6.2.5 Combined pull-out and concrete cone failure for post-installed chemical fasteners

6.2.5.1 *General*

The strength of a single chemical fastener in tension or a fastener in tension in a fastener group to combined pull-out and concrete cone failure shall be calculated as follows:

$$N_{Rk,p} = N^0_{Rk,p}\left(\frac{A_{p,N}}{A^0_{p,N}}\right)\psi_{s,Np}\ \psi_{g,Np}\ \psi_{re,N}\ \psi_{ec,Np} \quad \ldots 6.2.5.1$$

where

$N^0_{Rk,p}$ = reference characteristic bond strength of a single chemical fastener to pull-out failure, determined in accordance with Clause 6.2.5.2

$A_{p,N}$ = actual bond influence area of a single chemical fastener, limited by adjacent fasteners and edges of the concrete member given in Clause 6.2.5.3

$A^0_{p,N}$ = reference bond influence area of a single chemical fastener for combined pull-out failure and concrete cone failure, given in Clause 6.2.5.3

$\psi_{s,Np}$ = parameter accounting for the influence on tensile strength of a fastener to pull-out failure, of the disturbance to the distribution of stresses in the concrete due to the proximity of a fastener to an edge of the concrete member

$\psi_{g,Np}$ = parameter accounting for the influence of a group effect on the tensile strength of a fastener to pull-out failure, as given in Clause 6.2.5.5

$\psi_{re,N}$ = parameter accounting for shell spalling due to a dense layer of reinforcement, calculated according to Clause 6.2.3.5

$\psi_{ec,Np}$ = parameter accounting for eccentricity of loading on a fastener group for pull-out failure, calculated according to Clause 6.2.5.6, substituting $s_{cr,Np}$ for $s_{cr,N}$

6.2.5.2 *Characteristic bond strength of an individual chemical fastener*

The characteristic bond strength of an individual chemical fastener ($N^0_{Rk,p}$) remote from the effects of adjacent fasteners and edges of the concrete member shall be calculated as follows:

$$N^0_{Rk,p} = \tau_{Rk}\pi\ d\ h_{ef}\psi_{sus} \quad \ldots 6.2.5.2$$

where

τ_{Rk} = characteristic bond strength of chemical fastener that depends on concrete strength class

The characteristic bond strength shall be determined in accordance with Appendix A as either—

(a) $\tau_{Rk,cr}$ for cracked concrete; or

(b) $\tau_{Rk,ucr}$ for uncracked concrete.

d = diameter of metal component of fastener (excluding chemical)

h_{ef} = effective embedment depth of fastener

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

ψ_{sus} shall be taken as either of the following:

(a) 1 for $\alpha_{sus} \leq \psi^0_{sus}$

(b) $\psi^0_{sus} + 1 - \alpha_{sus}$ for $\alpha_{sus} > \psi^0_{sus}$

ψ^0_{sus} = product-dependent factor accounting for the effects of a sustained loading on the bond strength of the chemical fastener

ψ^0_{sus} shall be taken as either of the following:

(a) Value determined in accordance with Appendix A.

(b) If no value of ψ^0_{sus} has been determined from Appendix A, $\psi^0_{sus} = 0.6$

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

A chemical fastener shall only be used in applications involving a sustained tension load if it has met all the relevant requirements of Appendix A.

C6.2.5.2 *The value of ψ^0_{sus} relates to a sustained load that is present for a 50 year design life with the temperature of the concrete equal to 43°C for a minimum of 10 years. For fasteners in applications having a long-term temperature other than 43°C, a different value of ψ^0_{sus} will apply, which may be determined via testing. At temperatures lower than 43°C, the value of ψ^0_{sus} will generally be greater than 0.6.*

6.2.5.3 *Geometric effect of edge distance and spacing*

The geometric effect of edge distance and spacing shall be accounted for via the ratio $A_{p,N}/A^0_{p,N}$ where—

$A_{p,N}$ = actual bond influence area of a chemical fastener, limited by the edges of the concrete member ($c \leq c_{cr,Np}$) and overlapping areas from adjacent fasteners ($s \leq s_{cr,Np}$)

$A^0_{p,N}$ = reference bond influence area of a single chemical fastener for combined pull-out failure and concrete cone failure

$$= (s_{cr,Np})^2 \quad \text{. . . 6.2.5.3(1)}$$

$$s_{cr,Np} = 7.3d\sqrt{\tau_{Rk}\ \psi_{sus}} \leq 3h_{ef} \quad \text{. . . 6.2.5.3(2)}$$

$s_{cr,Np}$ spacing that is required for a fastener to develop its characteristic tensile strength against pull-out failure

d = diameter of metal component of fastener (excludes chemical)

τ_{Rk} = value of $\tau_{Rk,ucr}$ for $f'_c = 20$ MPa, determined in accordance with Appendix A

h_{ef} = effective embedment depth of fastener

$c_{cr,Np}$ = $s_{cr,Np}/2$ . . . 6.2.5.3(3)

ψ_{sus} = factor accounting for the effects of sustained loading on bond strength (see Clause 6.2.5.2)

NOTE: The value of $s_{cr,Np}$ calculated in Equation 6.2.5.3(2) is valid for cracked and uncracked concrete.

6.2.5.4 *Disturbance to the distribution of stresses*

The disturbance to the distribution of stress in the concrete due to an edge of the concrete member shall be calculated according to Clause 6.2.3.4 by substituting $\psi_{s,Np}$ for $\psi_{s,N}$ and $c_{cr,Np}$ for $c_{cr,N}$.

6.2.5.5 *Effect of closely spaced fasteners*

The group effect of closely spaced fasteners shall be accounted for by the parameter $\psi_{g,Np}$ as follows:

$$\psi_{g,Np} = \psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0.5} \left(\psi^0_{g,Np} - 1\right) \geq 1 \qquad \ldots 6.2.5.5(1)$$

where

$$\psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right)\left(\frac{\tau_{Rk}}{\tau_{Rk,c}}\right)^{1.5} \geq 1 \qquad \ldots 6.2.5.5(2)$$

$$\tau_{Rk,c} = \frac{k_3}{\pi d}\sqrt{h_{ef} f'_c} \qquad \ldots 6.2.5.5(3)$$

k_3 = parameter relating to the state of the concrete for combined pull-out and concrete cone failure for a chemical anchor

k_3 shall be taken as either of the following:

(a) 7.7 for cracked concrete.

(b) 11.0 for uncracked concrete.

s = spacing of fasteners, taken as the mean value in the event of unequal spacing

$s_{cr,Np}$ = characteristic spacing of fasteners in accordance with Equation 6.2.5.3(2)

6.2.5.6 *Eccentricity of loading on a fastener group*

The parameter $\psi_{ec,Np}$ accounts for a group effect when there is a difference in tension loads acting on individual fasteners in a group. $\psi_{ec,Np}$ shall be calculated in accordance with Clause 6.2.3.6 by substituting $\psi_{ec,Np}$ for $\psi_{ec,N}$ and $s_{cr,Np}$ for $s_{cr,N}$.

6.2.5.7 *Narrow concrete member*

The concrete member shall be considered to be narrow if three or more edge distances are less than the characteristic edge distance for combined pull-out and concrete cone failure ($c_{cr,Np}$) [see examples in Figure 6.2.3.8(A)]. A more precise estimation of strength shall be obtained with the modified parameters h'_{ef}, $s'_{cr,Np}$ and $c'_{cr,Np}$ where—

h'_{ef} = modified effective embedment depth of fastener, determined in accordance with Equations 6.2.3.8(1) and 6.2.3.8(2) with $s_{cr,Np}$ and $c_{cr,Np}$ substituted for $s_{cr,N}$ and $c_{cr,N}$, respectively

$s'_{cr,Np}$ = modified characteristic spacing of fasteners to ensure the transmission of the characteristic strength of the fastener, calculated in accordance with Equation 6.2.5.3(2)

$c'_{cr,Np}$ = modified characteristic edge distance of a fastener for combined pull-out and concrete cone failure determined in accordance with Equation 6.2.5.3(3)

The following conditions shall apply for a narrow member:

(a) h'_{ef} is substituted into Equation 6.2.5.3(2).

(b) The modified characteristic spacing ($s'_{cr,Np}$) and modified characteristic edge distance ($c'_{cr,Np}$) are substituted for $c_{cr,Np}$ and $s_{cr,Np}$ respectively, in Equation 6.2.3.4 for the determination of $\psi_{s,Np}$, Equation 6.2.3.6 for the determination of $\psi_{ec,Np}$, and Equation 6.2.5.5(1) for the determination of $\psi_{g,Np}$.

6.2.6 Concrete splitting failure

6.2.6.1 *Concrete splitting failure during installation*

To avoid concrete splitting failure due to installation, the following, as determined in accordance with Appendix A, shall apply:

(a) Edge distance, $c \geq c_{min}$.

(b) Spacing, $s \geq s_{min}$.

(c) Concrete member thickness, $h \geq h_{min}$.

(d) Reinforcement provided in accordance with Appendix A.

NOTE: Splitting failure during installation may, for example, be caused by an installation torque on a post-installed fasteners.

6.2.6.2 *Concrete splitting failure due to loading*

Verification of concrete splitting failure shall not be required, if condition (a) or (b) is fulfilled:

(a) The concrete member depth is $h > h_{cr,sp}$ for a given value of $c_{cr,sp}$ and both of the following conditions are met:

  (i) Edge distance for single fasteners is $c > c_{cr,sp}$ with the characteristic spacing being equal to $s_{cr,sp} = 2c_{cr,sp}$.

  (ii) Edge distance for fastener groups is $c > 1.2c_{cr,sp}$.

(b) The characteristic concrete cone failure strength and characteristic pull-out failure strength for cracked concrete are calculated and reinforcement resisting concrete splitting forces (see below) limits crack width to $w_k \leq 0.3$ mm.

NOTE: In the case of concrete splitting under load, the characteristic edge distance ($c_{cr,sp}$) corresponding to h_{min} and characteristic spacing of fasteners ($s_{cr,sp}$) are determined in accordance with Appendix A, with the characteristic spacing being equal to $s_{cr,sp} = 2c_{cr,sp}$.

Where minimum reinforcement requirements are not specified in Appendix A, the required cross-sectional area of reinforcement ($A_{s,re}$) to resist concrete splitting forces shall be calculated as follows:

$$A_{s,re} = k_4 \frac{\sum N^*}{\phi_{Ms,re} f_{sy}} \quad \ldots 6.2.6.2(1)$$

where

k_4 = parameter relating to concrete splitting failure that depends on the type of fastener

k_4 shall be taken as one of the following:

(i) 2.0 for deformation-controlled expansion fasteners.

(ii) 1.5 for torque-controlled expansion fasteners.

(iii) 1.0 for undercut fasteners.

(iv) 0.5 for chemical fasteners and anchor channel.

$\sum N^*$ = sum of the design tensile force applied to the fasteners in the fixture in tension

f_{sy} = yield strength of reinforcing steel

$\phi_{Ms,re}$ = capacity reduction factor for tensile failure of supplementary reinforcement

Where neither Item (a) nor (b) applies, the characteristic strength of a fastener or group of fasteners to splitting failure ($N_{Rk,sp}$) shall be calculated as follows:

$$N_{Rk,sp} = N^0_{Rk,sp} \frac{A_{c,N}}{A^0_{c,N}} \psi_{s,N} \psi_{re,N} \psi_{ec,N} \psi_{h,sp} \quad \ldots 6.2.6.2(2)$$

where

$N^0_{Rk,sp}$ = reference characteristic tensile strength of a single fastener to concrete splitting failure, determined in accordance with Appendix A

$A_{c,N}$ = actual projected area of the failure cone of the fastener that is limited by adjacent fasteners and edges of the concrete member (see Clause 6.2.3.3), replacing $c_{cr,N}$ and $s_{cr,N}$ with $c_{cr,sp}$ and $s_{cr,sp}$, respectively that correspond to h_{min}

$A^0_{c,N}$ = reference projected area of the failure cone of a single fastener (refer to Clause 6.2.3.3) replacing $c_{cr,N}$ and $s_{cr,N}$ with $c_{cr,sp}$ and $s_{cr,sp}$ respectively, that correspond to h_{min}

$\psi_{s,N}$ = parameter accounting for the influence on tensile strength of a fastener of the disturbance to the distribution of stresses in the concrete due to the proximity of a fastener to an edge of the concrete member given in Clause 6.2.3.4 with $c_{cr,N}$ being replaced by $c_{cr,sp}$, which corresponds to a member thickness equal to h_{min}

$\psi_{re,N}$ = parameter accounting for the shell spalling effect (refer to Clause 6.2.3.5)

$\psi_{ec,N}$ = parameter accounting for eccentricity of the resultant load in a fastener group, given in Clause 6.2.3.6, with $s_{cr,N}$ being replaced by $s_{cr,Np}$, which corresponds to a member thickness equal to h_{min}

$\psi_{h,sp}$ = parameter accounting for the influence of concrete member thickness on the splitting strength of a fastener under tensile loading

$$= \left(\frac{h}{h_{min}}\right)^{2/3} \le \max\left[1, \left(\frac{h_{ef} + 1.5c_1}{h_{min}}\right)^{2/3}\right] \le 2 \quad \ldots 6.2.6.2(3)$$

Where multiple minimum member thicknesses (h_{min}) and corresponding values for effective embedment depths (h_{ef}) are determined for a characteristic edge distance to splitting failure ($c_{cr,sp}$) in accordance with Appendix A, the value of h_{min} adopted in Equation 6.2.6.2(2) shall also be adopted in Equation 6.2.6.2(3).

Where the characteristic strength of a single fastener to concrete splitting failure ($N^0_{Rk,sp}$) is not determined in accordance with Appendix A, it shall be calculated as follows:

$$N^0_{Rk,sp} = \min\left(N_{Rk,p}, N^0_{Rk,c}\right) \quad \ldots 6.2.6.2(4)$$

where

$N_{Rk,p}$ = characteristic pull-out strength for post-installed mechanical fasteners, determined in accordance with Clause 6.2.4, or replaced by $N^0_{Rk,p}$, determined in accordance with Clause 6.2.5 for bonded anchors

$N^0_{Rk,c}$ = reference characteristic tensile strength of a fastener to concrete cone failure, determined in accordance with Clause 6.2.3.2

C6.2.6.2 *The reinforcement should be placed in a symmetrical manner and close to the fastener(s).*

6.2.7 Concrete blow-out failure

6.2.7.1 *General*

The strength against concrete blow-out failure shall be considered when $c \le 0.5h_{ef}$ for post-installed undercut fasteners. The characteristic strength for concrete blow-out failure shall be considered in each direction independently as follows:

$$N_{Rk,cb} = N^0_{Rk,cb}\left(\frac{A_{c,Nb}}{A^0_{c,Nb}}\right)\psi_{s,Nb}\,\psi_{g,Nb}\,\psi_{ec,Nb} \quad \ldots 6.2.7.1$$

where

$N^0_{Rk,cb}$ = reference characteristic tensile strength of a fastener to concrete blow-out failure (see Clause 6.2.7.2)

$A_{c,Nb}$ = actual projected area for the fastener that is limited by the edges of the concrete member ($c_2 \le 2c_1$), the presence of adjacent fasteners ($s \le 4c_1$) or the member thickness (see Clause 6.2.7.3)

$A^0_{c,Nb}$ = reference projected area of a single fastener with an edge distance equal to c_1 [see Figure 6.2.7.2(b) and Clause 6.2.7.3]

$\psi_{s,Nb}$ = parameter accounting for the disturbance of stresses in the concrete due to the close proximity of the fastener to a corner of the concrete member see (Clause 6.2.7.4)

$\psi_{g,Nb}$ = parameter accounting for a group effect, refer to Clause 6.2.7.5

$\psi_{ec,Nb}$ = parameter accounting for eccentricity of loading on a fastener group (see Clause 6.2.7.6)

Where a group of fasteners is close to an edge, blow-out failure shall be investigated for the fastener closest to the edge.

6.2.7.2 *Characteristic concrete blow-out strength of an individual fastener*

The characteristic strength to concrete blow-out failure of an individual fastener remote from the effects of adjacent fasteners and additional edges of the concrete member shall be determined as follows:

$$N^0_{Rk,cb} = k_5\, c_1 \sqrt{A_h}\, \sqrt{f'_c} \quad \ldots 6.2.7.2$$

where

k_5 = parameter related to the state of the concrete for the determination of the characteristic concrete blow-out strength of an individual fastener

k_5 shall be taken as either of the following:

(a) 8.7 for cracked concrete.

(b) 12.2 for uncracked concrete.

c_1 = edge distance of fastener in direction 1 [see example in Figure 6.2.7.3(A)(a)]

A_h = loadbearing area of the head of the fastener, determined in accordance with Appendix A

f'_c = characteristic compressive strength of concrete at 28 days

6.2.7.3 *Geometric effect of edge distance and spacing*

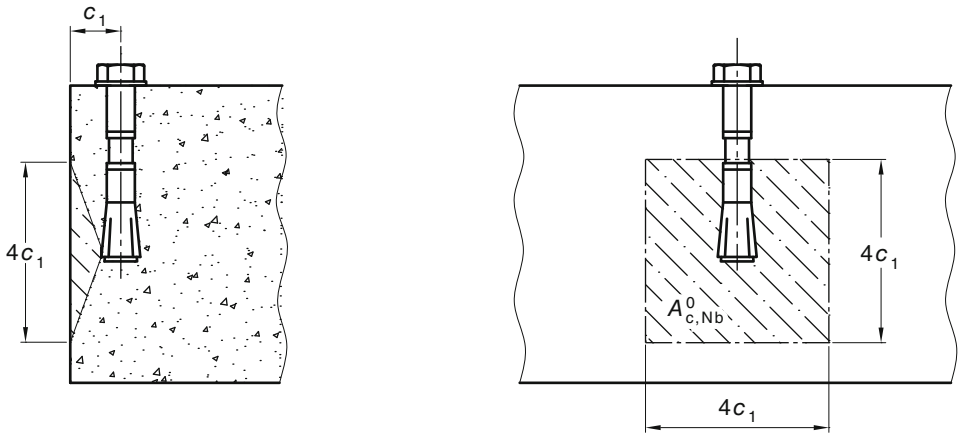
The geometric effect of edge distance and spacing shall be accounted for via the ratio $\frac{A_{c,Nb}}{A^0_{c,Nb}}$

where—

$A^0_{c,Nb}$ = reference projected area of a single fastener with an edge distance equal to c_1 [see example in Figure 6.2.7.3(A)(b)]

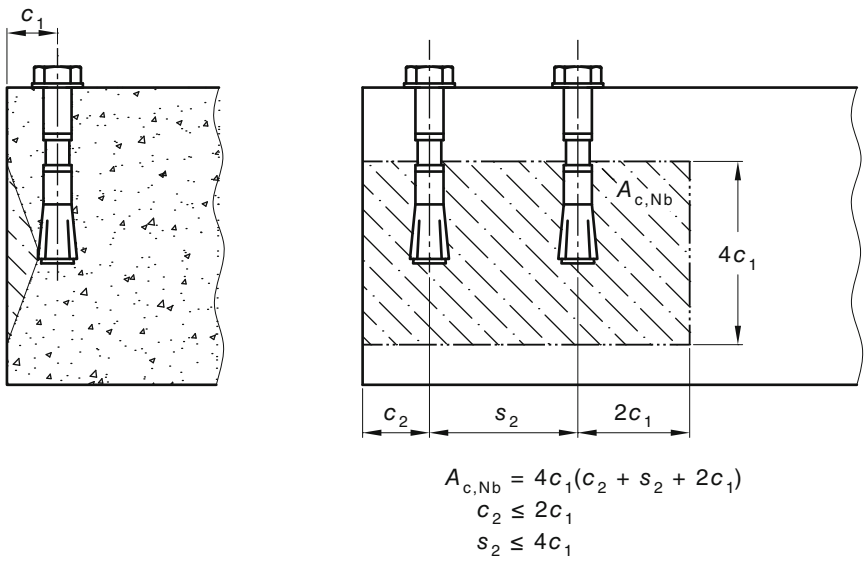
= $(4c_1)^2$

$A_{c,Nb}$ = actual projected area that is limited by the edges of the concrete member ($c_2 \leq 2c_1$) and overlapping areas of adjacent fasteners ($s \leq 4c_1$) or the thickness of the member [see examples in Figures 6.2.7.3(B) and 6.2.7.3(C)]



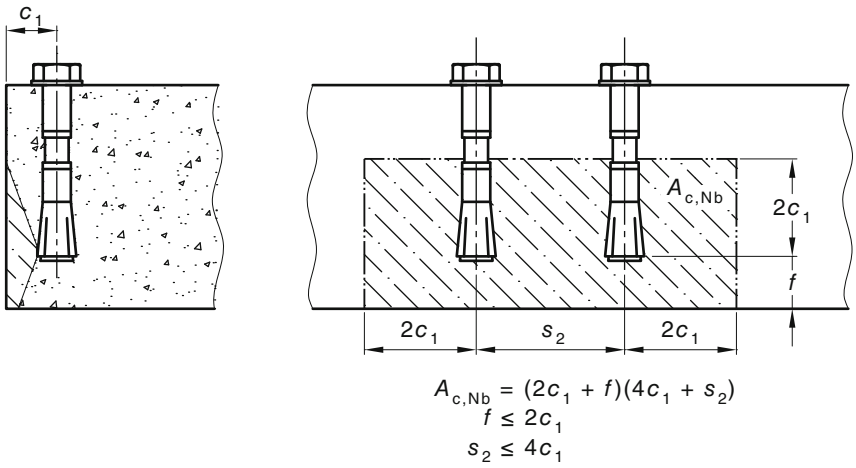
(a) Break-out body (b) Reference area of break-out body

FIGURE 6.2.7.3(A) EXAMPLES OF IDEALIZED BREAK-OUT BODY AND REFERENCE PROJECTED AREA ($A^0_{c,Nb}$) OF AN INDIVIDUAL FASTENER EXPERIENCING CONCRETE BLOW-OUT FAILURE



(a) Break-out body (b) Idealized area of break-out body

FIGURE 6.2.7.3(B) EXAMPLES OF BREAK-OUT BODY AND IDEALIZED AREA FOR MULTIPLE FASTENERS CLOSE TO AN EDGE EXPERIENCING CONCRETE BLOW-OUT FAILURE



(a) Break-out body (b) Idealized area of break-out body

FIGURE 6.2.7.3(C) EXAMPLES OF BREAK-OUT BODY AND IDEALIZED AREA FOR MULTIPLE FASTENERS WITHOUT EDGE EFFECTS

6.2.7.4 *Distribution of stresses in concrete*

The disturbance to the distribution of stresses in concrete due to the presence of an edge shall be accounted for by the parameter $\psi_{s,Nb}$ as follows:

$$\psi_{s,Nb} = 0.7 + 0.3\frac{c_2}{2c_1} \le 1 \qquad \ldots 6.2.7.4$$

where

c_1 = edge distance in direction 1 [see example in Figure 6.2.7.3(A)(a)]

c_2 = edge distance in direction 2, that is the smallest edge distance in a narrow member with multiple edge distances

6.2.7.5 *Effect of closely spaced fasteners*

The group effect of closely spaced fasteners shall be accounted for by the parameter $\psi_{g,Nb}$ as follows:

$$\psi_{g,Nb} = \sqrt{n} + \left(1 - \sqrt{n}\right)\frac{s_2}{4c_1} \geq 1 \quad \ldots 6.2.7.5$$

where

n = number of fasteners in a row parallel to the edge of the concrete member

s_2 = spacing of fasteners in direction 2

$\leq 4c_1$

c_1 = edge distance of fastener in direction 1

6.2.7.6 *Eccentricity of loading on a fastener group*

The parameter $\psi_{ec,Nb}$ accounts for a group effect when there is a difference in tension loads acting on individual fasteners in a group and shall be calculated in accordance with Clause 6.2.3.6 by substituting $\psi_{ec,Nb}$ for $\psi_{ec,N}$ and $s_{cr,Nb}$ for $s_{cr,N}$ where—

$s_{cr,Nb} = 4c_1$ . . . 6.2.7.6

spacing that is required for a fastener to develop its characteristic tensile strength against concrete blow-out failure

6.2.8 Supplementary reinforcement

Where the fastener design includes provision for supplementary reinforcement, the supplementary reinforcement shall be designed in accordance with AS 3600. The failure modes considered in the design of supplementary reinforcement shall include the following:

(a) Steel fracture of the supplementary reinforcement.

(b) Anchorage failure of the supplementary reinforcement.

6.3 CAST-IN ANCHOR CHANNEL

6.3.1 General

The verifications in Table 3.4.2.2 shall be undertaken in accordance with Clauses 6.3.2 to 6.3.7.

6.3.2 Steel failure

6.3.2.1 *General*

The following characteristic strength values, as determined from Appendix A, shall be used:

(a) Channel bolt fracture ($N_{Rk,s}$).

(b) Anchor fracture ($N_{Rk,s,a}$).

(c) Connection between anchor and channel ($N_{Rk,s,c}$).

(d) Basic value for local flexure of channel lips ($N^0_{Rk,s,l}$)

(e) Local flexure of channel lip ($N_{Rk,s,l}$).

(f) Flexure of channel ($M_{Rk,s,flex}$).

6.3.2.2 *Characteristic strength against lip failure*

The characteristic strength to channel lip failure ($N_{Rk,s,l}$) shall be calculated as follows:

$$N_{Rk,s,l} = N^0_{Rk,s,l}\,\psi_{l,N} \quad \ldots 6.3.2.2(1)$$

where

$N^0_{Rk,s,l}$ = basic characteristic strength for local channel lip failure determined in accordance with Appendix A

$$\psi_{l,N} = 0.5\left(1+\frac{s_{cbo}}{s_{l,N}}\right) \le 1 \quad \ldots 6.3.2.2(2)$$

s_{cbo} = actual spacing of channel bolts under tensile loading

$s_{l,N}$ = characteristic spacing of channel bolts under tensile loading for channel lip failure, determined in accordance with Appendix A

6.3.3 Concrete cone failure

6.3.3.1 *General*

The strength against concrete cone failure shall be determined according to one of the following conditions:

(a) If $h_{ch}/h_{ef} \le 0.4$ and $b_{ch}/h_{ef} \le 0.7$, h_{ef} shall be determined from Figure 1.3(B)(a) and the characteristic strength against concrete cone failure shall be calculated according to Equation 6.3.3.1.

(b) If $h_{ch}/h_{ef} > 0.4$ or $b_{ch}/h_{ef} > 0.7$ the characteristic strength against concrete cone failure shall be calculated according to Equation 6.3.3.1 using one of the following:

(i) $h_{ef} = h^*_{ef}$ where h^*_{ef} is determined according to Figure 1.3(B)(b).

(ii) h_{ef} is determined according to Figure 1.3(B)(a); however, the value of $s_{cr,N}$ used in Equation 6.3.2.2(2) shall be determined according to Appendix A and shall be not less than the value of $s_{cr,N}$ used in condition (a) above where $h_{ch}/h_{ef} \le 0.4$ and $b_{ch}/h_{ef} \le 0.7$, h_{ef}.

The characteristic strength of a single anchor in a channel profile to concrete cone failure shall be calculated as follows:

$$N_{Rk,c} = N^0_{Rk,c}\,\psi_{ch,s,N}\,\psi_{ch,e,N}\,\psi_{ch,c,N}\,\psi_{re,N} \quad \ldots 6.3.3.1$$

where

$N_{Rk,c}$ = characteristic strength of a single anchor in anchor channel to concrete cone failure

$N^0_{Rk,c}$ = reference characteristic tensile strength of a fastener, remote from the effects of adjacent anchors or edges of the concrete member, to concrete cone failure, calculated in accordance with Clause 6.2.3.2

A modified effective embedment depth (h'_{ef}) shall be adopted if the fastener is situated in a narrow member (see Clause 6.3.3.5)

$\psi_{ch,s,N}$ = parameter accounting for the influence of neighbouring anchors on the concrete cone strength of a single anchor in an anchor channel profile given in Clause 6.3.3.2

$\psi_{ch,e,N}$ = parameter accounting for the influence of an edge of the concrete member on the concrete cone strength, given in Clause 6.3.3.3