} \text{ for each failure mode where } V_{Rd,i} > N_{Rd,i} \]

\[ = 1 \text{ where no information exists in the ETA, which is conservative} \]
5.2 FAILURE MODES OTHER THAN STEEL

The resistance of a fastener to modes of failure other than steel failure (pull-out failure, combined pull-out and cone failure, concrete cone failure, splitting failure, blow-out, edge failure, pry-out failure) is assessed via the following:

$$\left( \frac{N_{Ed}}{N_{Rd,i}} \right)^{1.5} + \left( \frac{V_{Ed}}{V_{Rd,i}} \right)^{1.5} \leq 1 \quad (62)$$

or

$$\left( \frac{N_{Ed}}{N_{Rd,i}} \right) + \left( \frac{V_{Ed}}{V_{Rd,i}} \right) \leq 1.2 \quad (63)$$

with $N_{Ed}/N_{Rd,i} \leq 1$ and $V_{Ed}/V_{Rd,i} \leq 1$

The largest value of $N_{Ed}/N_{Rd,i}$ and $V_{Ed}/V_{Rd,i}$ for the different failure modes is assessed.

For anchor channels the values of $N_{Rd,i}$ and $V_{Rd,i}$ are:

$$N_{Rd,i} = \min(N_{Rd,cr}, N_{Rd,cp}) \quad (64)$$

$$V_{Rd,i} = \min(V_{Rd,cr}, V_{Rd,cp}) \quad (65)$$

6 TRAINING FOR INSTALLERS

Anchor products that have been installed incorrectly will most likely perform in an unpredictable manner that differs from the specifier’s intent. An awareness of this danger is critical. Most types of anchors that are presently used are sensitive to installation practice. The training of installers is frequently overlooked which may cause gross errors during installation that in turn could have catastrophic consequences. AEFAC is currently developing a training and accreditation scheme for installers of anchor products, to ensure that the product that has been awarded the appropriate prequalification is installed as per the supplier or manufacturer’s installation instructions. The implementation of this training program together with appropriate prequalification and the design guidelines outlined in this paper, form a quality assurance system for the anchor industry.

7 CONCLUSIONS

The Australian anchor industry is largely dependent on data and design recommendations provided by different suppliers which lack consistency and harmony with other design standards. AEFAC was formed as an industry initiative to develop standards and guidelines to enhance the Australian anchor industry. This paper has presented a procedure for the design of cast-in and post-installed anchors for use in concrete based on the European pre-standard, prEN 1992-4:2013 that is intended to become a harmonised European Standard. The procedure covers the resistance to tension forces, shear forces and combined tension and shear forces, and has been endorsed by AEFAC for adoption by the Australian building and construction industry. The procedure is only applicable to products having a European Technical Assessment and together with a training regime currently being developed by AEFAC, will safeguard the quality and safety of anchors used in the Australian building and construction industry.

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10 APPENDIX

A list of the notation used throughout this paper has been provided below. More comprehensive descriptions are available in [9].

- \( a \) – spacing of reinforcement
- \( A_{c,N}, A_{c,\text{Nb}}, A_{c,V}, A_{h,N} \) – actual influence area for respective failure modes
- \( A^0_{c,N}, A^0_{c,\text{Nb}}, A^0_{c,V}, A^0_{h,N} \) – idealised influence area for respective failure modes
- \( A_h \) – bearing area of head of headed insert
- \( c, c_1, c_2 \) – distance
- \( c_{c,N}, c_{c,\text{Nb}}, c_{c,V}, c_{cr,V} \) – critical edge distance to ensure characteristic resistance for respective failure modes
- \( c_{\text{min}} \) – minimum edge distance
- \( C_{ed} \) – compression force acting on fixture
- \( d \) – nominal diameter of fastener
- \( d_{h} \) – diameter of head of fastener
- \( e_{N}, e_{V} \) – eccentricity of resultant load on anchor group
- \( f \) – distance between anchor head and lower surface of concrete member
- \( f_{cb} \) – characteristic compressive strength of concrete measured via cylinder test
- \( h \) – thickness of concrete member
- \( h_{ch} \) – height of anchor channel
- \( h_{c,V} \) – minimum member thickness to avoid concrete edge breakout
- \( h_{f} \) – effective embedment depth
- \( h_{\text{min}} \) – minimum member thickness to avoid splitting
- \( k_{s,N}, k_{s,c,N}, k_{s,\text{Nb}}, k_{s,V} \) – parameters related to state of concrete
- \( k_{f}, k_{s}, k_{a}, k_{b}, k_{b}, k_{f0} \) – parameters in equations
- \( l \) – length of fastener
- \( n, n_{ch} \) – number of fasteners
- \( N_{ed}, N_{c,N} \) – design tension force
- \( N_{c}, N_{0} \) – tension force in fastener
- \( N_{ed,i}, N_{ed,\text{ai}} \) – design tension resistance to type of failure mode
- \( N_{RL,E}, N_{RL,\text{cb}}, N_{RL,\text{p}}, N_{RL,sp} \) – characteristic tensile resistance of an anchor to respective failure mode
- \( N_{RL,0}, N_{RL,\text{cb}}, N_{RL,\text{p}}, N_{RL,sp} \) – characteristic tensile resistance of a reference anchor to respective failure mode free from edge and spacing effects
- \( s, s_{ij}, s_{ij}, s_{ij} \) – spacing of fasteners
- \( s_{cr,N}, s_{cr,\text{Nb}}, s_{cr,V} \) – spacing of fasteners required to achieve characteristic resistance of anchor
- \( s_{\text{min}} \) – minimum fastener spacing
- \( V, V_{ij}, V_0 \) – shear force applied to fastener
- \( V_{ed} \) – design shear force
- \( V_{RL,i}, V_{RL,\text{ai}} \) – design shear resistance to type of failure mode
- \( V_{RL,0}, V_{RL,\text{cb}}, V_{RL,\text{p}}, V_{RL,sp} \) – characteristic shear resistance of an anchor to respective failure mode
- \( V_{RL,0}, V_{RL,\text{cb}}, V_{RL,\text{p}}, V_{RL,sp} \) – characteristic shear resistance of a reference anchor to respective failure mode free from edge and spacing effects
- \( z \) – internal lever arm
- \( a, a_{ij}, \beta \) – exponent
- \( \alpha_l \) – angle between load and line perpendicular to edge
- \( \psi_{ch,N}, \psi_{ch,\text{Nb}}, \psi_{ch,V} \) – parameter relating to the effect of a corner close to the anchor for respective failure modes
- \( \psi_{ch,N} \) – parameter relating to effect of nearby edge
- \( \psi_{h,Nb}, \psi_{h,V} \) – parameter relating to the effect of two corners
- \( \psi_{h,Nb}, \psi_{h,Nb}, \psi_{h,h,V} \) – parameter relating to the effect of member thickness for respective failure modes
- \( \psi_{h,Nb}, \psi_{h,v}, \psi_{h,v} \) – parameter relating to neighbouring anchors for respective failure modes
- \( \psi_{h,v}, \psi_{h,v} \) – parameter relating to direction of shear load
- \( \psi_{t,Nb}, \psi_{t,v}, \psi_{t,v} \) – parameter related to eccentricity of loading for respective failure modes
- \( \psi_{t,Nb}, \psi_{t,v}, \psi_{t,v} \) – parameter related to group effects for respective failure modes
- \( \psi_{t,v}, \psi_{t,v} \) – parameter related to member thickness for respective failure modes
- \( \psi_{m,N} \) – parameter relating to compression of fixture
- \( \psi_{m,N}, \psi_{m,N}, \psi_{m,v} \) – parameter relating to reinforcement for respective failure modes
- \( \psi_{m,N}, \psi_{m,N}, \psi_{m,v} \) – parameter relating to disturbance to stresses due to nearby edge for respective failure modes
- \( \psi_{m,v} \) – parameter relating to effect of shear load angle
- \( \tau_{RL,E}, \tau_{RL,\text{cb}}, \tau_{RL,\text{p}}, \tau_{RL,sp} \) – bond strength including consideration of state of concrete (cracked/non-cracked)