Australian Engineered Fasteners and Anchors Council

AEFAC STANDARD PART I

DESIGN OF POST-INSTALLED AND CAST-IN FASTENINGS TO CONCRETE

Public consultation draft
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All feedback is to be included in the *AEFAC Standard Public Comment Template* available for download at www.aefac.org.au/resources.php.

Questions and feedback are to be submitted via email to David Heath, Chair of the AEFAC Standard Development Committee, djheath@swin.edu.au.

PREFACE

This Australian Engineered Fasteners and Anchors Council (AEFAC) Standard Part 1 was prepared by the AEFAC Standard Development Committee. This document was approved on XX/XX/2015.

This Design Guideline was published on XX/XX/2015 and is available at www.aefac.org.au.

The following are represented on the AEFAC Standard Development Committee:

- Allthread Industries Pty Ltd
- Ancon Building Products
- Australian Building Codes Board
- Australian Engineered Fasteners and Anchors Council
- Australian Steel Institute
- Australian Window Association
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- Concrete Institute of Australia
- Edith Cowan University
- Engineers Australia
- Hilti (Aust.)
- Housing Industry Association Ltd
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- ITW Construction Systems
- National Precast Concrete Association Australia
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- Swinburne University of Technology
- Würth Australia Pty Ltd

This Standard has adopted the terms ‘normative’ and ‘informative’ for the appendix to which they apply. A ‘normative’ appendix is an integral part of the Standard, whereas an ‘informative’ appendix is provided for information and guidance.

CONTENTS

1 SCOPE AND GENERAL

1.1 SCOPE AND APPLICATION

1.1.1 Scope

This Standard provides the minimum requirements for the design of individual fasteners or fastener groups used to transmit loads to concrete.

The type of fasteners covered in this Standard are as follows –

a) Post-installed fasteners –
   (i) Mechanical anchors (e.g. expansion anchors, undercut anchors and concrete screws)
   (ii) Chemical anchors (e.g. bonded anchors, bonded expansion anchors)
b) Cast-in fasteners –
   (i) Headed fasteners
   (ii) Anchor channel with rigid connection (e.g. forged or welded) between the channel and anchor

1.1.2 Application

This Standard is intended to apply to the design of safety-critical fasteners to concrete structures.

The design theory for fasteners embodied in this Standard utilises the tensile strength of concrete and is closely based on the design procedure published in prEN 1992-4 "Eurocode 2: Design of concrete structures – part 4: design of fastenings for use in concrete".

This Standard relies upon design parameters and product specifications that are stated in the corresponding Report of Assessment (refer to AEFAC Standard Part 2).

Concrete members shall be composed of normal-weight concrete without fibres with further provisions provided in Clause 2.5.

Supplementary reinforcement and reinforcing steel inserts in bonded anchors shall have a ductility class type N in accordance with AS/NZS 4671.

1.1.3 Exclusions

This Standard is applicable to the design of permanent structures. It is not intended for the design of fasteners for use in applications pertaining to lifting, transport or erection of prefabricated concrete elements.

This Standard shall not be used for the design of fasteners that do not have a Report of Assessment.

This Standard does not apply to fasteners in redundant non-structural systems whereby excessive slip of failure of a fastener will result in the load being transmitted to neighbouring fasteners without violating the serviceability and ultimate limit state requirements of the fixture.

This Standard does not apply to other types of fasteners such as lifting inserts, brace inserts, ferrules, post-installed reinforcing bars, headed reinforcement or anchorage for prestressing strands.

The design provisions in this Standard for anchor channels do not apply to the following –

i) Shear in the longitudinal direction of anchor channel.
ii) Fatigue loading

This Standard does not cover the design of fixtures.

1.1.4 Loading on fasteners

The design provisions in this Standard are relevant to static, quasi-static and fatigue loading and may include tension, shear, bending or torsion moments, or a combination thereof.

A fastener shall have a nominal prequalification for static loading and shall receive explicit prequalification for fatigue loading as noted in the Report of Assessment in order to be eligible for use in fatigue applications.

The mechanism for transfer of axial compression shall be either direct bearing of the bottom plate of the fixing on the concrete, or via fasteners specifically suitable for the transfer of compression.

1.1.4.1 Exposure to fire

This Standard does not address the design of fasteners for exposure to fire. The fasteners shall be designed for exposure to fire in accordance with fire engineering principles.

1.1.4.2 Durability

This Standard does not cover design for durability.

Note: It is assumed that the fastener possesses the necessary durability performance throughout its intended service life without the need for undue maintenance.

1.1.4.3 Seismic design

This Standard does not cover design for seismic actions.

Note: Guidelines for the design of fasteners to seismic actions may be found in prEN 1992-4:2013 that is applicable to fasteners that have been prequalified for use in seismic applications in accordance with ETAG 001 Annex E.

1.2 REFERENCES

A list of normative and informative references is included in Section 11.

1.3 DEFINITIONS

1.3.1 General

For the purpose of this Standard, the definitions below apply.

1.3.2 Administrative definitions

1.3.2.1 Report of Assessment

A product appraisal that is based on rigorous testing and assessment of safety-critical fasteners which provides the design parameters and product specification necessary for use with this Standard. The Report of Assessment shall comply with the requirements of AEFAC Standard Part 2. Fasteners with a current European Technical Assessment/Approval (ETA) satisfy the requirements of the Report of Assessment.

1.3.3 Technical definitions

1.3.3.1 Anchor

A type of fastener made from steel or malleable iron to be cast into or post-installed into hardened concrete. The function of the anchor is to transmit load from a fixture to the connected concrete member.

1.3.3.2 Anchor channel

A profiled steel element with integrated anchors that is installed in position prior to the casting of concrete.

1.3.3.3 Anchor group

Two or more anchors having the same characteristics whose spacing does not exceed the anchor's characteristic spacing and act to support the same attachment.

1.3.3.4 Anchor spacing

The distance between the centre lines of two anchors.

1.3.3.5 Base material

The material in which the fastener is installed.

1.3.3.6 Blow-out failure

A mode of failure that is characterised by spalling of the side face of the concrete member that is confined to a region adjacent to the head of the fastener. This failure mode does not involve concrete break-out at the top surface of the concrete member.

1.3.3.7 Bond failure

A mode of failure for chemical anchors that is characterised by pull-out of the fastener caused by either separation at the interface of the bonding compound and the embedded steel element or between the bonding compound and the base material.

1.3.3.8 Capacity reduction factor

A factor used to multiply the nominal capacity to obtain the design capacity.

1.3.3.9 Cast-in fastener

A fastener that is installed into position prior to the casting of concrete (refer to Figure 2).

1.3.3.10 Channel bolt

A screw or bolt positioned in the steel profile of the anchor channel that is used to connect an element to the anchor channel.

1.3.3.11 Characteristic edge distance

The distance required between the free edge of a concrete member and the centreline axis of the fastener in order to develop the characteristic strength of the fastener.

1.3.3.12 Characteristic spacing

The distance required between two fasteners with the same characteristics in order for the characteristic strength of the fastener to be achieved.

1.3.3.13 Characteristic strength

The 5% fractile (value with a 95% probability of being exceeded with a confidence of 90%).

1.3.3.14 Chemical anchor

A post-installed fastener that includes a steel element (threaded rod or reinforcing bar) and a bonding compound that transmits loads from the embedded steel element into the base material.

1.3.3.15 Chemical expansion anchor

A chemical anchor with an embedded steel element with a profile specially designed such that the application of displacement on it results in follow-up expansion.

1.3.3.16 Combined pull-out and concrete cone failure

A mode of failure possible for chemical anchors that is characterised by bond failure in the lower portion of the embedded fastener and concrete cone failure in the upper portion of the embedded fastener.

1.3.3.17 Concrete cone failure

A mode of failure that is characterised by the formation of a cone or wedge of concrete surrounding a fastener or group of fasteners that become separated from the base material.

1.3.3.18 Concrete pry-out failure

A mode of failure that is characterised by the formation of a concrete spall on the opposing side of the fastener relative to the direction of shear loading.

1.3.3.19 Concrete screw

A post-installed fastener installed into a pre-drilled hole that contains threads to engage with the substrate via mechanical interlock.

1.3.3.20 Deformation-controlled expansion anchor

A post-installed fastener installed into a pre-drilled hole that requires an internal plug in the sleeve to be driven via a hammer during the setting procedure of installation, resulting in lateral expansion of the fastener. A follow-up expansion behaviour does not exist.

Note: Also known as 'drop-in' anchor or 'knock-in' anchor.

1.3.3.21 Edge distance

The distance between the free edge of the concrete member and the centreline axis of the fastener.

1.3.3.22 Effective embedment depth

The length of the fastener that is considered to effectively engage the base material. This is generally smaller than the total length of the fastener that is embedded (refer to Figure 3 and Figure 4).

1.3.3.23 Fastener

See anchor.

1.3.3.24 Fastener group

See anchor group.

1.3.3.25 Fixture

The element that is being secured to the base material via fasteners.

1.3.3.26 Headed fastener

A cast-in fastener that derives its tensile strength via mechanical interlock between its head and the base material.

1.3.3.27 Mechanical interlock

A mechanism of load transfer involving the bearing of a surface of the fastener against a surface of the base material.

1.3.3.28 Minimum edge distance

The minimum distance required between the free edge of the concrete member and the centreline axis of the fastener to facilitate adequate placing and compaction of concrete for cast-in fasteners and to avoid damage during installation of post-installed fasteners. This is product dependent and is specified in the Report of Assessment.

1.3.3.29 Minimum member thickness

The minimum thickness of the concrete member in which a fastener may be installed. This is product dependent and is specified in the Report of Assessment.

1.3.3.30 Minimum spacing

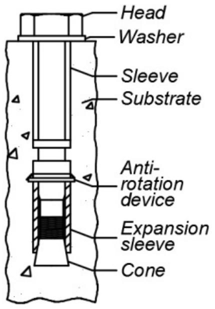
The minimum distance required between the centreline of two fasteners to facilitate adequate placing and compaction of concrete for cast-in fasteners and to avoid damage to the concrete during installation of post-installed fasteners. This is product dependent and is specified in the Report of Assessment.

1.3.3.31 Post-installed fastener

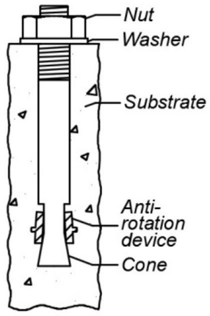
A fastener that is installed in concrete in the hardened state (refer to Figure 1).

1.3.3.32 Pull-out failure

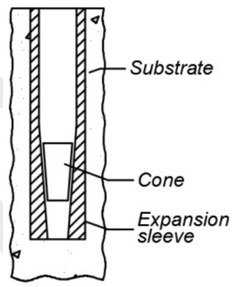
Mode of failure characterised by either the fastener pulling out of the concrete prior to the development of the full concrete strength, or by the body of the fastener pulling through the expansion sleeve prior to the development of full concrete strength.



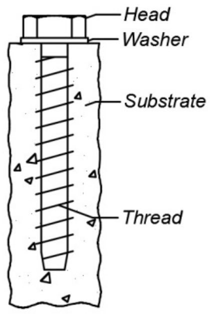
(a) TORQUE-CONTROLLED EXPANSION ANCHOR



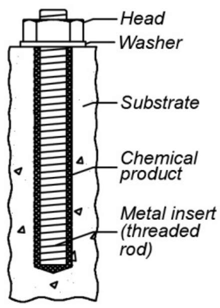
(b) STUD (EXPANSION) ANCHOR



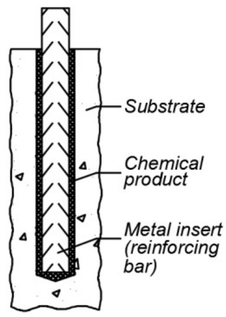
(c) DISPLACEMENT-CONTROLLED EXPANSION ANCHOR



(d) SCREW ANCHOR



(e) BONDED ANCHOR WITH THREADED ROD INSERT



(f) BONDED ANCHOR WITH REBAR INSERT

FIGURE 1: IDENTIFICATION OF COMPONENTS OF POST-INSTALLED ANCHORS.

1.3.3.33 Splitting failure

A mode of failure that is characterised by cracks in the concrete member which form in the plane of the axis of the fastener.

1.3.3.34 Safety-critical fastener

A fastener whose failure may result in collapse or partial collapse of the structure, endanger human life and/or cause considerable economic loss. The application may be structural or non-structural.

1.3.3.35 Steel failure of fastener

A mode of failure characterised by fracture of steel fastener parts.

1.3.3.36 Supplementary reinforcement

Reinforcement specifically designed to tie a concrete break-out body to the remainder of the concrete member that resists the load applied to the fastener upon splitting of the concrete.

1.3.3.37 Torque-controlled expansion anchor

A post-installed fastener installed into a pre-drilled hole that develops its tensile strength via friction between its sleeves that expand laterally against the hole wall due to a wedge being drawn up behind the sleeves. The lateral expansion occurs due to the application of torque to the fastener during installation. Follow-up expansion may occur due to the application of tensile load.

1.3.3.38 Undercut anchor

A type of post-installed fastener that derives its tensile strength via mechanical interlock between its head and an undercut region in the base material at the head of the fastener that is achieved via a special drill or by the fastener during installation.

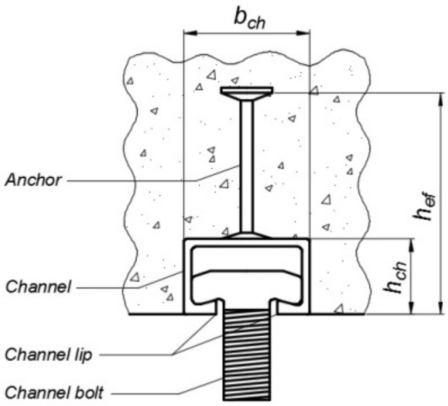
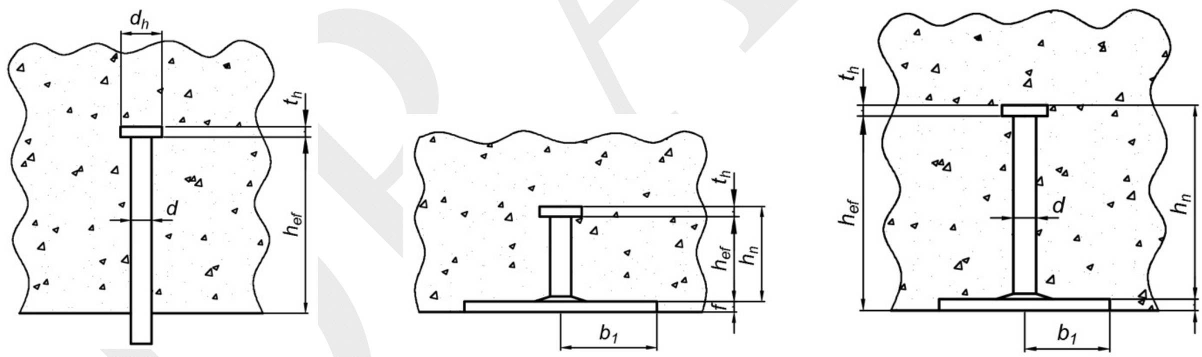


FIGURE 2: IDENTIFICATION OF COMPONENTS OF AN ANCHOR CHANNEL.



(a) HEADED FASTENER

(b) HEADED FASTENER WITH LARGE ANCHOR PLATE IN AT LEAST ONE DIRECTION, $b_1 > 0.5h_n$ or $t > 0.2h_n$

(c) HEADED FASTENER WITH SMALL ANCHOR PLATE IN BOTH DIRECTIONS SUCH THAT $b_1 \leq 0.5h_n$ AND $t \leq 0.2h_n$

FIGURE 3: IDENTIFICATION OF EFFECTIVE EMBEDMENT DEPTH, h_{ef} FOR CAST-IN HEADED FASTENERS.

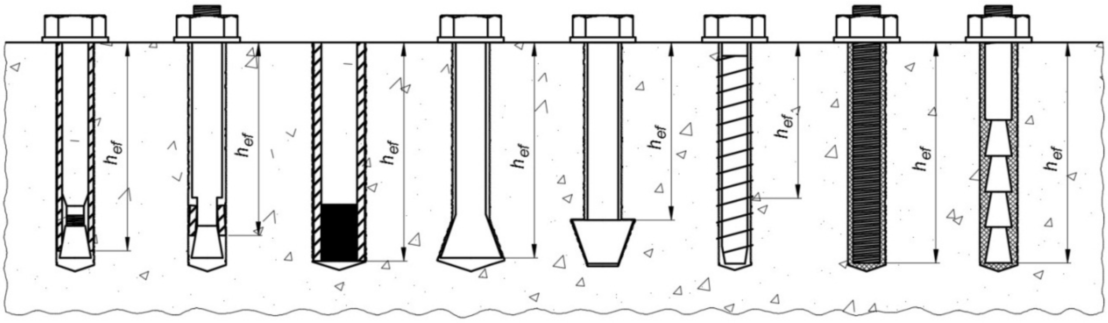


FIGURE 4: IDENTIFICATION OF EFFECTIVE EMBEDMENT DEPTH, h_{ef} FOR POST-INSTALLED MECHANICAL AND CHEMICAL ANCHORS.

1.4 NOTATION

The symbols used in this Standard are listed below.

Unless specified otherwise, nominal units for length are millimetres (mm) and nominal units for material strength are megapascals (MPa).

$A_{c,N}$	=	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
$A_{c,Nb}$	=	reference projected area of concrete cone failure of a fastener under tensile loading
$A_{c,V}$	=	actual area of idealised concrete break-out body of a fastener under shear loading
A_h	=	area of the load-bearing head of a fastener
$A_{p,N}$	=	actual bond influence area of a single chemical fastener
A_s	=	stress cross-sectional area of the fastener
$A^0_{c,N}$	=	reference projected area of the failure cone of the fastener under tensile loading
$A^0_{c,Nb}$	=	reference projected area of a single fastener for blow-out failure
$A^0_{c,V}$	=	reference projected area of the break-out body of a fastener under shear loading
$A^0_{p,N}$	=	reference bond influence area of a single chemical fastener for combined pull-out failure and concrete cone failure
a	=	spacing between the outermost fasteners of adjacent fastener groups or between the outermost fasteners and an individual fastener
a_3	=	distance between the assumed point of restraint of the fastener loaded in shear and the surface of the concrete
b_{ch}	=	width of the anchor channel
c	=	edge distance from the centreline axis of a fastener or centreline axis of anchor channel (refer to Figure 5)
$c_{cr,N}$	=	edge distance of a single fastener required to ensure the characteristic strength of the fastener is achieved when loaded in tension
$c_{cr,Np}$	=	edge distance of a single fastener required to ensure the characteristic strength of the fastener is achieved for a bonded fastener under tensile loading

$c_{cr,sp}$	=	characteristic edge distance in the case of splitting under load
$c_{cr,V}$	=	edge distance of a single fastener required to ensure the characteristic strength of the fastener is achieved when loaded in shear
c_{max}	=	maximum edge distance to the fastener
c_{min}	=	minimum edge distance to the fastener
c_1	=	edge distance in direction 1
c_2	=	edge distance in direction 2
$c_{2,max}$	=	largest of two edge distances parallel to the direction of loading
$c'_{cr,Np}$	=	modified characteristic edge distance of a chemical fastener for combined pull-out and concrete cone failure
d	=	diameter of fastener bolt or thread diameter, or diameter of the stud or shank of a headed stud
d_a	=	diameter of an anchor in an anchor channel
d_b	=	nominal diameter of a reinforcing bar
d_f	=	diameter of the clearance hole in the fixture
d_h	=	diameter of the head of the fastener
d_{nom}	=	outside diameter of the fastener
E_s	=	modulus of elasticity of steel
e	=	eccentricity of applied load
e_N	=	eccentricity of the resultant tension force acting on a group of fasteners relative to the centre of gravity of the fasteners loaded in tension
e_s	=	distance between the centreline of supplementary reinforcement and the line of action of the design shear force
e_V	=	eccentricity of the resultant shear force acting on a group of fasteners relative to the centre of gravity of the fasteners loaded in shear
F_{Rk}	=	characteristic strength of fastener
F^0_{Rk}	=	single value representing the basic characteristic strength of a fastener designed according to Method B
f	=	distance between the head of the fastener and the upper or lower surface of the concrete member
f_{sy}	=	characteristic yield strength of reinforcement (referred to as R_e in AS/NZS 4671)
f_{yf}	=	yield tensile strength of fastener
f_{uf}	=	ultimate tensile strength of fastener
f'_c	=	characteristic compressive strength of concrete measured via cylinder tests at 28 days
f'_{ct}	=	characteristic uniaxial flexural tensile strength of concrete

h	=	concrete member depth in which the fastener is installed
h_{ch}	=	height of anchor channel
$h_{cr,V}$	=	characteristic member thickness for a fastener loaded in shear
h_{ef}	=	effective embedment depth of a fastener
h_{min}	=	minimum concrete member depth (published in the Report of Assessment)
h_n	=	total embedment depth of headed fastener beneath anchor plate to which it is welded
h'_{ef}	=	modified effective embedment depth
I_y	=	moment of inertia of channel relative to the y-axis of the channel
$k_{cr,N}$	=	parameter relating to cracked concrete loaded in tension
$k_{ucr,N}$	=	parameter relating to uncracked concrete loaded in tension
k	=	parameter
$k_{cr,V}$	=	parameter related to cracked concrete loaded in shear
$k_{ucr,V}$	=	parameter for uncracked concrete loaded in shear
L_{st}	=	development length of a bar for a tensile stress less than the yield stress
l_a	=	length of lever arm of fastener loaded in shear
l_f	=	parameter related to the length of the fastener
$M_{Rk,s}$	=	characteristic flexural strength
$M_{Rk,s,flex}$	=	characteristic flexural strength of an anchor channel
$M^0_{Rk,s}$	=	reference characteristic flexural strength of a fastener
M^*	=	design bending moment
M_{ch}^*	=	design bending moment experienced by anchor channel due to the application of design tensile load, N_{ch}^*
n	=	number of fasteners in a group
N_{fat}	=	fatigue tensile load acting on the fastener
N^h_{fat}	=	fatigue tensile load acting on the most loaded fastener in a group
N^g_{fat}	=	resultant fatigue tensile load acting on a fastener group
N_i	=	tension force applied to a fastener that influences the performance of the fastener under consideration
N_o	=	tension force in the fastener under consideration
$N_{Rk,c}$	=	characteristic tensile strength of a fastener to concrete cone failure
$N_{Rk,cb}$	=	characteristic tensile strength of a fastener to blow-out failure
$N_{Rk,i}$	=	characteristic tensile strength of a fastener or group to failure mode '*i*'
$N_{Rk,p}$	=	characteristic tensile strength of a fastener to pull-out failure

$N_{Rk,s}$ = characteristic tensile strength of a fastener to steel failure

$N_{Rk,sp}$ = characteristic tensile strength of a fastener to splitting failure

$N_{Rk,s,a}$ = characteristic tensile strength of a fastener in anchor channel against steel fracture

$N_{Rk,s,c}$ = characteristic tensile strength of a fastener in anchor channel against failure of the connection between the anchor and channel

$N_{Rk,i}$ = characteristic tensile strength of a fastener to failure mode 'i'

$N_{Rk,s,l}$ = characteristic tensile strength of a fastener in anchor channel against local failure by flexure of the channel lips

N^0_{Rk} = reference characteristic tensile strength of a fastener

$N^0_{Rk,c}$ = reference characteristic tensile strength of a fastener to concrete cone failure

$N^0_{Rk,cb}$ = reference characteristic tensile strength of a fastener to blow-out failure

$N^0_{Rk,p}$ = reference characteristic tensile strength of a fastener to pull-out failure

$N^0_{Rk,sp}$ = reference characteristic tensile strength of a fastener to splitting failure

N^* = design tensile load applied to a fastener or group of fasteners

N_a^* = design tensile load acting on an individual anchor in the anchor channel

N_c^* = design compressive force

N_{cb}^* = design tensile load acting on one channel bolt in the anchor channel

N_{ch}^* = design tensile load applied to anchor channel

N_h^* = design tensile load acting on a fastener group

$N_{h,re}^*$ = design tensile force resisted by supplementary reinforcement

N_{re}^* = design tensile force in the supplementary reinforcement

n = number of fasteners

n_{ch} = number of fasteners in an anchor channel within a distance equal to the characteristic spacing of the fastener under consideration

R_u = nominal capacity of the fastener

S^* = design action effect resulting from the ultimate limit state design loads

s = distance (spacing) between two fasteners (refer to Figure 5)

s_{cbo} = actual spacing of anchor channel bolts

s_{crit} = critical spacing under shear loading caused by a torsion moment applied to a fixture secured by the fasteners

$s_{cr,N}$ = spacing that is required for a fastener to develop its characteristic tensile strength

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

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

$s_{cr,V}$	=	spacing that is required for a fastener to develop its characteristic shear strength against concrete edge failure
s_i	=	distance between fastener under consideration and neighbouring fastener
$s_{l,v}$	=	characteristic spacing of anchors for channel lip failure under shear loading
s_{max}	=	maximum centre-to-centre spacing of fasteners
s_{min}	=	minimum centre-to-centre spacing of fasteners
$s'_{cr,Np}$	=	modified spacing that is required for a fastener to develop its characteristic tensile strength against pull-out failure
T^*	=	design torque applied to fixture
t	=	thickness of anchor plate
t_{fix}	=	thickness of fixture in contact with the fastener
t_{grout}	=	thickness of a layer of grout
t_h	=	thickness of the head of a headed fastener
V_{fat}	=	fatigue shear load acting on the fastener
V^h_{fat}	=	fatigue shear load acting on the most loaded fastener in a group
V^g_{fat}	=	resultant fatigue shear load acting on a fastener group
V_i	=	shear force applied to a fastener that influences the performance of the fastener under consideration
V_o	=	shear force in the fastener under consideration
$V_{Rk,c}$	=	characteristic shear strength of a fastener to concrete edge failure
$V_{Rk,cp}$	=	characteristic shear strength of a fastener to pry-out failure
$V_{Rk,i}$	=	characteristic shear strength of a fastener to failure mode '*i*'
$V_{Rk,s}$	=	characteristic shear strength of a fastener to steel failure
$V_{Rk,s,a}$	=	characteristic shear strength of anchor against steel fracture
$V_{Rk,s,c}$	=	characteristic shear strength of anchor channel against failure of the connection between anchor and channel
$V_{Rk,s,l}$	=	characteristic shear strength of anchor channel to flexural failure of channel lip
$V_{Rk,s,M}$	=	characteristic shear strength of a fastener to steel failure when a grout layer of limited thickness is present
V_u	=	shear capacity of concrete element determined in accordance with AS 3600
$V^0_{Rk,c}$	=	reference characteristic shear strength of a fastener to concrete edge failure
$V^0_{Rk,s}$	=	reference characteristic shear strength of a fastener to steel failure
$V^0_{Rk,s,m}$	=	reference characteristic shear strength of a fastener accounting for ductility

V^*	=	design shear load applied to a fastener or group of fasteners
V_a^*	=	design shear load acting on one anchor in anchor channel
V_{cb}^*	=	design shear load acting on one channel bolt in the anchor channel
V_h^*	=	design shear load acting on the most loaded fastener in a group
V_g^*	=	design shear load acting on a fastener group
w_k	=	width of concrete crack
z	=	internal lever arm
α	=	parameter
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
α_M	=	parameter accounting for the degree of restraint of a lever arm
α_V	=	angle between the applied load and the direction perpendicular to the free edge under consideration
β	=	parameter
$\beta_{N,fat}$	=	parameter representing the ratio of design fatigue action to design fatigue strength for tensile loading
$\beta_{V,fat}$	=	parameter representing the ratio of design fatigue action to design fatigue strength for shear loading
χ_{ind}	=	load factor for indirect actions
$\chi_{F,fat}$	=	load factor for fatigue loading
δ_d	=	permissible displacement of fastener for serviceability limit state
ϕ	=	capacity reduction factor
ϕ_c	=	capacity reduction factor for concrete
ϕ_i	=	capacity reduction factor for strength of fastener or fastener group for failure mode 'i'
ϕ_{inst}	=	capacity reduction factor for installation
ϕ_{Mc}	=	capacity reduction factor for concrete break-out failure, edge break-out failure, blow-out failure and pry-out failure
ϕ_{Mcb}	=	capacity reduction factor for concrete blow-out failure
$\phi_{Mc,fat}$	=	capacity reduction factor for a concrete mode of failure under fatigue loading
ϕ_{Mp}	=	capacity reduction factor for pull-out failure
$\phi_{M,fat}$	=	capacity reduction factor for a material under fatigue loading
$\phi_{Mc,fat}$	=	capacity reduction factor for a concrete mode of failure
$\phi_{Mp,fat}$	=	capacity reduction factor for a pull-out mode of failure
ϕ_{Ms}	=	capacity reduction factor for steel failure

ϕ_{Msp} = capacity reduction factor for concrete splitting failure

$\phi_{Ms,ca}$ = capacity reduction factor for the connection between anchor and channel in tension and shear

$\phi_{Ms,fat}$ = capacity reduction factor for steel failure mode under fatigue loading

$\phi_{Ms,flex}$ = capacity reduction factor for steel failure of anchor channel in flexure

$\phi_{Msp,fat}$ = capacity reduction factor for a splitting mode of failure under fatigue loading

$\phi_{Ms,l}$ = capacity reduction factor for local failure of anchor channel by bending of lips in tension and shear

$\phi_{Ms,N,fat}$ = capacity reduction factor for steel failure under tensile loading

$\phi_{Ms,V,fat}$ = capacity reduction factor for steel failure under shear loading

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

$\phi_{s.l}$ = capacity reduction factor for steel failure of anchor channel

$\psi_{ch,c,N}$ = parameter accounting for the influence of a corner on the tensile strength of a fastener to concrete cone failure

$\psi_{ch,c,Nb}$ = parameter accounting for the influence of a corner on the tensile strength of a fastener to blow-out failure

$\psi_{ch,c,V}$ = parameter accounting for the influence of a corner on the shear strength of a fastener to concrete edge failure

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

$\psi_{ch,h,Nb}$ = parameter accounting for the influence of thickness of the concrete member on the tensile strength of the fastener to blow-out failure

$\psi_{ch,h,V}$ = parameter accounting for the influence of member thickness on the shear strength of the fastener to concrete edge failure

$\psi_{ch,s,N}$ = parameter accounting for the influence of neighbouring fasteners on the tensile strength of the fastener

$\psi_{ch,s,Nb}$ = parameter accounting for the influence of neighbouring fasteners on the characteristic tensile strength of the fastener to blow-out failure

$\psi_{ch,s,V}$ = parameter accounting for the disturbance to the distribution of stresses in the concrete on the shear strength of the fastener

$\psi_{ch,90^o,V}$ = parameter accounting for the influence of shear loads acting parallel to the free edge of the concrete member

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

$\psi_{ec,Nb}$ = parameter accounting for the influence of eccentricity of loading on the blow-out strength of a fastener group

$\psi_{ec,Np}$ = Parameter accounting for eccentricity of loading on a fastener group for pull-out failure

$\psi_{ec,V}$	=	parameter accounting for the influence on shear strength of the eccentricity of the resultant load acting on a fastener group
$\psi_{F,N}$	=	reduction factor applied to the tensile strength to account for the uneven distribution of the loads, provided in the Report of Assessment
$\psi_{F,V}$	=	reduction factor applied to the shear strength to account for the uneven distribution of loads, provided in the Report of Assessment
$\psi_{g,Nb}$	=	parameter accounting for the influence of a group effect on the tensile strength of a fastener to blow-out failure
$\psi_{g,Np}$	=	parameter accounting for the influence of a group effect on the tensile strength of a fastener to pull-out failure
$\psi_{h,sp}$	=	parameter accounting for the influence of concrete member thickness on the splitting strength of a fastener under tensile loading
$\psi_{h,V}$	=	parameter accounting for the influence of concrete member thickness on the shear strength of a fastener
$\psi_{M,N}$	=	parameter accounting for the influence of a compression force between the fixture and concrete on the tensile strength of a fastener
$\psi_{re,N}$	=	parameter accounting for the shell spalling effect
$\psi_{re,V}$	=	parameter accounting for the shell spalling effect
ψ_{sus}	=	factor accounting for the effects of sustained loading on bond strength
$\psi_{s,N}$	=	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
$\psi_{s,Nb}$	=	parameter accounting for the influence on shear strength of a fastener to blow-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
$\psi_{s,Np}$	=	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
$\psi_{s,V}$	=	parameter accounting for the influence on shear 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
$\psi^0_{g,Np}$	=	parameter accounting for the influence of a group effect on the tensile strength of a fastener to pull-out failure
ψ^0_{sus}	=	product dependent factor accounting for the effects of sustained loading on bond strength taken from the Report of Assessment
$\psi_{\alpha,V}$	=	parameter accounting for the influence of the angle of the applied load on the shear strength of a fastener
σ_L	=	stresses experienced in the concrete due to external loads including those applied to the

fastener

σ_{st} = tensile stress in reinforcement

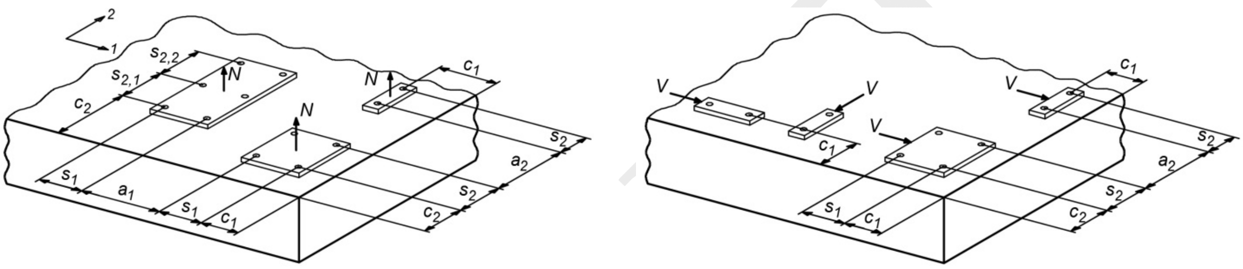
σ_R = stresses induced in the concrete due to the restraint of intrinsic loads plus stresses due to extrinsic imposed deformation

τ_{Rk} = characteristic bond strength

$\tau_{Rk,c}$ = characteristic bond strength for assessing the spacing of chemical fasteners

$\tau_{Rk,cr}$ = characteristic bond strength for cracked concrete

$\tau_{Rk,ucr}$ = characteristic bond strength uncracked concrete



(A) APPLICATION OF TENSILE LOAD TO FASTENINGS

(B) APPLICATION OF SHEAR LOAD TO FASTENINGS.

FIGURE 5: DEFINITION OF SPACING AND EDGE DISTANCE FOR FIXTURES CONTAINING FASTENINGS TO CONCRETE.

2 MATERIALS AND INSTALLATION

2.1 GENERAL

2.2 TYPES OF FASTENERS AND FASTENING GROUPS

This Standard is applicable to the design of individual fasteners and fastener groups. All fasteners in a group shall be of the same type, size and depth. The transfer of load to fasteners in a group occurs via the fixture.

Design parameters such as material strength and product dimensions, and suitable applications for the fastener are given in the Report of Assessment.

This Standard is limited to the configuration of fasteners shown in Figure 6 with the following conditions:

i) Without hole clearance, all edge distances, all load directions
ii) With limited hole clearance, no edge effects ($c_i \geq \max(10h_{ef}, 60d_{nom})$), all load directions
iii) With limited hole clearance, close to an edge ($c_i < \max(10h_{ef}, 60d_{nom})$), tension-only loads

In addition to the configurations listed above, this Standard also covers configurations illustrated in Figure 7 that have limited hole clearance, are close to an edge ($c_i < \max(10h_{ef}, 60d_{nom})$), and include loading in all directions.

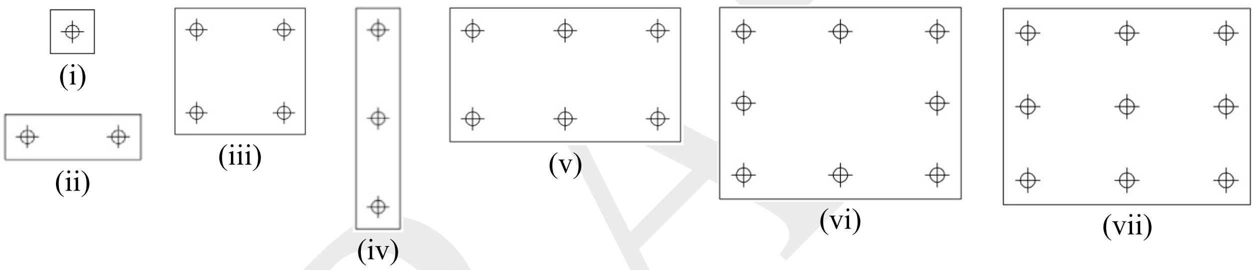


FIGURE 6: CONFIGURATIONS OF FASTENINGS REMOTE FROM EDGES.

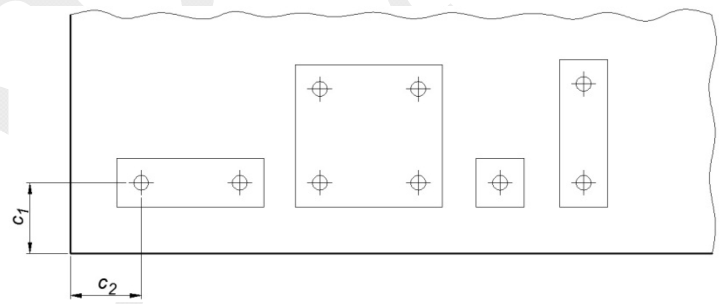


FIGURE 7: CONFIGURATIONS OF FASTENINGS CLOSE TO AN EDGE.

2.3 DIMENSIONS OF FASTENERS

This Standard is limited to design provisions for fasteners with a minimum diameter or minimum thread size equal to 6 mm (M6) or a corresponding cross-section. The effective embedment depth of a fastener, h_{ef} shall be taken from the Report of Assessment and shall in general, have a minimum value of $h_{ef} \geq 40$ mm. The effective embedment depth of chemical fasteners shall be limited to $h_{ef} \leq 20d_{nom}$.

2.4 FASTENER MATERIALS

This Standard is limited to design provisions for fasteners that have a tensile strength limited to $f_u \leq 1000$ MPa, with the exception of concrete screws which do not have a limit.

Metal fasteners covered in this Standard include the following:

i) Carbon steel (ISO 898, AS/NZS 4291.1, AS/NZS 4671)
ii) Stainless steel (ISO 4506, AS/NZS 4671)
iii) Malleable cast iron (ISO 5922).

2.5 CONCRETE

Concrete members shall exhibit a characteristic compressive strength at 28 days (f'_c) in the range of 12 MPa to 90 MPa, with either the strength grade determined in accordance with AS 1379, or the compressive strength determined statistically from compressive strength tests in accordance with AS 1012.9. The strength grade(s) of concrete that a fastener may be used in shall be taken from the Report of Assessment.

The characteristic compressive strength (f'_c) for design purposes shall not exceed 60 MPa.

The range of concrete strength design parameters for a given fastener design shall be provided in the corresponding Report of Assessment.

The density of normal-weight concrete shall be taken as 2400 kg/m^3.

2.6 REINFORCEMENT

Where the fastening design includes supplementary reinforcement to resist loads, the reinforcement steel shall comply with the requirements of AS/NZS 4671.

2.7 INSTALLATION

The performance of fasteners is significantly influenced by the quality of installation. Appendix A provides a list of assumptions related to the design and execution of fasteners that should be followed to ensure that the fastener performs as intended.

This Standard does not cover gross errors such as incorrect diameter drill bit, incorrect drilling system, incorrect setting tools, no hole cleaning, incorrect technique for fastener placement and poor alignment.

3 GENERAL DESIGN REQUIREMENTS

3.1 GENERAL

Safety-critical post-installed and cast-in fasteners for use in concrete shall be designed for ultimate limit state and serviceability limit state in accordance with the requirements of AS/NZS 1170.0 and the requirements of Sections 6, 7 and 8 (strength requirements) and Section 9 (serviceability requirements).

An alternative simplified design procedure for post-installed fasteners in Appendix B may be used instead of the provisions of Clauses 6.2 (tensile strength), 7.2 (shear strength), 8.1.1 and 8.2.1 (strength against combined tension and shear loading) that account for all loading directions and modes of failure.

Fasteners to be designed for fatigue loading shall comply with the requirements of this Standard and shall have prequalification for fatigue in the Report of Assessment.

The provisions of Appendix C shall be followed to ensure the safe transmission of loads from the fastener to the concrete member.

This Standard assumes minimum standards for the installation of fasteners and for the welding design of headed fasteners that should be followed. These provisions are included in Appendix A.

3.2 VERIFICATIONS FOR DESIGN

3.2.1 Strength limit state

The fastener shall be designed for the ultimate limit state to ensure that the design action effect (S^*) does not exceed the design capacity (ϕR_u) as follows –

$$S^* \leq \phi R_u \tag{1}$$

where

S^* = design action effect resulting from the ultimate limit state design loads determined in accordance with the requirements of AS/NZS 1170 and Section 4

ϕ = capacity reduction factor that shall not exceed a value included in Table 1.

R_u = nominal capacity of the fastener determined from Sections 6 to 8

3.2.2 Serviceability limit state

Design for the serviceability limit state shall limit deflections in accordance with Section 9 using information provided in the Report of Assessment.

Cracking in concrete shall be considered for applications involving supplementary reinforcement or an embedded base plate close to an edge.

3.2.3 Load factors

For the verification of indirect actions, a load factor of χ_{ind} = 1.2 for concrete failure and χ_{ind} = 1.0 for all other modes of failure shall be applied.

For the verification of fatigue actions, a load factor of χ_{fat} = 1.0 shall be applied for all modes of failure.

3.2.4 Capacity reduction factors

The capacity reduction factor for concrete including fastener sensitivity to installation, ϕ_{Mc} is product dependent (refer to Table 1).

The capacity reduction factors for strength relating to static loading vary according to mode of failure and are found in Table 1.

The capacity reduction factor for the serviceability limit state, ϕ_M shall be taken as 1.0.

The capacity reduction factors for fatigue loading are included in Table 1.

3.3 CONCRETE CONDITION

The designer shall determine whether the concrete in the vicinity of the fastener is cracked or non-cracked. A non-cracked condition is such that no cracking of the concrete occurs along the entire embedment length of the fastener under the characteristic combination of loading at the serviceability limit state condition.

Note: It is conservative to assume that the concrete is cracked and the selection of a non-cracked condition should be justified by the designer via stress analysis.

A non-cracked condition is satisfied as follows –

$$\sigma_L + \sigma_R \leq f'_{ct} \qquad (2)$$

where

σ_L = stresses experienced in the concrete due to external loads including those applied to the fastener, calculated assuming a non-cracked condition.

σ_R = stresses induced in the concrete due to the restraint of intrinsic loads (e.g. shrinkage) plus stresses due to extrinsic imposed deformation (e.g. temperature variation, movement of concrete support), calculated assuming a non-cracked condition. In the absence of a detailed analysis, σ_R = 3 MPa may be assumed.

f'_{ct} = characteristic uniaxial flexural tensile strength of concrete calculated according to AS 3600, recommended to be taken as $f'_{ct} = 0$.

For concrete members that transmit loads in two directions the above verification shall be performed for both directions.

Note: The project specification should typically include the following information –
The strength grade of concrete adopted for design.
Condition of the concrete, determined in accordance with Clause 3.3.
Notification that the type, number, geometry and manufacturer of the fasteners should not be changed without the written consent of the responsible engineer.
Notification that the fasteners shall be installed to the specified embedment depth.
Construction drawings or supplementary design drawings including the following details –
Type and number of fasteners
Location of fasteners, including tolerances
Edge distance and spacing of fasteners, including tolerances (normally only positive)
Details of fixture including thickness and hole diameter (if applicable)
Position of the attachment on the fixture, including tolerances
Maximum thickness of mortar/grout between concrete and underside of fixture (if applicable)
Special installation instructions (if applicable) that complement the manufacturer's installation instructions.
Reference to the manufacturer's installation instructions.
A note on site testing may be included for proof loading to verify correct installation.

3.4 REPORT OF ASSESSMENT

This Standard shall be used in combination with products that have a Report of Assessment that provides the design parameters of the fastener relating to its intended use. Full details of the Report of Assessment are included in AEFAC Standard Part 2.

A product with a current European Technical Assessment/Approval (ETA) satisfies the requirements of the Report of Assessment.

3.5 VERIFICATION OF FASTENER STRENGTH

The ultimate strength of the fastener shall be verified in accordance with Equation (1) by considering modes of failure under tensile loading (refer to Clause 3.5.1), modes of failure under shear loading (refer to Clause 3.5.2) and combined tension and shear loading (refer to Clause 3.5.3).

3.5.1 Tensile strength of fastener

3.5.1.1 Post-installed and cast-in headed fasteners

The design of post-installed fasteners and cast-in headed fasteners subjected to tensile loading shall be performed in accordance with the verifications listed in Table 2. The mode of failure producing the lowest design strength shall be decisive. Illustrations of each failure mode are provided in Figure 8.

TABLE 1: CAPACITY REDUCTION FACTORS FOR MODES OF FAILURE OF POST-INSTALLED AND CAST-IN FASTENERS.

Mode of failure	**Capacity reduction factor**		
Steel failure – fasteners			
Tension	ϕ_{Ms}	=	$5 f_{yf} / (6 f_{uf}) \leq 1/1.4$
Shear – with and without lever arm		=	$f_{yf} / f_{uf} \leq 0.8$ when $f_{uf} \leq 800$ MPa and $f_{yf}/f_{yf} \leq 0.8$
		=	2/3 when $f_{uf} > 800$ MPa or $f_{yf}/f_{uf} > 0.8$
Steel failure – anchor channels			
Tension – anchors and channel bolts	ϕ_{Ms}	=	$5 f_{yf} / (6 f_{uf}) \leq 1/1.4$
Shear – with and without lever arm		=	$f_{yf} / f_{uf} \leq 0.8$ when $f_{uf} \leq 800$ MPa and $f_{yf}/f_{yf} \leq 0.8$
		=	2/3 when $f_{uf} > 800$ MPa or $f_{yf}/f_{uf} > 0.8$
Connection between anchor and channel in tension and shear	$\phi_{Ms,ca}$	=	$1/1.8$
Local failure of channel lips by bending under tension and shear	$\phi_{Ms,l}$	=	$1/1.8$
Flexural failure of anchor channel	$\phi_{Ms,flex}$	=	$1/1.15$
Steel failure – supplementary reinforcement			
Tension	$\phi_{Ms,re}$	=	0.8
Concrete failure – tension			
Concrete cone failure, concrete edge failure, blow-out failure, pry-out failure	ϕ_{Mc}	=	$\phi_c \phi_{inst}$
	ϕ_c	=	1/1.5 in general
	ϕ_{inst}	=	1.0 for headed fasteners and anchor channel in tension and shear that have been installed in accordance with Appendix A
		$\leq$	1.0 for post-installed fasteners in tension, as per Report of Assessment
		=	1.0 for post-installed fasteners in shear
Splitting failure	ϕ_{Msp}	=	ϕ_{Mc}
Pull-out failure			
Pull-out failure, combined pull-out and concrete cone failure	ϕ_{Mp}	=	ϕ_{Mc}
Fatigue loading			
Fatigue loading	$\phi_{Ms,fat}$	=	1/.35 for steel failure
	$\phi_{Mc,fat} = \phi_{Msp,fat} = \phi_{Mp,fat} = \phi_{inst}$ /1.5 (concrete cone failure, splitting failure and pull-out failure)		

Note: The value for the capacity reduction factor is generally a fraction since the values are derived from partial safety factors from prEN 1992-4 and the accuracy has been maintained to avoid rounding errors.

TABLE 2: VERIFICATIONS REQUIRED FOR HEADED AND POST-INSTALLED FASTENERS LOADED IN TENSION.

Mode of failure	**Reference**		**Single fastener**	**Fastener group**	
	Figure	**Clause**		**Most loaded fastener**	**Fastener group**
Steel failure of fastener	Figure 8(a)	6.2.1	$N^* \leq \phi_{Ms} N_{Rk,s}$	$N_h^* \leq \phi_{Ms} N_{Rk,s}$	
Concrete cone failure	Figure 8(b)	6.2.2	$N^* \leq \phi_{Mc} N_{Rk,c}$		$N_g^* \leq \phi_{Mc} N_{Rk,c}$
Pull-out failure of fastener[a]	Figure 8(c)	6.2.3	$N^* \leq \phi_{Mp} N_{Rk,p}$	$N_h^* \leq \phi_{Mp} N_{Rk,p}$	
Combined pull-out and concrete cone[b]	Figure 8(d)	6.2.4	$N^* \leq \phi_{Mp} N_{Rk,p}$		$N_g^* \leq \phi_{Mp} N_{Rk,p}$
Splitting failure	Figure 8(e)	6.2.5	$N^* \leq \phi_{Msp} N_{Rk,sp}$		$N_g^* \leq \phi_{Msp} N_{Rk,sp}$
Blow-out failure[c]	Figure 8(f)	6.2.6	$N^* \leq \phi_{Mcb} N_{Rk,cb}$		$N_g^* \leq \phi_{Mcb} N_{Rk,cb}$
Steel failure of reinforcement	Figure 8(g)	6.2.7	Design according to AS 3600		
Anchorage failure of reinforcement	Figure 8(h)	6.2.7	Design according to AS 3600		

[a] Not required for post-installed chemical fasteners
[b] Not required for headed and post-installed mechanical fasteners
[c] Exception see Clause 6.2.6.1.

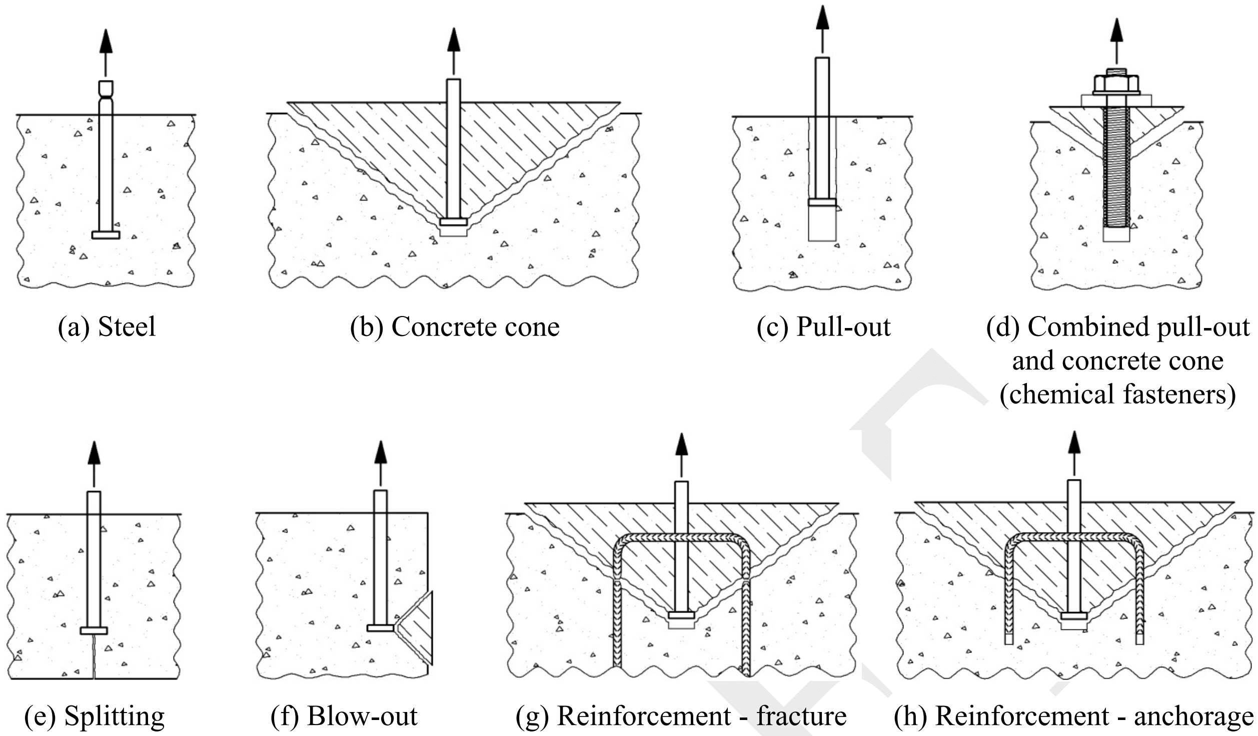


FIGURE 8: MODES OF FAILURE FOR POST-INSTALLED AND CAST-IN FASTENERS SUBJECTED TO TENSILE LOADING.

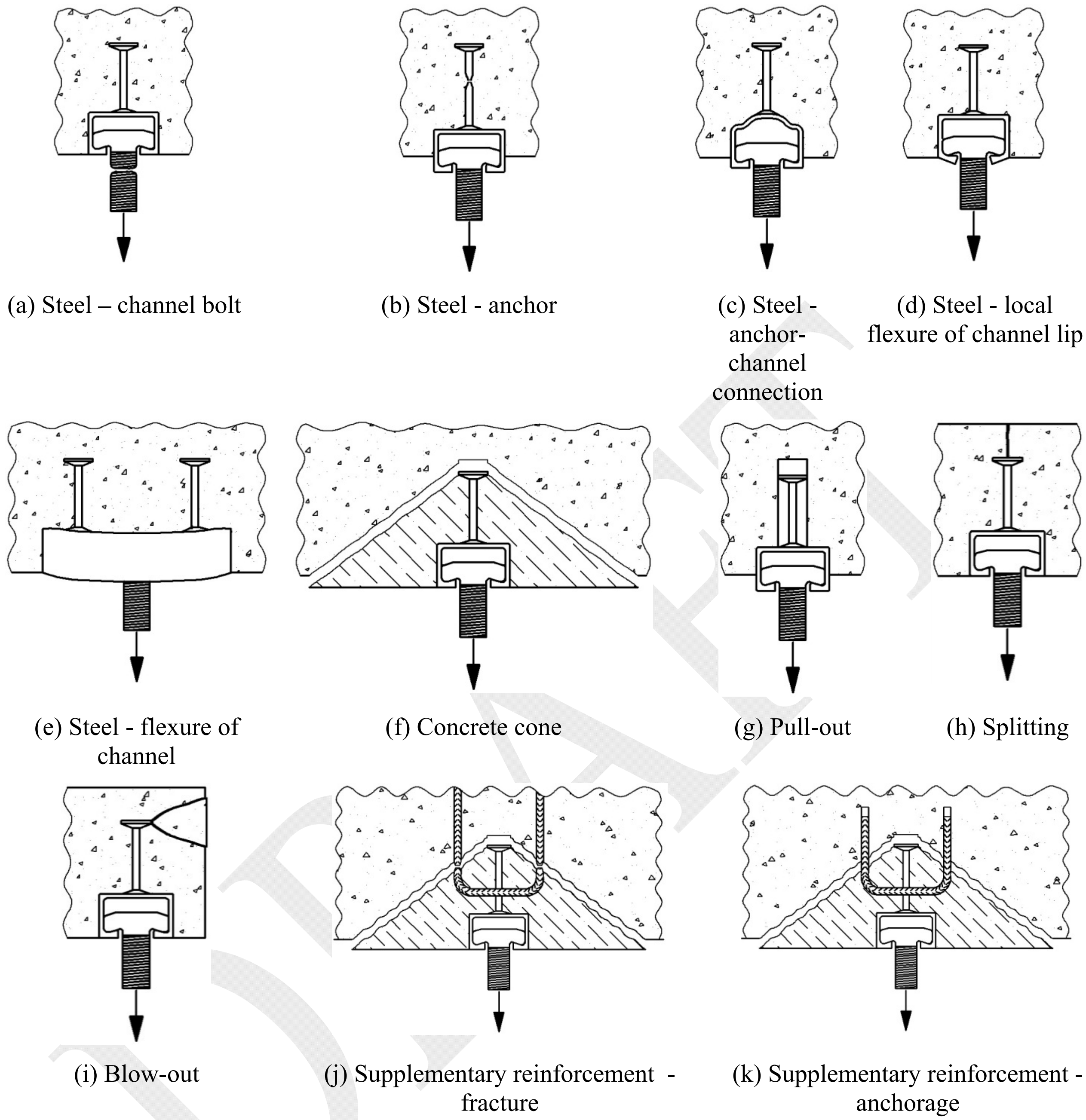
3.5.1.2 Cast-in anchor channel

The design of anchor channel subjected to tensile loading shall be performed in accordance with the verifications listed in Table 3. The mode of failure producing the lowest design strength shall be decisive. Illustrations of each failure mode are provided in Figure 9.

TABLE 3: VERIFICATIONS REQUIRED FOR ANCHOR CHANNEL LOADED IN TENSION.

Mode of failure	**Reference**		**Channel**	**Most unfavourable anchor or channel bolt**
	Figure	**Clause**		
Channel bolt fracture	Figure 9(a)	6.3.1		$N^* \leq \phi_{Ms} N_{Rk,s}$
Anchor fracture	Figure 9(b)	6.3.1		$N_a^* \leq \phi_{Ms} N_{Rk,s,a}$
Connection between anchor and channel	Figure 9(c)	[d]		$N_a^* \leq \phi_{Ms,ca} N_{Rk,s,c}$
Local flexure of channel lip	Figure 9(d)	[d]	$N^* \leq \phi_{Ms,l} N_{Rk,s,l}$ [b]	
Flexure of channel	Figure 9(e)	[d]	$M^* \leq \phi_{Ms,flex} M_{Rk,s,flex}$	
Concrete cone failure	Figure 9(f)	6.3.2		$N_a^* \leq \phi_{Mc} N_{Rk,c}$ [c]
Pull-out failure	Figure 9(g)	6.3.3		$N_a^* \leq \phi_{Mp} N_{Rk,p}$
Splitting failure	Figure 9(h)	6.3.4		$N_a^* \leq \phi_{Msp} N_{Rk,sp}$ [c]
Blow-out failure[a]	Figure 9(i)	6.3.5		$N_a^* \leq \phi_{Mc} N_{Rk,cb}$ [c]
Steel failure of supplementary reinforcement	Figure 9(j)	6.3.6	Design according to AS 3600	
Anchorage failure of supplementary reinforcement	Figure 9(k)	6.3.6	Design according to AS 3600	

[a] Not required for anchors with $c > 0.5h_{ef}$.
[b] Most loaded anchor or channel bolt.
[c] The most unfavourable anchor shall be determined on the basis of consideration of the load on the anchor in conjunction with the edge distance and spacing.
[d] Characteristic strength found in Report of Assessment



(a) Steel – channel bolt
(b) Steel - anchor
(c) Steel - anchor-channel connection
(d) Steel - local flexure of channel lip
(e) Steel - flexure of channel
(f) Concrete cone
(g) Pull-out
(h) Splitting
(i) Blow-out
(j) Supplementary reinforcement - fracture
(k) Supplementary reinforcement - anchorage

FIGURE 9: MODES OF FAILURE FOR ANCHOR CHANNEL SUBJECTED TO TENSILE LOADING.

3.5.2 Shear strength of fastener

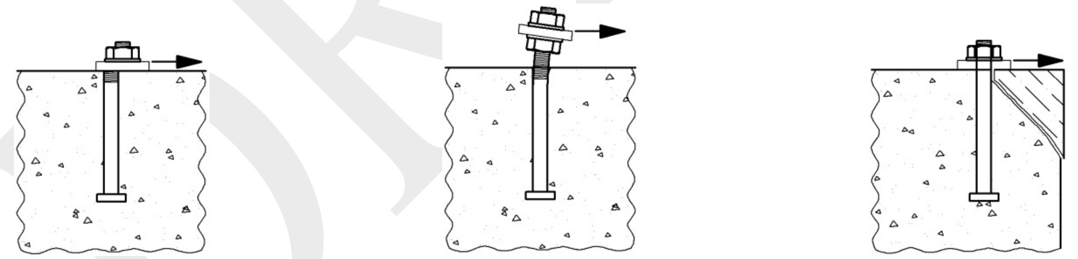
3.5.2.1 Post-installed and cast-in headed fasteners

The design of post-installed fasteners and cast-in headed fasteners subjected to shear loading shall be performed in accordance with the verifications listed in Table 4. The mode of failure producing the lowest design strength shall be decisive. Illustrations of each failure mode are provided in Figure 10.

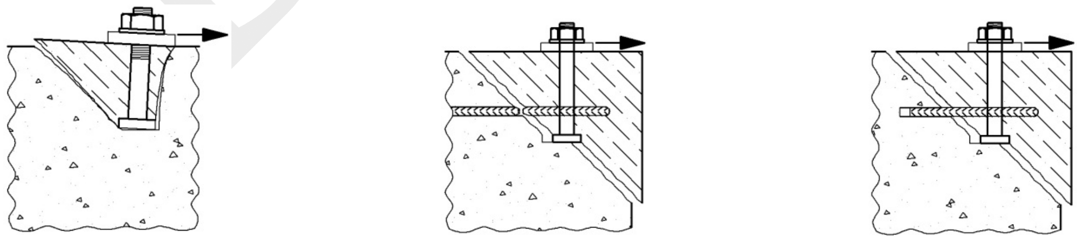
TABLE 4: VERIFICATIONS REQUIRED FOR HEADED AND POST-INSTALLED FASTENERS LOADED IN SHEAR.

Mode of failure	Reference		Single fastener	Fastener group	
	Figure	Clause		Most loaded fastener	Fastener group
Steel failure of fastener without lever arm	Figure 10(a)	7.2.1.1	$V^* \leq \phi_{Ms} V_{Rk,s,m}$	$V_h^* \leq \phi_{Ms} V_{Rk,s,m}$	
Steel failure of fastener with lever arm	Figure 10(b)	7.2.1.2	$V^* \leq \phi_{Ms} V_{Rk,s}$	$V_h^* \leq \phi_{Ms} V_{Rk,s}$	
Concrete edge failure	Figure 10(c)	7.2.2	$V^* \leq \phi_{Mc} V_{Rk,c}$		$V_g^* \leq \phi_{Mc} V_{Rk,c}$
Concrete pry-out failure	Figure 10(d)	7.2.3	$V^* \leq \phi_{Mc} V_{Rk,cp}$		$V_g^* \leq \phi_{Mc} V_{Rk,cp}$ [a]
Steel failure of supplementary reinforcement	Figure 10(e)	7.2.4	Design according to AS 3600		
Anchorage failure of supplementary reinforcement	Figure 10(f)	7.2.4	Design according to AS 3600		

[a] Exception see Clause 7.2.3



(a) Steel – without lever arm (b) Steel – with lever arm (c) Concrete edge



(d) Concrete pry-out (e) Supplementary reinforcement - fracture (f) Supplementary reinforcement – anchorage

FIGURE 10: MODES OF FAILURE FOR CAST-IN HEADED AND POST-INSTALLED FASTENERS SUBJECTED TO SHEAR LOADING.

3.5.2.2 Cast-in anchor channel

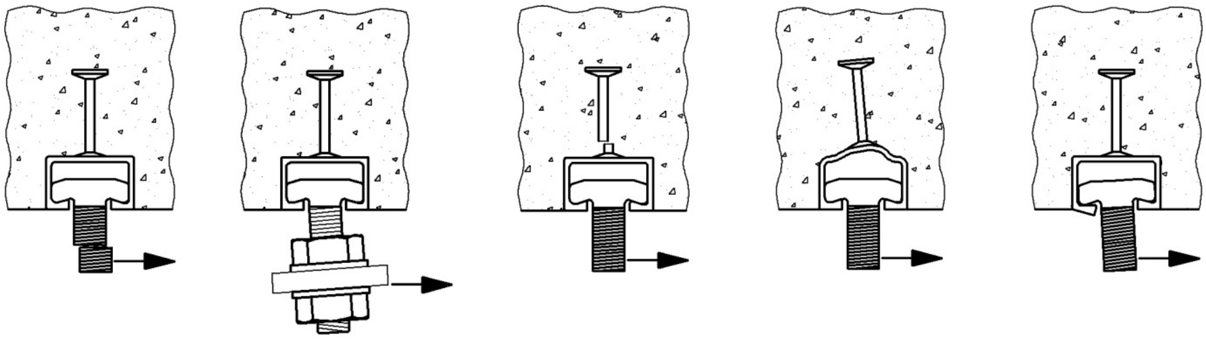
The design of anchor channel subjected to shear loading shall be performed in accordance with the verifications listed in Table 5. The mode of failure producing the lowest design strength shall be decisive. Illustrations of each failure mode are provided in Figure 11.

TABLE 5: VERIFICATIONS REQUIRED FOR ANCHOR CHANNEL LOADED IN SHEAR.

Mode of failure	**Reference Figure**	**Reference Clause**	**Channel**	**Most unfavourable anchor or channel bolt**
Channel bolt without lever arm	Figure 11(a)	7.3.1.1		$V^* \leq \phi_{Ms} V_{Rk,s}$
Channel bolt with lever arm	Figure 11(b)	7.3.1.1		$V^* \leq \phi_{Ms} V_{Rk,s}$
Anchor	Figure 11(c)	7.3.1.1		$V^* \leq \phi_{Ms} V_{Rk,s,a}$
Connection between anchor and channel	Figure 11(d)	7.3.1.1		$V^* \leq \phi_{Ms} V_{Rk,s,c}$
Local flexure of channel lip	Figure 11(e)	7.3.1.2	$V^* \leq \phi_{Ms,l} V_{Rk,s,l}$ [a]	
Concrete edge failure	Figure 11(g)	7.3.2		$V_a^* \leq \phi_{Mc} V_{Rk,c}$ [b]
Pry-out failure	Figure 11(f)	7.3.3		$V_a^* \leq \phi_{Mc} V_{Rk,cp}$
Steel failure of supplementary reinforcement	Figure 11(h)	7.3.4	Design according to AS 3600	
Anchorage failure of supplementary reinforcement	Figure 11(i)	7.3.4	Design according to AS 3600	

[a] Verification for most loaded channel bolt.

[b] The most unfavourable anchor shall be determined on the basis of consideration of the load on the anchor in conjunction with the edge distance and spacing.



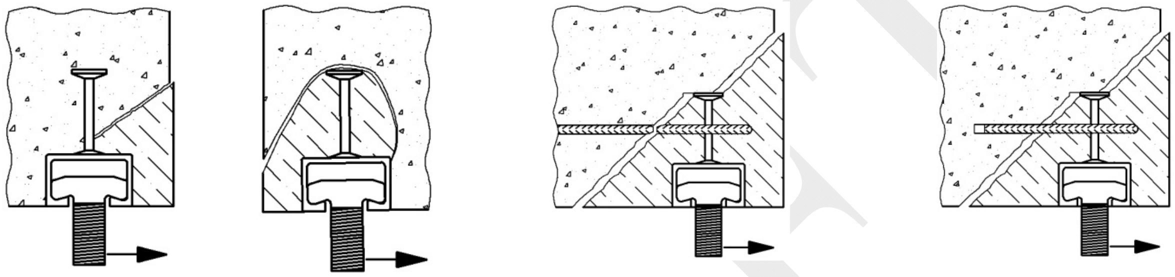
(a) Steel – channel bolt without lever arm

(b) Steel – channel bolt with lever arm

(c) Steel - anchor

(d) Steel – anchor/channel connection

(e) Steel – flexure of channel lip



(f) Concrete edge

(g) Pry-out

(h) Supplementary reinforcement – fracture

(i) Supplementary reinforcement - anchorage

FIGURE 11: MODES OF FAILURE FOR ANCHOR CHANNEL SUBJECTED TO SHEAR LOADING.

3.5.3 Combined tension and shear strength of fastener

Verification of strength of post-installed fasteners and cast-in headed fasteners under combined tension and shear loading shall be performed in accordance with Clause 8.1.1 (steel failure) and Clause 8.2.1 (modes of failure other than steel).

Verification of strength of anchor channel under combined tension and shear loading shall be performed in accordance with Clause 8.1.2 (steel failure) and Clause 8.2.2 (modes of failure other than steel).

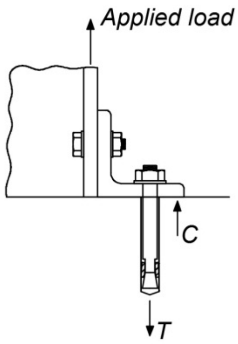
4 DETERMINATION OF FORCES ACTING ON FASTENERS

4.1 GENERAL

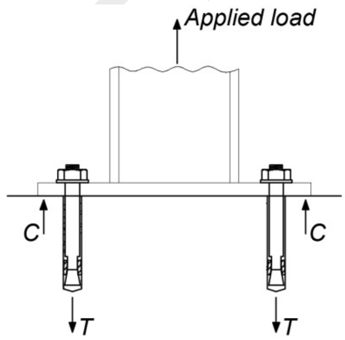
The loads applied to fasteners shall be established via elastic analysis at the ultimate and serviceability limit states with loads applied to a fixture being transferred to fasteners as equivalent tension or shear forces.

The frictional force developing between a fixture plate and concrete due to the presence of a bending moment and/or normal compression force shall be neglected for the design of fastenings.

Eccentricity of loading on fasteners and prying forces (refer to Figure 12) shall be considered in design.



(a) Example one



(b) Example two

FIGURE 12: EXAMPLES OF ECCENTRICITY AND PRYING ACTION IN FIXTURES RESULTING IN AMPLIFICATION OF TENSILE FORCES ACTING ON FASTENERS.

4.2 HEADED FASTENERS AND POST-INSTALLED FASTENERS

4.2.1 Tension and compression loads

When a fixture is subject to a normal force and/or bending moments, the calculation of design loads applied to fasteners shall be made based on linear distribution of strains and a linear relationship between stress and strain.

Key assumptions for calculating the distribution of load to fasteners in a fixture are as follows –

1. All fasteners in a fixture have equal stiffness.
2. The fixture is sufficiently rigid under the applied loading such that the assumption of a linear strain distribution remains valid provided the strains in the fixture remain elastic and the deformation of the fixture is negligible in comparison with axial displacement of the fastener(s). If this provision is not upheld the calculation of design loads acting on the fasteners shall include provision for the elastic deformation of the fixture.
3. Compression forces are not resisted by fasteners; the fixture transmits compression forces directly via bearing to the concrete or via a layer of structural grout.
4. The modulus of elasticity of concrete, E_c, is to be determined in accordance with AS 3600.

Where fasteners in a group resist different design tensile loads, N_i* (refer to Figure 13) the resultant design tensile load acting on the group, N_g*, acts at an eccentricity, e_N, relative to the centroid of the fasteners resisting tension (refer to Figure 14). The eccentricity shall be calculated for consideration in the verification of strength against concrete cone failure, combined pull-out and concrete cone failure of bonded fasteners, splitting failure and blow-out failure modes. For the purpose of calculating the eccentricity of N_g*, fasteners that are not arranged in a rectangular pattern may be rearranged into a rectangle pattern. This simplification results in a larger eccentricity that leads to a conservative estimate of concrete resistance (refer to Figure 14(d)).

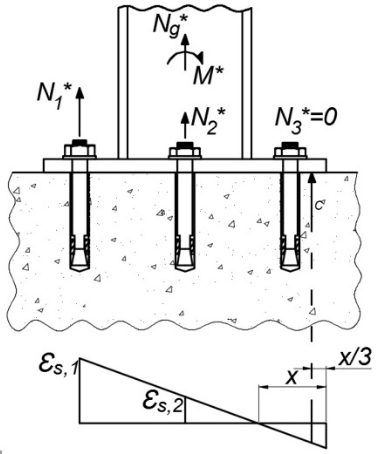


FIGURE 13: EXAMPLE OF A RIGID FIXTURE CONNECTED TO CONCRETE VIA FASTENINGS WITH AN APPLIED TENSILE LOAD AND BENDING MOMENT.

4.2.2 Shear loads

4.2.2.1 General

The diameter of the clearance hole in the fixture, d_f, for a respective external diameter of fastener d or d_{nom}, shall conform to the requirements of Table 6 in the direction of the shear load. If the hole is slotted in the direction of shear load the fastener is not considered to resist the shear load.

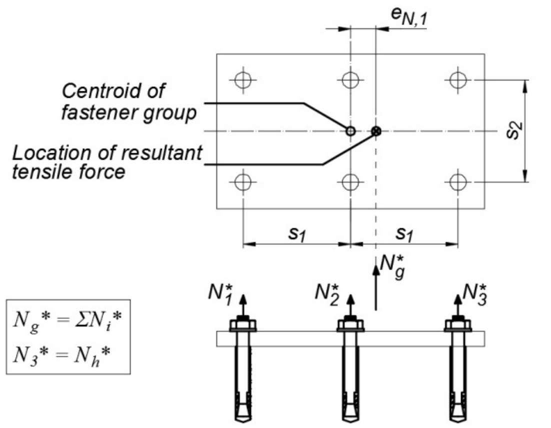
The fastener shall be considered to have no hole clearance under the following circumstances –

(a) Fastener has been welded to the fixture
(b) Fastener has been screwed into the fixture
(c) Gap between fixture and fastener has been filled with mortar having a compressive strength greater than 40 MPa
(d) Gap between fixture and fastener has been eliminated by another means.

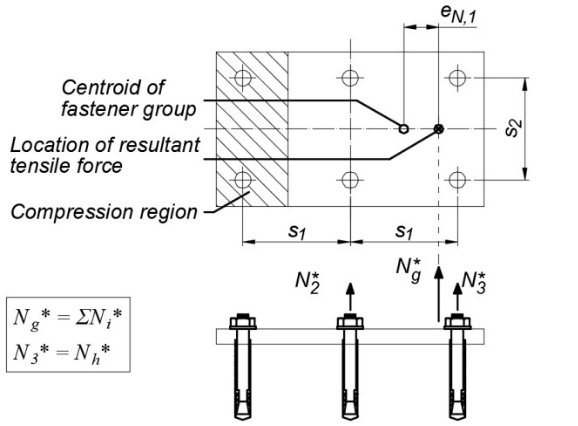
TABLE 6: HOLE CLEARANCE IN FIXTURE (DIMENSIONS IN **MM**).

External diameter of fastener d^a or $d_{nom}{}^b$	6	8	10	12	14	16	18	20	22	24	27	30	>30
Diameter of clearance hole in the fixture, d_f	7	9	12	14	16	18	20	22	24	26	30	33	d + 3 or d_{nom} + 3

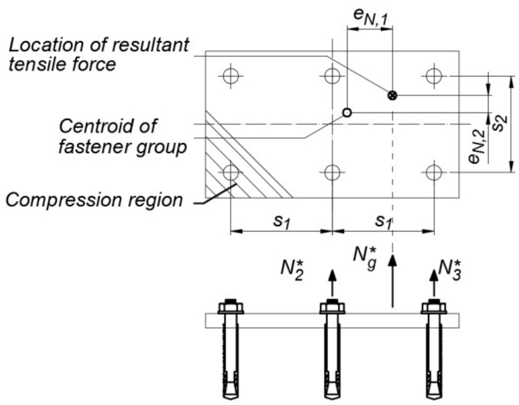
[a] bolt bears against fixture
[b] sleeve of fastener bears against fixture



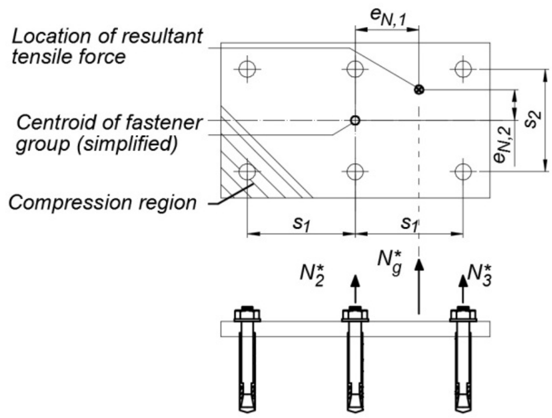
(a) ECCENTRICITY IN ONE DIRECTION, ALL FASTENERS LOADED IN TENSION



(b) ECCENTRICITY IN ONE DIRECTION, TWO FASTENERS NOT LOADED DUE TO ZONE OF COMPRESSION

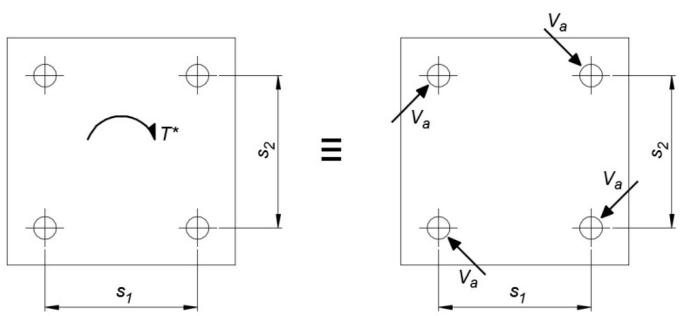


(c) ECCENTRICITY IN TWO ORTHOGONAL DIRECTIONS, ONE FASTENER NOT LOADED DUE TO ZONE OF COMPRESSION



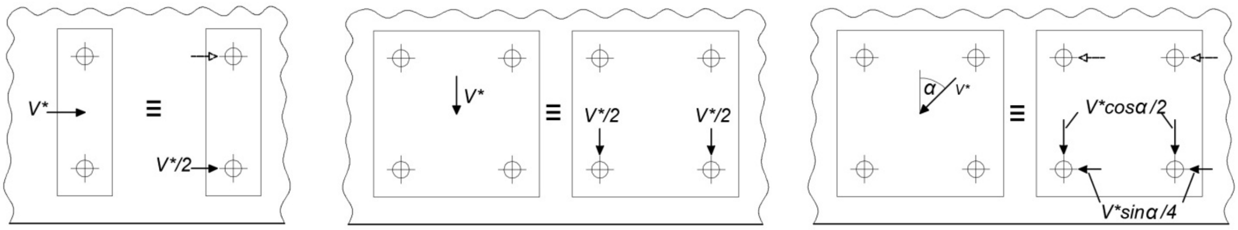
(d) ECCENTRICITY IN TWO ORTHOGONAL DIRECTIONS, ONE FASTENER NOT LOADED DUE TO ZONE OF COMPRESSION, SIMPLIFIED LOCATION FOR CENTRE OF GRAVITY

FIGURE 14: EXAMPLES OF THE APPLICATION OF ECCENTRIC LOADS TO FIXTURES.



$$V_a = \frac{T_{ed}}{I_p}\left[\left(\frac{s_1}{2}\right)^2\left(\frac{s_2}{2}\right)^2\right]^{0.5}$$

FIGURE 15: DETERMINATION OF SHEAR LOADS APPLIED TO FASTENERS UNDER THE APPLICATION OF A TORQUE MOMENT TO THE FIXTURE.



(a) Two fasteners with a shear load parallel to edge

(b) Four fasteners with a shear load perpendicular to edge

(c) Four fasteners with an oblique shear load

FIGURE 16: DETERMINATION OF SHEAR LOADS APPLIED TO FASTENERS IN FIXTURES IN CLOSE PROXIMITY TO AN EDGE.

4.2.2.2 Load distribution

The distribution of shear load is considered to occur equally among all fasteners in a group under each of the following circumstances –

(a) The fasteners are distant to a free edge such that $c \geq \max(10h_{ef}, 60d_{nom})$
(b) Verification of steel failure
(c) Verification of pry-out failure
(d) A torsion moment is applied to the fixture (refer to Figure 15)
(e) The shear load is applied parallel to the free edge (refer to Figure 16(a))

The direction of shear load influences the strength of fasteners located close to an edge as follows –

(a) When the component of applied shear load acts perpendicular and towards an edge (refer to Figure 16(b)), only fastener(s) located closest to the edge are effective in resisting concrete edge failure.
(b) The component of shear load acting parallel to an edge is considered to be equally distributed among all fasteners in the group (refer to Figure 16(c)).
(c) The component of shear load acting away from a free edge does not significantly influence the concrete edge strength and may be neglected when verifying concrete edge failure (refer to Figure 16(c)).

4.2.2.3 Shear load without a lever arm

(a) A shear load shall be considered to act without a lever arm under the following conditions –
   (i) The fixture is steel and is in contact with the fastener over a minimum length of $0.5t_{fix}$.
   (ii) Adequate restraint of the fixture is provided through: i) direct fixing of the fixture to the concrete substrate, or ii) a levelling mortar of compressive strength at least equal to that of the base material and not less than 30 MPa, with a thickness no greater than $t_{grout} \leq 0.5d$ over a rough concrete surface (refer to AS 3600) that provides complete coverage of the underside of the fixture.
(b) If the above conditions are not met the shear load is considered to be applied to a fastener with a lever arm. If only condition (b) above is not met the shear capacity of the fastener may be reduced without designing for a lever arm providing all of the following conditions are met –
   (i) There are a minimum of two fasteners in the direction of the applied shear load.
   (ii) The only action applied to the fixture is shear load.

(iii) The spacing of fasteners is greater than 10d, applicable in orthogonal directions in the case of an inclined shear load comprising two orthogonal components.

(iv) The thickness of a layer of grout – if any – is limited to $t_{grout} \leq 5d$ for fasteners without a sleeve or $t_{grout} \leq 5d_{nom}$ for fasteners containing a sleeve, and not greater than 40 mm.

(v) a levelling mortar of compressive strength at least equal to that of the base material and not less than 30 MPa, over a rough concrete surface (refer to AS 3600) that provides complete coverage of the underside of the fixture.

4.2.2.4 Shear load with a lever arm

If the applied shear load acts with a lever arm (refer to Figure 17), the design bending moment acting on the fastener, M^*, shall be calculated as follows –

$$M^* = V^* \left(\frac{l_a}{\alpha_M} \right) \tag{3}$$

where

M^* = design bending moment acting on the fastener

V^* = shear load applied to the fastener

l_a = lever arm of the shear force applied to the fastener

= $a_3 + e_1$

a_3 = distance between the assumed point of restraint of the fastener loaded in shear and the surface of the concrete

= $0.5d_{nom}$

= 0 provided one of the following conditions exist –

i) a nut and washer are clamped to the surface of the concrete (or to the surface of anchor channel), or

ii) a layer of levelling mortar exists under the entire fixture that has a compressive strength at least equal to 30 MPa and a thickness $t_{grout} \leq 0.5d$

e_1 = eccentricity of the applied shear load relative to the concrete surface, neglecting the thickness of a levelling grout or mortar

α_M = parameter based on engineering experience that accounts for the degree of restraint of an anchor channel at the side of the fixture under consideration

= 1.0 for the condition of no restraint, assumed for fixtures that can freely rotate

= 2.0 for the condition of restraint, assumed for a fixture prevented from rotating

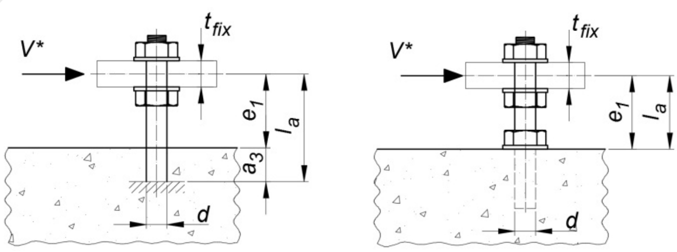


FIGURE 17: FIXTURE LOADED IN SHEAR WITH A LEVER ARM.

4.3 ANCHOR CHANNEL

4.3.1 General

The force resisted by each anchor in an anchor channel depends on the assumed anchor stiffness and the degree of restraint. The distribution of tension forces among anchors in anchor channel may be calculated by assuming the anchor channel to be a statically determinate beam system that is supported on anchors and has partial restraint at its ends. Under shear loading the distribution of applied load to individual anchors is influenced by the channel-to-concrete contact zone and the resultant pressure distribution.

Where the number of anchors in the anchor channel is limited to two, the calculation of loads resisted by each anchor may be performed assuming the anchor behaves as a simply supported beam with a length equal to anchor spacing. Alternatively, the triangle load distribution method may be used to calculate the load on each anchor in an anchor channel containing two or more anchors.

The design of an anchor channel for shear load applies only in the direction that is perpendicular to the longitudinal direction of the channel.

4.3.2 Tension loads

The tension resisted by each anchor in the channel, N_i* may be calculated by assuming a linear distribution of load over the influence length, l_i, and accounting for the condition of equilibrium as follows –

$$N_i^* = kA'_i N^* \tag{4}$$

where

$$k = \frac{1}{\sum_{1}^{n} A'_i} \tag{5}$$

A'_i = ordinate on the normalised load distribution triangle with base length $2l_i$, at the location of the anchor, i, under consideration

n = number of anchors located within the influence length of the anchor channel, l_i, on either side of the applied load (refer to Figure 18).

N^* = design tensile load

l_i = $13 I_y^{0.05} s^{0.5} \geq s$

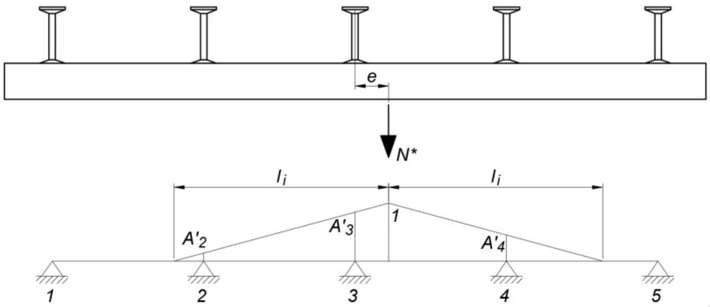
I_y = moment of inertia of channel relative to the y-axis of the channel

Where multiple loads are applied to the channel the principles of superposition may be employed to determine the load resisted by each anchor.

In the event that the exact position of the applied load on the channel is unknown, the most unfavourable position shall be assumed for each failure mode, such as directly over an anchor for steel rupture or concrete cone failure, or mid-way between anchors for channel bending failure.

Determination of the design bending moment acting on the channel, M_{ch}*, due to an applied tension load, N_{ch}*, shall be based upon the principle of a simply supported beam with a span equal to the spacing of the anchors.

The characteristic flexural strength of the anchor channel published in the Report of Assessment accounts for partial end restraint and continuous beam action developing in channels with more than two anchors that are not accounted for using the simplified load analysis method. The characteristic values of flexural strength published in the Report of Assessment may be larger than the plastic moment and calculated using the geometric and material properties of the channel.



$$A'_2 = \frac{l_i - e - s}{l_i} \qquad N_2^* = A'_2\,kN^*$$

$$A'_3 = \frac{l_i - e}{l_i} \qquad N_3^* = A'_3\,kN^*$$

$$N_4^* = A'_4\,kN^*$$

$$A'_4 = \frac{l_i - e + s}{l_i} \qquad N_1^* = N_5^* = 0$$

FIGURE 18: CALCULATION OF ANCHOR FORCES IN ANCHOR CHANNEL USING THE TRIANGULAR LOAD DISTRIBUTION METHOD.

4.3.3 Shear loads

Consideration of the presence of a lever arm for loads applied to the channel bolt shall occur in accordance with Clause 4.2.2.

The procedure for determining the load acting on each anchor in the channel shall follow the procedure outlined in Clause 4.3.2.

When a shear load is applied perpendicular to an anchor channel, the anchor channel resists the applied load through a combination of compression between the channel and concrete, as well and tensile force developing in the anchors. The proportion of the applied shear load resisted by the channel and anchors depends largely on the geometry of the anchor channel. The above approach for determining the distribution of loads has been adopted to simplify the interaction between tensile and shear loads applied to the channel.

Verification of the concrete edge failure mode may be neglected when the shear load acts away from the free edge.

4.4 SUPPLEMENTARY REINFORCEMENT

4.4.1 General

The determination of design tension forces acting on supplementary reinforcement shall be determined using strut-and-tie techniques provided in AS 3600.

4.4.2 Tension loads

Supplementary reinforcement shall be designed for either a single fastener, N^* or a fastener group, N_h^* that shall be applied to the entire group.

Supplementary reinforcement for anchor channel shall be based upon the most unfavourable loading condition, N_a^* on an anchor in the channel.

4.4.3 Shear loads

If supplementary reinforcement is aligned with the direction of the design shear force, V^*, acting on a fixture, perpendicular and towards an edge, the design tension force in the supplementary reinforcement, N_{re}^* (refer to Figure 19) may be calculated as follows –

$$N_{re}^* = \left(\frac{e_s}{z} + 1\right) V^* \quad (6)$$

where

e_s = distance between the centreline of supplementary reinforcement and the line of action of the design shear force

$z \approx 0.85d$

$d \leq \min\left(2h_{ef}, 2c_1\right)$

The internal lever arm may be small relative to deep sections, hence the requirement to limit the depth, d.

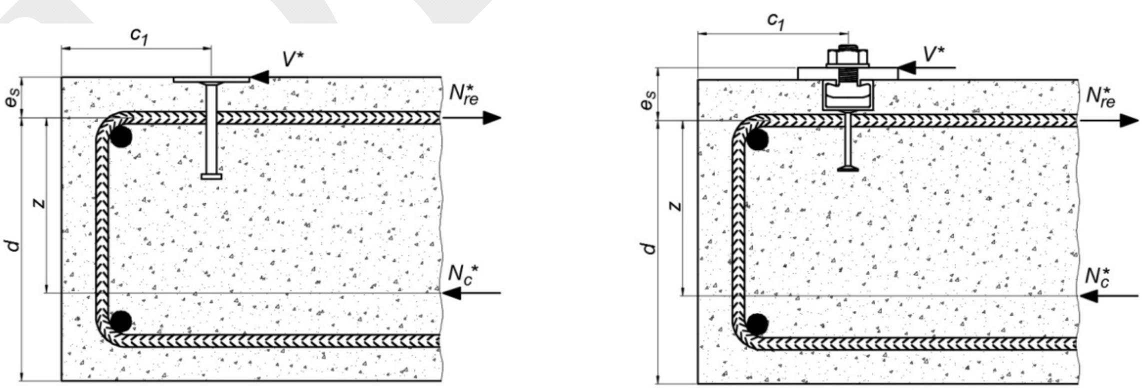
The direction of shear loading influences the design of supplementary reinforcement as follows –

i) When the design shear force is inclined and towards the edge, it may be assumed that the full design shear force acts perpendicular and towards the free edge.
ii) When the design shear force acts parallel to the free edge or an inclined shear force acts away from the free edge, it is conservative to assume that the component of the design shear load parallel to the edge, acts perpendicular to and towards the free edge for the purpose of designing supplementary reinforcement.

When a fixture loaded in shear contains multiple fasteners, the fastener resisting the greatest shear load, V_h^* shall be identified and adopted for the determination of the design tension force resisted by the supplementary reinforcement, $N_{h,re}^*$, according to Equation (6), for all fasteners.

If the supplementary reinforcement is not aligned with the direction of the design shear load, the design tension load for the supplementary reinforcement shall be modified accordingly.

The design tension force for the supplementary reinforcement in anchor channels shall be the greater of the design shear force on the most loaded anchor and the design shear force on the most loaded channel bolt.



(a) SHEAR LOAD APPLIED TO HEADED FASTENER WITH ANCHOR PLATE

(b) SHEAR LOAD APPLIED TO FIXTURE CLAMPED BY CHANNEL BOLT.

FIGURE 19: SURFACE REINFORCEMENT TO RESIST APPLIED SHEAR LOAD.

5 DETAILING OF SUPPLEMENTARY REINFORCEMENT

If supplementary reinforcement is to be included in the design of post-installed or cast-in fasteners to resist the entire load, it is not necessary to verify strength of the fastener to concrete cone failure for tensile loading (refer to Table 2 and Table 3) or concrete edge failure for shear loading (refer to Table 4 or Table 5).

The design of supplementary and surface reinforcement shall be in accordance with the requirements of AS 3600. Strength verifications relating to supplementary reinforcement in Table 2 to Table 5 shall be based on a development length for a level of stress in the reinforcing steel, σ_{st} not exceeding the yield strength of the reinforcing steel, f_{sy}. Limitations on the geometry of a hook (mandrel) or cog are provided in AS 3600.

When designing supplementary reinforcement for a fastener group, the design shall be based on the most loaded fastener and an identical design adopted for all other fasteners in that group. The placement of supplementary reinforcement shall be symmetrical and as close to the fastener as practicable. Reinforcement positioned at a distance greater than $0.75h_{ef}$ is not considered to be effective. The placement of supplementary reinforcement should enclose surface reinforcement where possible.

Supplementary reinforcement in the concrete failure cone shall have a minimum anchorage length as follows –

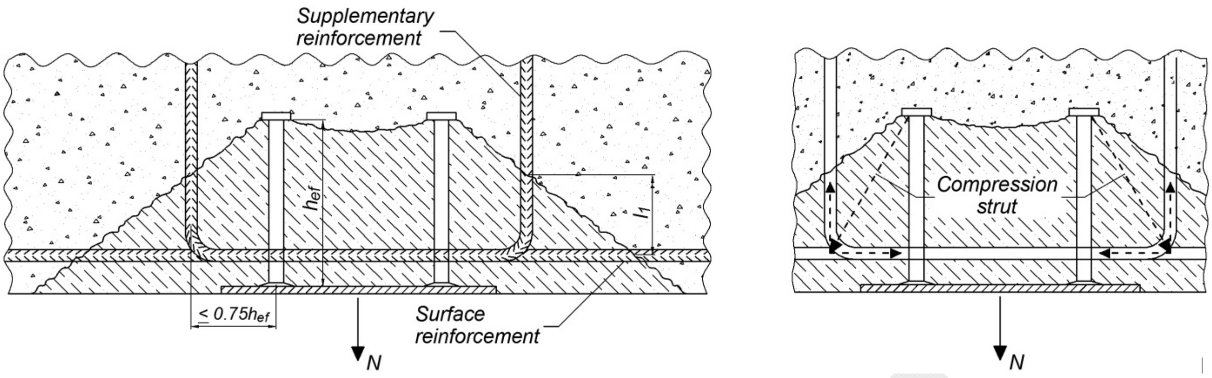
i. $l_1 \geq 4d_b$ for bends, hooks or loops, or
ii. $l_1 \geq 10d_b$ for straight bars with or without welded transverse bars

Anchorage of the supplementary reinforcement outside the concrete failure cone shall be for a minimum development length, L_{st} in accordance with AS 3600.

If the supplementary reinforcement is not adequately lapped with reinforcement in the structural element, the strength against concrete cone failure, $N_{Rk,c}$ for the supplementary reinforcement shall be calculated in accordance with Clause 6.2.2, assuming h_{ef} is equal to the length of embedment of the supplementary reinforcement outside the concrete failure cone.

In addition to the supplementary reinforcement, surface reinforcement shall be provided to resist the forces determined from the strut-and-tie model as illustrated in Figure 20.

Underutilised reinforcement in the concrete member design may be utilised for supplementary reinforcement provided that the minimum detailing requirements for supplementary reinforcement outlined in this Standard are met.



(a) PLACEMENT OF SUPPLEMENTARY AND SURFACE REINFORCEMENT TO RESIST CONCRETE CONE FAILURE.

(b) STRUT-AND-TIE MODEL FOR SUPPLEMENTARY AND SURFACE REINFORCEMENT.

FIGURE 20: PLACEMENT OF SUPPLEMENTARY REINFORCEMENT AND SURFACE REINFORCEMENT FOR AN ASSUMED STRUT-AND-TIE MODEL TO RESIST CONCRETE CONE FAILURE.

6 DESIGN FOR TENSILE LOADING

6.1 GENERAL

The characteristic strength to tensile loading for the modes of failure for post-installed fasteners and cast-in headed fasteners outlined in Table 2 is determined in accordance with Clause 6.2. The characteristic strength to tensile loading for the modes of failure for cast-in anchor channel outlined in Table 3 is determined in accordance with Clause 6.3.

6.2 POST-INSTALLED FASTENERS AND CAST-IN HEADED FASTENERS

The verifications in Table 2 shall apply.

6.2.1 Steel failure

The characteristic tensile steel strength of the fastener shall be calculated in accordance with AS 4100 based on the material properties of the fastener published in the Report of Assessment.

6.2.2 Concrete cone failure

6.2.2.1 General

The characteristic strength of a fastener, a group of fasteners or the tensioned fasteners in a group to concrete cone failure is given as follows –

$$N_{Rk,c} = N^0_{Rk,c}\left(\frac{A_{c,N}}{A^0_{c,N}}\right)\psi_{s,N}\psi_{re,N}\psi_{ec,N}\psi_{M,N} \quad (7)$$

where

$N_{Rk,c}$ = characteristic strength of a fastener to concrete cone failure

$N^0_{Rk,c}$ = characteristic strength of a fastener, remote from the effects of adjacent fasteners or edges of the concrete member, to concrete cone failure given in Clause 6.2.2.2

$A_{c,N}$ = actual projected area of the failure cone of the fastener that is limited by adjacent fasteners and edges of the concrete member given in Clause 6.2.2.3

$A^0_{c,N}$ = reference projected area of the failure cone of the fastener given in Clause 6.2.2.3

$\psi_{s,N}$ = parameter related to the distribution of stresses in the concrete due to the proximity of the fastener to an edge of the concrete member given in Clause 6.2.2.4

$\psi_{re,N}$ = parameter accounting for the shell spalling effect given in Clause 6.2.2.5

$\psi_{ec,N}$ = parameter accounting for eccentricity of the resultant load in a fastener group given in Clause 6.2.2.6

$\psi_{M,N}$ = parameter accounting for the effect of a compression force between the fixture and concrete given in Clause 6.2.2.7

6.2.2.2 Characteristic strength of a single fastener

The characteristic strength of a fastener, remote from the effects of adjacent fasteners or edges of the concrete member shall be taken as –

$$N^0_{Rk,c} = k_9.\sqrt{f'_c}.h_{ef}^{1.5} \tag{8}$$

with

k_9 = $k_{cr,N}$ for cracked concrete may be taken as –

(i) 7.7 for post-installed fasteners

(ii) 8.9 for cast-in headed fasteners

= $k_{ucr,N}$ for non-cacked concrete may be taken as –

(i) 11.0 for post-installed fasteners

(ii) 12.7 for cast-in headed fasteners

The parameters $k_{cr,N}$ and $k_{ucr,N}$ may be found in the Report of Assessment.

6.2.2.3 Geometric effect of edge distance and spacing

The ratio of $A_{c,N}/A^0_{c,N}$ takes into account the effect of adjacent fasteners and edges of the concrete member on the characteristic strength of the fastener to concrete cone failure where –

$A^0_{c,N}$ = reference projected area of a single fastener with an edge distance at least equal to $1.5h_{ef}$

$$= s_{cr,N}.\mathrm{s}_{\mathrm{cr,N}} \tag{9}$$

$A_{c,N}$ = actual projected area that is limited by the edges of the concrete member ($c \leq c_{cr,N}$) and overlapping areas of adjacent fasteners ($s \leq s_{cr,N}$).

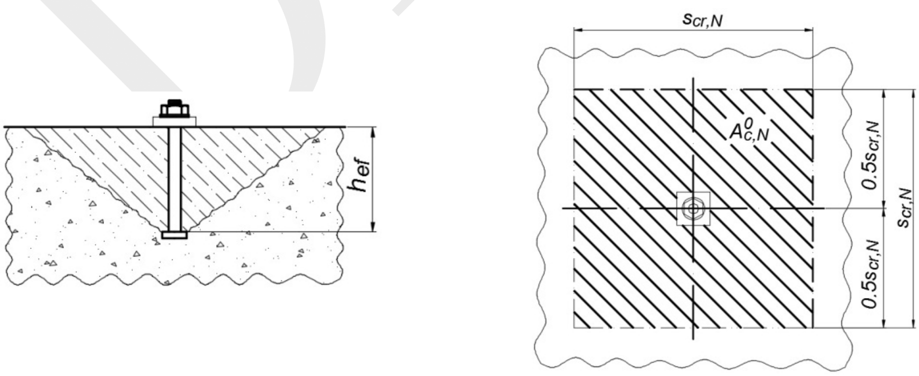
The indicative characteristic spacing of headed fasteners and post-installed fasteners to ensure the transmission of the characteristic tensile strength of a single fastener is –

$$s_{cr,N} = 2c_{cr,N} \tag{10}$$

$$= 3h_{ef} \tag{11}$$

$c_{cr,N}$ = characteristic edge distance given in the Report of Assessment

An example illustration of $A_{c,N}$ and $A^0_{c,N}$ is provided in Figure 21 and Figure 22.

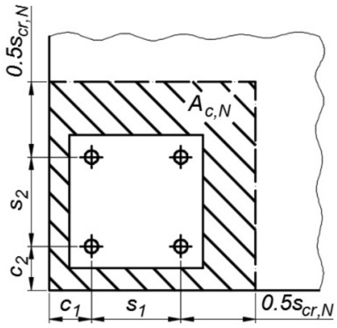


$A^0_{c,N} = s_{cr,N}$ x $\mathrm{s}_{cr,N}$

(a) (b)

FIGURE 21: PROJECTED AREA OF THE CONCRETE CONE OF A SINGLE FASTENER.

Note: For headed and post-installed fasteners, $s_{cr,N} = 2c_{cr,N} = 3h_{ef}$.



$A_{c,N} = (c_1 + s_1 + 0.5s_{cr,N}) \times (c_2 + s_2 + 0.5s_{cr,N})$

if $c_1; c_2 \leq c_{cr,N}$

$s_1; s_2 \leq s_{cr,N}$

FIGURE 22 PROJECTED AREA OF THE CONCRETE CONE OF A FASTENER IN A GROUP AND CLOSE TO AN EDGE.

6.2.2.4 Distribution of stresses in concrete

The disturbance to the distribution of stresses in concrete due to the presence of an edge is accounted for by the parameter $\psi_{s,N}$ as follows –

$$\psi_{s,N} = 0.7 + 0.3\left(\frac{c}{c_{cr,N}}\right) \leq 1 \tag{12}$$

where

c = edge distance

$c_{cr,N}$ = edge distance of a single fastener to ensure the characteristic strength of the fastener is achieved

Where multiple edges of the concrete member – such as a fastener in a corner or in a narrow member – the smallest edge distance, c shall be inserted in Equation (12).

6.2.2.5 Shell spalling

The presence of a dense layer of reinforcement in the concrete member introduces a potential plane of weakness when considering the strength of the fastener which is accounted for by the parameter $\psi_{re,N}$ as follows –

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1 \tag{13}$$

where

h_{ef} = effective embedment depth of fastener

There shall be no reduction due to shell spalling for either of the following conditions –

(a) The spacing of reinforcement of any diameter is no less than 150 mm, or
(b) The spacing of reinforcement is no less than 100 mm for a diameter of the reinforcement that is no greater than 10 mm.

6.2.2.6 Eccentricity of loading on a fastener group

The parameter $\psi_{ec,N}$ accounts for a group effect when there is a difference in tension loads resisted by individual fasteners in a group as follows –

$$\psi_{ec,N} = \frac{1}{1+2.e_N / s_{cr,N}} \leq 1 \tag{14}$$

where

e_N = eccentricity of the resultant tension force acting on a group of fasteners relative to the centre of gravity of the tensioned fasteners

$s_{cr,N}$ = characteristic spacing of fastener to ensure the transmission of the characteristic strength of the fastener

If there is an eccentricity in two orthogonal directions, the parameter $\psi_{ec,N}$ should be determined for both directions and the product of these values substituted in Equation (7).

6.2.2.7 Compression between fixture and concrete

The parameter $\psi_{M,N}$ accounts for the effect of a compression force between the fixture and concrete as follows –

$\psi_{M,N}$ = 1 under the following conditions

(i) Fastenings that have an edge $c < 1.5h_{ef}$
(ii) Fastenings that are distant from edge effects ($c > 1.5h_{ef}$) that have an applied bending moment and tension force where $N_c*/N* < 0.8$, or
(iii) Fastenings with $z/h_{ef} \geq 1.5$

$$= 2 - \frac{2z}{3h_{ef}} \geq 1 \tag{15}$$

for all other applications

where

z = internal lever arm

h_{ef} = effective embedment depth of the fastener

Where bending is present in two directions the lever arm, z shall be determined for the combined bending moments in both directions and the axial force.

6.2.2.8 Narrow concrete member

The concrete member is considered to be narrow if three or more edge distances are less than the characteristic edge distance, $c_{cr,N}$ as illustrated in Figure 23 (a) and (b). A more precise estimation of strength is obtained with a modified effective embedment depth, h'_{ef} as follows –

$$h'_{ef} = \frac{c_{max}}{c_{cr,N}} h_{ef} \tag{16}$$

for individual fasteners

$$= \quad \max\left\{\frac{c_{\max}}{c_{cr,N}} h_{ef} ; \frac{s_{\max}}{s_{cr,N}} h_{ef}\right\} \text{ for fasteners in groups} \tag{17}$$

where

c_{max} = maximum edge distance of the fastener $\leq c_{cr,N}$

$c_{cr,N}$ = characteristic edge distance to ensure transmission of the characteristic strength of the fastener

s_{max} = s_2 for applications having three edges $\leq s_{cr,N}$

= maximum centre-to-centre spacing between fasteners $\leq s_{cr,N}$

$s_{cr,N}$ = characteristic spacing between fasteners to ensure the transmission of the characteristic strength of the fastener

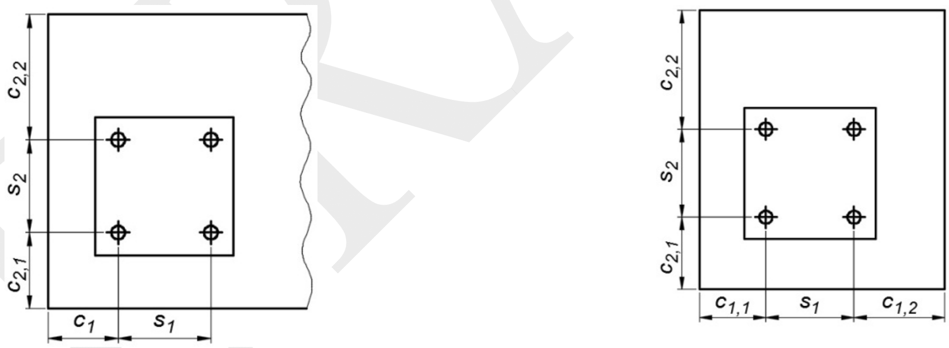
If a fixture includes three holes without hole clearance that are located close to an edge, the maximum centre-to-centre distance of the outside fasteners is $s_{max} \leq 2s_{cr,N}$.

The following conditions apply in a narrow concrete member –

(a) h'_{ef} is substituted into Equation (8)
(b) The modified characteristic spacing $s'_{cr,N}$ and modified characteristic edge distance $c'_{cr,N}$ are substituted for $c_{cr,N}$ and $s_{cr,N}$ respectively, in Equations (9), (12) and (14) where –

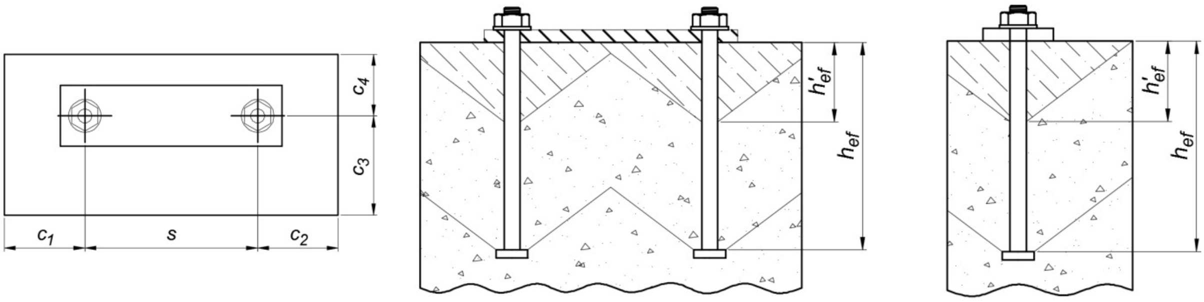
$$s'_{cr,N} \quad = \quad 2c'_{cr,N} = s_{cr,N}\left(\frac{h'_{ef}}{h_{ef}}\right) \tag{18}$$

An example of a modified effective embedment depth, h'_{ef} is provided in Figure 24.



(a) c_1, $c_{2,1}$, $c_{2,2} \leq c_{cr,N}$ (b) $c_{1,1}$, $c_{1,2}$, $c_{2,1}$, $c_{2,2} \leq c_{cr,N}$

FIGURE 23: EXAMPLES OF FASTENINGS IN NARROW MEMBERS.



(a) PLAN VIEW (b) CROSS-SECTION (SIDE VIEW) (c) CROSS-SECTION (END VIEW).

FIGURE 24: CALCULATION OF h'_{ef} FOR A FIXTURE CONTAINING TWO FASTENERS.

6.2.3 Pull-out failure

Pull-out failure shall be considered for post-installed mechanical and cast-in headed fasteners with the characteristic strength against pull-out failure provided in the Report of Assessment.

The pull-out strength of a cast-in headed fastener is limited by the bearing pressure under the head of the fastener given by –

$$N_{Rk,p} = \mathrm{k}_1 A_h f'_c \tag{19}$$

where

k_1 = parameter relating to the state of the concrete

= 8.0 for fasteners in cracked concrete

= 11.2 for fasteners in uncracked concrete

A_h = area of the load-bearing head of the fastener

$$= \frac{\pi}{4}\left(d_h^{\,2} - d^2\right) \tag{20}$$

d_h = diameter of head of fastener

$\leq$ $6t_h + d$

t_h = thickness of the head of the headed fastener

d = diameter of the shank of the fastener

f'_c = characteristic compressive strength of concrete

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

6.2.4.1 General

The strength of a single chemical fastener in tension or a fastener in tension in a group of fasteners to combined pull-out and concrete cone failure may be estimated as follows –

$$N_{Rk,p} = N^0_{Rk,p}\left(\frac{A_{p,N}}{A^0_{p,N}}\right)\psi_{s,Np}\psi_{g,Np}\psi_{re,N}\psi_{ec,Np} \tag{21}$$

where

$N^0_{Rk,p}$ = characteristic bond strength of a single chemical fastener determined in accordance with Clause 6.2.4.2

$A_{p,N}$ = actual bond influence area of a single chemical fastener that is limited by adjacent fasteners and edges of the concrete member given in Clause 6.2.4.3

$A^0_{p,N}$ = reference bond influence area of a single chemical fastener given in Clause 6.2.4.3

$\psi_{s,Np}$ = parameter accounting for the disturbance to the distribution of stress in the concrete due to an edge of the concrete member calculated in accordance with Clause 6.2.4.4

$\psi_{g,Np}$ = parameter accounting for a group effect, refer to Clause 6.2.4.5

$\psi_{re,N}$ = parameter accounting for shell spalling due to a dense layer of reinforcement, calculated according to Clause 6.2.2.5

$\psi_{ec,Np}$ = parameter accounting for eccentricity of loading on a fastener group calculated according to Clause 6.2.4.6, substituting $s_{cr,Np}$ for $s_{cr,N}$.

6.2.4.2 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 is calculated as follows –

$$N^0_{Rk,p} = \tau_{Rk}\pi d h_{ef}\psi_{sus} \tag{22}$$

where

τ_{Rk} = characteristic bond strength of chemical fastener that may depend on concrete strength class, given in the Report of Assessment

= $\tau_{Rk,cr}$ for cracked concrete

= $\tau_{Rk,ucr}$ 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

= 1 for $\alpha_{sus} \leq \psi^0_{sus}$

= $\psi^0_{sus} + 1 - \alpha_{sus}$ for $\alpha_{sus} > \psi^0_{sus}$

ψ^0_{sus} = product dependent factor accounting for the influence of a sustained load on the bond strength of the chemical fastener, taken from the Report of Assessment. If no value of ψ^0_{sus} is provided in the Report of Assessment, a value of $\psi^0_{sus} = 0.6$ shall be adopted where sustained loading is present for a 50 year design life including a concrete temperature equal to 43°C for a minimum of 10 years. Additional testing and assessment of the chemical fastener is required for applications that have a long term concrete temperature other than 43°C.

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

6.2.4.3 Geometric effect of edge distance and spacing

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

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

$A^0_{p,N}$ = reference bond influence area of an individual chemical fastener

$$= s_{cr,Np}\, s_{cr,Np} \quad (23)$$

$$s_{cr,Np} = 7.3d\sqrt{\tau_{Rk}\psi_{sus}} \le 3h_{ef} \quad (24)$$

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

τ_{Rk} = value of $\tau_{Rk,ucr}$ for f'_c = 20 MPa, obtained from the Report of Assessment

h_{ef} = effective embedment depth of fastener

$$c_{cr,Np} = s_{cr,Np}/2 \quad (25)$$

ψ_{sus} = factor accounting for the effects of sustained loading on bond strength (refer to Clause 6.2.4.2)

6.2.4.4 Disturbance to the distribution of stresses

The disturbance to the distribution of stress in the concrete due to an edge of the concrete member is calculated according to Clause 6.2.2.4 by substituting $\psi_{s,Np}$ for $\psi_{s,N}$ and $c_{cr,Np}$ for $c_{cr,N}$.

6.2.4.5 Effect of closely spaced fasteners

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

$$\psi_{g,Np} = \psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0.5}\left(\psi^0_{g,Np} - 1\right) \ge 1 \quad (26)$$

where

$$\psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right)\left(\frac{\tau_{Rk}}{\tau_{Rk,c}}\right)^{1.5} \ge 1 \quad (27)$$

$$\tau_{Rk,c} = \frac{k_8}{\pi d}\sqrt{h_{ef} f'_c} \quad (28)$$

k_8 = parameter relating to the state of the concrete

= 7.7 for cracked concrete

= 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 (24)

6.2.4.6 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 and is calculated in accordance with Clause 6.2.2.6 by substituting $\psi_{ec,Np}$ for $\psi_{ec,N}$ and $s_{cr,Np}$ for $s_{cr,N}$.

6.2.4.7 Narrow concrete member

The concrete member is considered to be narrow if three or more edge distances are less than the characteristic edge distance, $c_{cr,Np}$ (refer to Figure 23 (a) and (b)). A more precise estimation of strength is 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 (16) and (17) 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 (24)

$c'_{cr,Np}$ = modified characteristic edge distance determined in accordance with Equation (25)

The following conditions apply in a narrow member

(a) h'_{ef} is substituted into Equation (24)
(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 (12) for the determination of $\psi_{s,Np}$, Equation (14) for the determination of $\psi_{ec,Np}$, and (26) for the determination of $\psi_{g,Np}$.

6.2.5 Splitting failure

6.2.5.1 Splitting failure during installation

Splitting failure shall be avoided during installation by complying with the following conditions as presented in the Report of Assessment:

- Minimum edge distance, c_{min}
- Minimum spacing, s_{min}
- Minimum concrete member thickness, h_{min} (published in the Report of Assessment)
- Minimum reinforcement

6.2.5.2 Splitting failure due to loading

Verification of splitting failure is not required if one of the following conditions is fulfilled:

(a) The concrete member depth is $h > h_{min} = c_{cr,sp}$ and one 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 splitting forces limits crack width to $w_k \leq 0.3$ mm.

In the case of splitting under load, the characteristic edge distance, $c_{cr,sp}$ and characteristic spacing of fasteners, $s_{cr,sp}$ are published in the Report of Assessment, with the characteristic spacing being equal to $s_{cr,sp} = 2c_{cr,sp}$.

Where guidance is not provided, the required cross-sectional area of reinforcement to resist splitting forces, A_s, may be calculated as follows –

$$A_s = k_{12} \frac{\sum N^*}{\phi_{Ms,re} f_{sy}}$$

where

k_{12} = parameter related to the type of fastener

= 2.0 for deformation-controlled expansion fasteners

= 1.5 for torque-controlled expansion fasteners

= 1.0 for undercut fasteners

= 0.5 for bonded fasteners, headed fasteners and anchor channel

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

f_{sy} = yield strength of reinforcing steel

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

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

In the event that the conditions of either (a) or (b) above are not met, the characteristic strength of a fastener or group of fasteners to splitting failure, $N_{Rk,sp}$ shall be calculated as follows –

$$N_{Rk,sp} = N^0_{Rk,sp} \frac{A_{c,N}}{A^0_{c,N}} \psi_{s,N} \psi_{re,N} \psi_{ec,N} \psi_{h,sp} \tag{29}$$

where

$N^0_{Rk,sp}$ = characteristic strength of a single fastener to splitting failure, given in the Report of Assessment

$A_{c,N}$ = actual projected area of the failure cone of the fastener that is limited by adjacent fasteners and edges of the concrete member, refer to Clause 6.2.2.3

$A^0_{c,N}$ = reference projected area of the failure cone of a single fastener, refer to Clause 6.2.2.3

$\psi_{s,N}$ = parameter related to the distribution of stresses in the concrete due to the proximity of the fastener to an edge of the concrete member, given in Clause 6.2.2.4 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 6.2.2.5

$\psi_{ec,N}$ = parameter accounting for eccentricity of the resultant load in a fastener group, given in Clause 6.2.2.6 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 actual member thickness, h on splitting strength

$$= \left(\frac{h}{h_{\min}}\right)^{2/3} \leq \max\left\{1; \left(\frac{h_{ef} + 1.5c_1}{h_{\min}}\right)^{2/3}\right\} \leq 2 \tag{30}$$

If multiple member thicknesses, h are published in the Report of Assessment, the adopted characteristic edge distance for splitting failure, $c_{cr,sp}$ shall correspond to the adopted member thickness in Equation (30).

If the characteristic strength of a single fastener to splitting failure, $N^0_{Rk,sp}$ is not published in the Report of Assessment, it may be conservatively estimated as follows –

$$N^0_{Rk,sp} = \min\left\{N_{Rk,p}, N^0_{Rk,c}\right\} \tag{31}$$

where

$N_{Rk,p}$ = characteristic pull-out strength for post-installed mechanical and cast-in fasteners determined in accordance with Clause 6.2.3

$N^0_{Rk,c}$ = characteristic concrete cone strength for post-installed chemical fasteners, determined in accordance with Clause 6.2.2.2

6.2.6 Blow-out failure

6.2.6.1 General

The strength against blow-out failure is a consideration for post-installed mechanical and cast-in headed fasteners undercut anchors acting as headed fasteners if the edge distance is $c \leq 0.5h_{ef}$. The characteristic strength for blow-out failure shall be considered in each direction independently as follows –

$$N_{Rk,cb} = N^0_{Rk,cb}\left(\frac{A_{c,Nb}}{A^0_{c,Nb}}\right)\psi_{s,Nb}\psi_{g,Nb}\psi_{ec,Nb} \tag{32}$$

where

$N^0_{Rk,cb}$ = characteristic strength of a single fastener remote from the effects of adjacent fasteners and edges of the concrete member, refer to Clause 6.2.6.2

$A_{c,Nb}$ = actual projected area for the fastener that is limited by the edges of the concrete member ($c_2 \leq 2c_1$), the presence of adjacent fasteners ($s \leq 4c_1$) or the member thickness, refer to Clause 6.2.6.3

$A^0_{c,Nb}$ = reference projected area of a single fastener with an edge distance equal to c_1 (refer to Figure 25(b)), refer to Clause 6.2.6.3

$\psi_{s,Nb}$ = 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, refer to Clause 6.2.6.4

$\psi_{g,Nb}$ = parameter accounting for a group effect, refer to Clause 6.2.6.5

$\psi_{ec,Nb}$ = parameter accounting for eccentricity of loading on a fastener group, refer to Clause 6.2.6.6

6.2.6.2 Characteristic blow-out strength of an individual fastener

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

$$N^0_{Rk,cb} \quad = \quad k_4 c_1 \sqrt{A_h}\sqrt{f'_c} \tag{33}$$

where

k_4 = parameter related to the state of the concrete

= 8.7 for cracked concrete

= 12.2 for uncracked concrete

c_1 = edge distance of fastener (refer to Figure 25(a))

A_h = load bearing area of the head of the fastener defined in Equation (20) or in the Report of Assessment

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

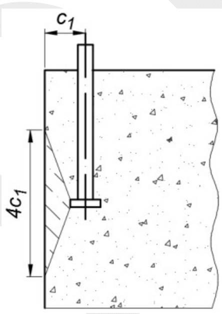
6.2.6.3 Geometric effect of edge distance and spacing

The ratio of $A_{c,Nb}/A^0_{c,Nb}$ takes into account the effect of adjacent fasteners and edges of the concrete member on the characteristic strength of the fastener to blow-out failure where –

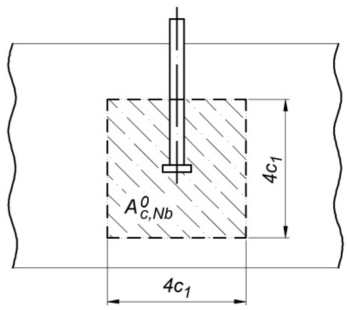
$A^0_{c,Nb}$ = reference projected area of a single fastener with an edge distance equal to c_1, refer to Figure 25

$$= (4c_1)^2 \tag{34}$$

$A_{c,Nb}$ = 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, refer to Figure 26 and Figure 27.

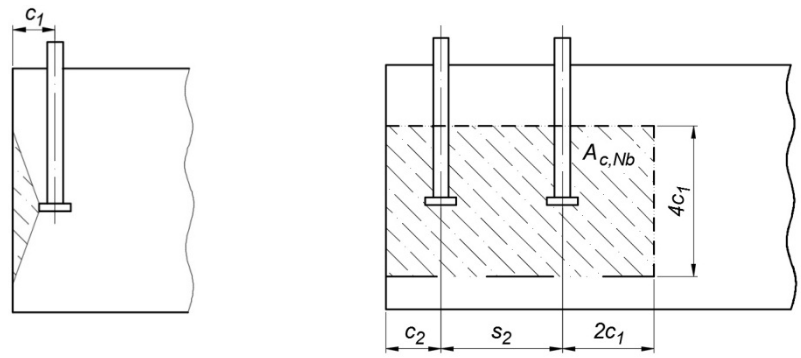


(a) BREAK-OUT BODY



(b) REFERENCE AREA OF BREAK-OUT BODY.

FIGURE 25: IDEALISED BREAK-OUT BODY AND REFERENCE AREA, $A^0_{c,Nb}$ OF AN INDIVIDUAL FASTENER EXPERIENCING BLOW-OUT FAILURE.



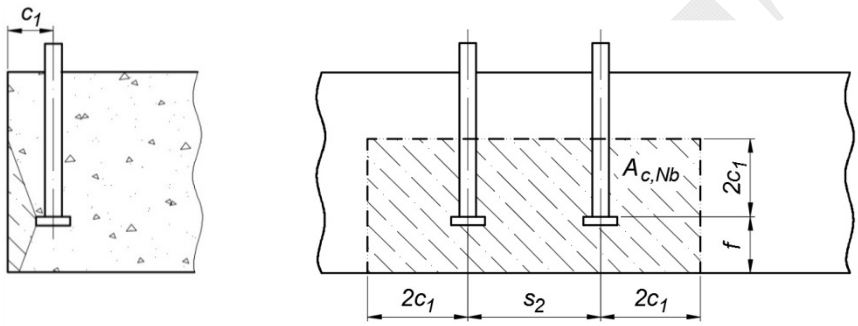
$A_{c,Nb} = 4c_1(c_2 + s_2 + 2c_1)$

$c_2 \leq 2c_1$

$s_2 \leq 4c_1$

(a) BREAK-OUT BODY. (b) IDEALISED AREA OF BREAK-OUT BODY.

FIGURE 26: EXAMPLE BREAK-OUT BODY AND IDEALISED AREA FOR MULTIPLE HEADED FASTENERS CLOSE TO AN EDGE EXPERIENCING BLOW-OUT FAILURE.



$A_{c,Nb} = (2c_1 + f)(4c_1 + s_2)$

$f \leq 2c_1$

$s_2 \leq 4c_1$

(a) BREAK-OUT BODY. (b) IDEALISED AREA OF BREAK-OUT BODY.

FIGURE 27: EXAMPLE BREAK-OUT BODY AND IDEALISED AREA FOR MULTIPLE HEADED FASTENERS WITHOUT EDGE EFFECTS.

6.2.6.4 Distribution of stresses in concrete

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

$$\psi_{s,Nb} = 0.7 + 0.3\frac{c_2}{2c_1} \leq 1 \tag{35}$$

where

c_1 = edge distance of fastener in direction 1

c_2 = edge distance of fastener perpendicular to direction 1 that is the smallest edge distance in a narrow member with multiple edge distances

6.2.6.5 Effect of closely spaced fasteners

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

$$\psi_{g,Nb} = \sqrt{n} + \left(1 - \sqrt{n}\right)\frac{s_1}{4c_1} \geq 1 \tag{36}$$

where

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

s_1 = spacing of fasteners in a group in direction 1

$\leq$ $4c_1$

c_1 = edge distance of fastener

6.2.6.6 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 is calculated in accordance with Clause 6.2.2.6 by substituting $\psi_{ec,Nb}$ for $\psi_{ec,N}$ and $s_{cr,Nb}$ for $s_{cr,N}$ where –

$$s_{cr,Nb} = 4c_1 \tag{37}$$

6.2.7 Supplementary reinforcement

Should the fastener design include provision for supplementary reinforcement, the supplementary reinforcement shall be designed in accordance with AS 3600. The failure modes consideration 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

The verifications in Table 3 shall apply.

6.3.1 Steel failure

The following values for characteristic resistance are provided in the Report of Assessment –

(i) Channel bolt fracture, $N_{Rk,s}$
(ii) Anchor fracture, $N_{Rk,s,a}$
(iii) Connection between anchor and channel, $N_{Rk,s,c}$
(iv) Basic value for local channel, $N^0_{Rk,s,l}$
(v) Local flexure of channel lip, $N_{Rk,s,l}$
(vi) Flexure of channel, $M_{Rk,s,flex}$

6.3.2 Concrete cone failure

The characteristic strength of a single fastener in a channel bar to concrete cone failure is calculated as follows –

$$N_{Rk,c} = N^0_{Rk,c}\psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N} \tag{38}$$

where

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

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

Clause 6.2.2.2.

$\psi_{ch,s,N}$ = parameter accounting for the influence of neighbouring fasteners on the concrete cone strength of a single fastener in the channel bar given in Clause 6.3.2.1

$\psi_{ch,e,N}$ = parameter accounting for the influence of an edge of the concrete member on the concrete cone strength given in Clause 6.3.2.2

$\psi_{ch,c,N}$ = parameter accounting for the influence of a corner on the concrete cone strength, given in Clause 6.3.2.3

$\psi_{re,N}$ = parameter accounting for the shell spalling effect, given in Clause 6.2.2.5

6.3.2.1 Influence of neighbouring fasteners

The influence of neighbouring fasteners on the concrete cone strength is calculated as follows –

$$\psi_{ch,s,N} = \frac{1}{1+\sum_{i=1}^{n_{ch}}\left[\left(1-\frac{s_i}{s_{cr,N}}\right)^{1.5}\frac{N_i}{N_o}\right]} \leq 1 \tag{39}$$

where

$n_{ch,N}$ = number of fasteners within a distance equal to $s_{cr,N}$ of the fastener under consideration (refer to Figure 28

s_i = distance between fastener under consideration and neighbouring fastener 'i'

$s_{cr,N}$ = characteristic spacing of the fastener to ensure the characteristic tensile strength of a single fastener

$$= 2\left(2.8-1.3\frac{h_{ef}}{180}\right)h_{ef} \geq 3h_{ef} \tag{40}$$

N_i = tension force in an influencing fastener 'i'

N_o = tension force in the anchor under consideration

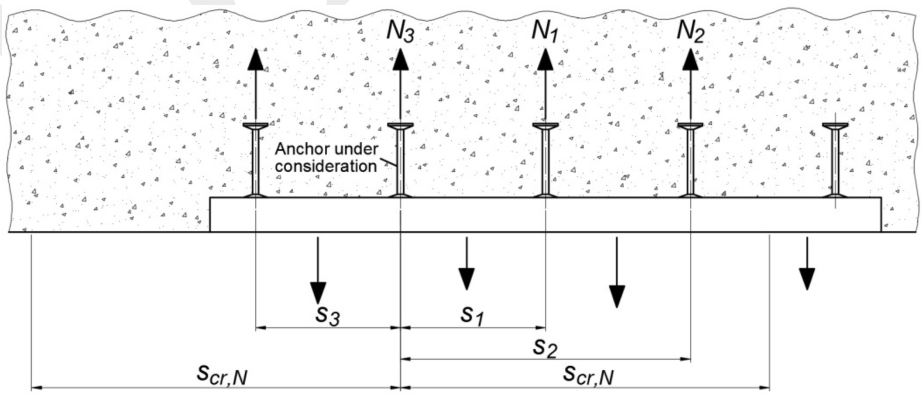


FIGURE 28: EXAMPLE OF ANCHOR CHANNEL CONTAINING MULTIPLE POINT LOADS.

6.3.2.2 Influence of an edge

The influence of an edge on the concrete cone strength of a single fastener is given by –

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \leq 1 \tag{41}$$

where

c_1 = edge distance of the anchor channel (refer to Figure 29(a))

$c_{cr,N}$ = characteristic edge distance of the fastener to ensure the characteristic tensile strength of a single fastener

$$= 0.5 s_{cr,N} \tag{42}$$

When the fastener under consideration is situated in a concrete member containing multiple edge distances (e.g. $c_{1,1}$, $c_{1,2}$ in Figure 29(b)) the minimum edge distance shall be adopted in Equation (41).

(a) CLOSE TO AN EDGE. (b) NARROW MEMBER.

FIGURE 29: ANCHOR CHANNEL LOCATED CLOSE TO AN EDGE AND WITHIN A NARROW MEMBER.

6.3.2.3 Influence of a corner

The parameter representing the influence of a corner on the concrete cone strength, $\psi_{ch,c,N}$, is calculated according to the following –

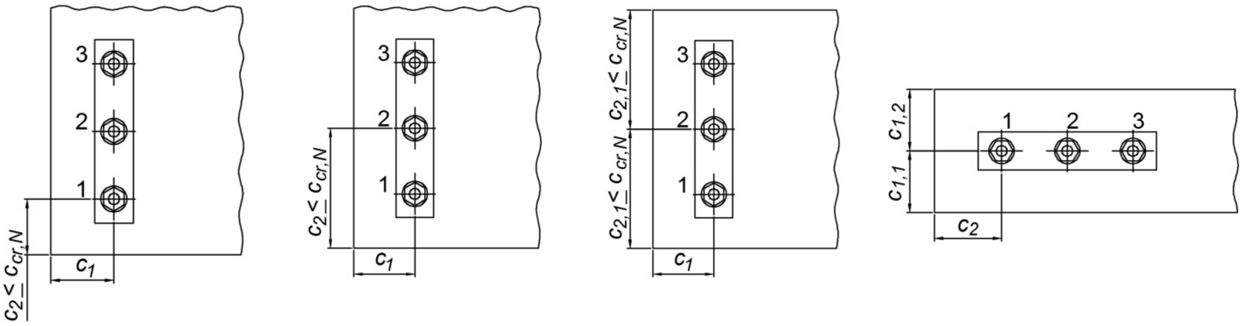
$$\psi_{ch,c,N} = \left(\frac{c_2}{c_{cr,N}}\right)^{0.5} \leq 1 \tag{43}$$

where

c_2 = corner distance for the fastener under consideration (refer to Figure 30)

$c_{cr,N}$ = characteristic edge distance of the fastener to ensure the characteristic tensile strength of a single fastener

If the fastener is influenced by two corners (e.g. $c_{2,1}$, $c_{2,2}$ in Figure 30(c)), $\psi_{ch,c,N}$ shall be determined for the smaller edge distance.



(a) ANCHOR ‘1’ UNDER CONSIDERATION

(b) ANCHOR ‘2’ UNDER CONSIDERATION

(c) ANCHOR ‘2’ UNDER CONSIDERATION

(d) ANCHOR ‘1’ UNDER CONSIDERATION

FIGURE 30: ESTABLISHING THE CORNER DISTANCE OF AN ANCHOR IN CHANNEL LOCATED CLOSE TO A FREE EDGE.

6.3.2.4 Narrow concrete member

The calculation of concrete cone failure strength in Equation (38) is conservative where the anchor under consideration has $h_{ef} > 180$ mm and has at least one of the following circumstances –

- Influenced by neighbouring anchors ($s < s_{cr,N}$)
- Influence of an edge of the concrete member
- Influenced by two corners that have an edge distance less than the characteristic edge distance of the fastener ($c < c_{cr,N}$)

A more precise estimation of strength is obtained by adopting a modified effective embedment depth, h'_{ef} calculated as follows –

$$h'_{ef} = \max\left(\frac{c_{\max}}{c_{cr,N}} h_{ef}, \frac{s_{\max}}{s_{cr,N}} h_{ef}\right) \ge 180mm \qquad (44)$$

where

c_{max} = maximum of all edge distances to the fastener, refer to Figure 30

$c_{cr,N}$ = characteristic edge distance to ensure the transmission of the characteristic strength of a single fastener

s_{max} = maximum centre-to-centre spacing of fasteners (s $\le s_{cr,N}$)

$s_{cr,N}$ = characteristic spacing to ensure the transmission of the characteristic strength of a single fastener

6.3.3 Pull-out failure

The characteristic strength against pull-out failure, $N_{Rk,p}$ is provided in the Report of Assessment and is limited by the bearing pressure under the head of the fastener in accordance with Clause 6.2.3.

6.3.4 Splitting failure

6.3.4.1 Splitting failure during installation

The relevant provisions of Clause 6.2.5.1 apply to prevent splitting failure during anchor channel installation.

6.3.4.2 Splitting failure due to loading

The relevant provisions of Clause 6.2.5.2 apply to prevent splitting failure due to loading with consideration of the anchor channel acting as a group.

In the event that verification of splitting failure is required the characteristic strength to splitting failure, $N_{Rk,sp}$ shall be calculated as follows –

$$N_{Rk,sp} = N^0_{Rk}\psi_{ch,s,N}\psi_{ch,e,N}\psi_{ch,c,N}\psi_{ch,re,N}\psi_{h,sp} \quad (45)$$

where

$$N^0_{Rk} = \min(N_{Rk,p}, N^0_{Rk,c}) \quad (46)$$

$N_{Rk,p}$ = characteristic pull-out strength of fastener, given in Clause 6.2.3

$N^0_{Rk,c}$ = characteristic concrete cone strength, given in Clause 6.2.2.2

$\psi_{ch,s,N}$ = parameter accounting for the influence of neighbouring fasteners, given by Equation 6.3.2.1

$\psi_{ch,e,N}$ = parameter accounting for the influence of an edge of the concrete member, given by Equation 0

$\psi_{ch,c,N}$ = parameter accounting for the influence of a corner, given by Equation 6.3.2.3

$\psi_{re,N}$ = parameter accounting for the shell spalling effect, given in Clause 6.2.2.5

$\psi_{h,sp}$ = parameter accounting for the influence of actual member thickness, h, given in Clause 6.2.5.2

The values $s_{cr,sp}$ and $c_{cr,sp}$ replace $s_{cr,N}$ and $c_{cr,N}$, respectively in the determination of $\psi_{ch,s,N}$, $\psi_{ch,e,N}$, and $\psi_{ch,c,N}$ and correspond to a minimum allowable member thickness, h_{min}.

6.3.5 Blow-out failure

If the fastener has an edge distance greater than $c = 0.5h_{ef}$, verification for blow-out failure is not required. For lesser edge distances, the strength against blow-out failure is calculated as follows –

$$N_{Rk,cb} = N^0_{Rk,cb}\psi_{ch,s,Nb}\psi_{ch,c,Nb}\psi_{ch,h,Nb} \quad (47)$$

where

$N^0_{Rk,cb}$ = characteristic strength of a single fastener to blow-out failure given in Clause 6.2.6.2.

$\psi_{ch,s,Nb}$ = parameter accounting for the influence of neighbouring fasteners calculated according to Clause 6.3.2.1 by substituting $s_{cr,Nb}$ for $s_{cr,N}$, where $s_{cr,Nb} = 4c_1$.

$\psi_{ch,c,Nb}$ = parameter accounting for the influence of a corner of the concrete member, calculated according to Clause 6.3.2.3and substituting $\psi_{ch,c,Nb}$ for $\psi_{ch,c,N}$ and $c_{cr,Nb}$ for $c_{cr,N}$ where

$c_{cr,Nb} = 0.5s_{cr,Nb}$.

$\psi_{ch,h,Nb}$ = parameter accounting for the influence of thickness of the concrete member, given in Clause 6.3.5.1.

6.3.5.1 Thickness of concrete member

Where the distance between the head of the fastener and the upper or lower surface of the concrete member, f is less than or equal to $2c_1$ (refer to Figure 31), the influence of member thickness on the blow-out strength is accounted for as follows –

$$\psi_{ch,h,Nb} = \frac{h_{ef} + f}{4c_1} \le \frac{2c_1 + f}{4c_1} \le 1 \tag{48}$$

where

h_{ef} = effective embedment depth of the fastener

f = distance between the head of the fastener and the upper or lower surface of the concrete member, refer to Figure 31

c_1 = edge distance in direction 1

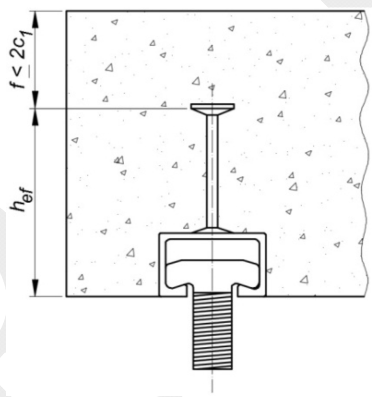
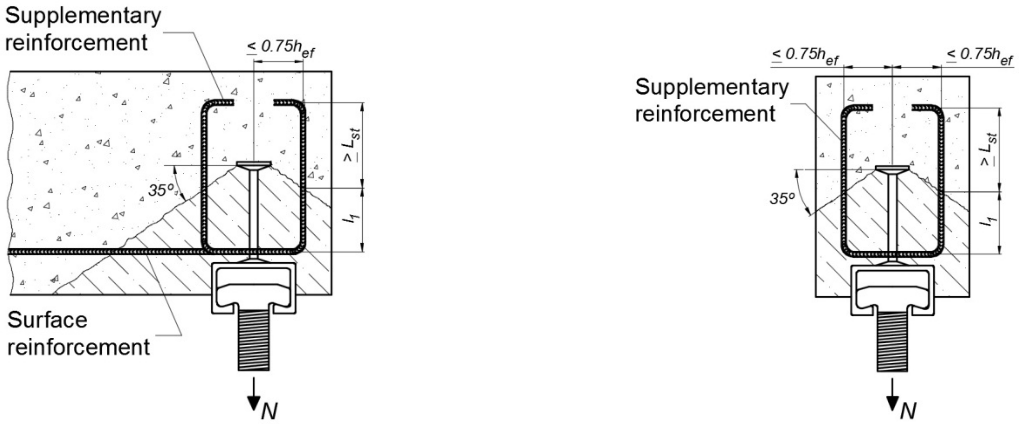


FIGURE 31: ANCHOR CHANNEL LOCATED IN A THIN CONCRETE MEMBER.

6.3.6 Supplementary reinforcement failure

Should the design of anchor channel include provision for supplementary reinforcement (see detailing requirements in Figure 32), Clause 6.2.7 shall be followed.



(a) CLOSE TO AN EDGE (b) NARROW CONCRETE MEMBER

FIGURE 32: SUPPLEMENTARY REINFORCEMENT ARRANGEMENT FOR ANCHOR CHANNEL.

7 DESIGN FOR SHEAR LOADING

7.1 GENERAL

The characteristic strength to shear loading for the modes of failure for post-installed fasteners and cast-in headed fasteners outlined in Table 4 is determined in accordance with Clause 6.2. The characteristic strength to shear loading for the modes of failure for anchor channel outlined in Table 5 is determined in accordance with Clause 6.3.

7.2 POST-INSTALLED FASTENERS AND CAST-IN HEADED FASTENERS

The verifications in Table 4 shall apply.

7.2.1 Steel failure

The presence of a lever arm for the purpose of design for shear load is determined in accordance with Clause 4.2.2.3 and Clause 4.2.2.4.

7.2.1.1 Shear force without lever arm

The characteristic shear strength of a fastener in shear, $V^0_{Rk,s}$ is provided in the Report of Assessment.

For a single fastener made from carbon steel that does not include a significant reduction in cross-section along its total length and that does not include a sleeve in the sheared section, $V_{Rk,s}$ should be determined in accordance with the requirements of AS 4100.

Note that for fasteners with h_{ef} / d < 5 in concrete having f'_c < 20 MPa, $V_{Rk,s}$ should be multiplied by a factor equal to 0.8.

Where a grout layer is present with a thickness $t_{grout} \leq 0.5d$, the characteristic shear strength of the fastener accounting for ductility, $V^0_{Rk,s,m}$ becomes –

$$V^0_{Rk,s,m} = k_{51} V_{Rk,s} \tag{49}$$

where

k_{51} = parameter published in the Report of Assessment that is applied for groups of fasteners

= 1 for single fasteners

If a fastener in a group is made from ductile steel it may be assumed that k_{51} = 1. If the fastener is made from steel with low ductility or steel that is non-ductile it may be assumed that k_{51} = 0.8.

Where the conditions of multiple fasteners in a fixture fulfil the requirements of Clause 4.2.2.3(b) the characteristic shear strength of one fastener, $V_{Rk,s}$ in uncracked concrete becomes –

$$V_{Rk,s} = \left(1 - 0.01 t_{grout}\right) k_{51} V^0_{Rk,s} \tag{50}$$

7.2.1.2 Shear force with lever arm

Where the fastener is considered to include a lever arm (refer to Clause 4.2.2.3(a)) the characteristic steel shear strength, $V_{Rk,s,M}$ shall be calculated as follows –

$$V_{Rk,s,M} = \frac{\alpha_M M_{Rk,s}}{l_a} \tag{51}$$

where

α_M = parameter accounting for the degree of restraint, given in Clause 4.2.2.4

l_a = length of lever arm, refer to Figure 17

$$M_{Rk,s} = M^{o}_{Rk,s}\left(1 - N^{*}/\phi_{s} N_{Rk,s}\right) \tag{52}$$

N^* = design tension load

$N_{Rk,s}$ = characteristic tensile strength of a fastener to steel failure

The characteristic flexural strength of the fastener, $M^0_{Rk,s}$, the characteristic tensile strength of the fastener, $N_{Rk,s}$ and the material capacity reduction factor, ϕ_{Ms} are published in the Report of Assessment.

7.2.2 Concrete edge failure

7.2.2.1 General

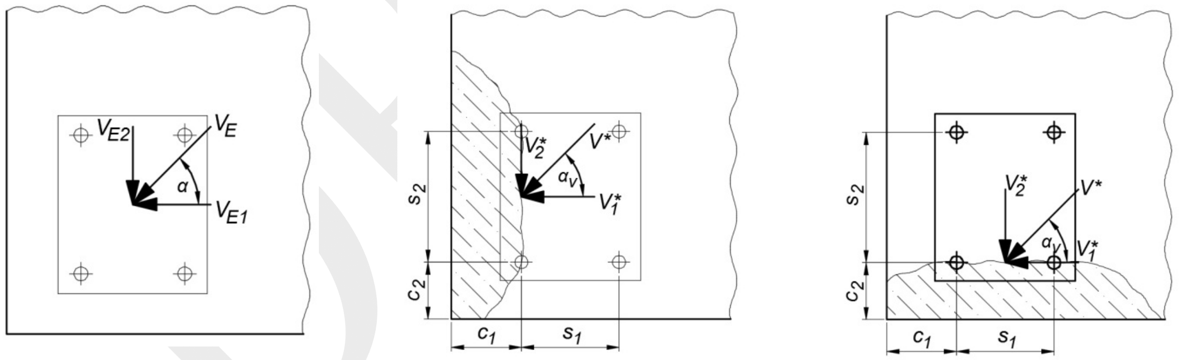
If fasteners are located in an embedded base plate that has a thickness $t < 0.25h_{ef}$ and the edge distance in the direction of shear load is $c \leq \max(10h_{ef}; 60d)$, the provisions for calculating strength against concrete edge failure remain valid.

If the shear load acts with a lever arm, the provisions for calculating strength against concrete edge failure are valid if $c > \max(10h_{ef}; 60d)$.

In a fastener group only the fasteners located closest to the edge are considered in the provisions for calculating strength against concrete edge failure.

Where a concrete member contains multiple edges (refer to Figure 33), the verification of strength against concrete edge failure shall be performed in each direction.

The minimum spacing between fasteners in a group shall be $s_{min} \geq 4d_{nom}$.



(a) APPLICATION OF LOAD TO FIXTURE.

(b) VERIFICATION OF FASTENERS ON LEFT EDGE.

(c) VERIFICATION OF FASTENERS ON LOWER EDGE.

FIGURE 33: VERIFICATION OF STRENGTH OF A FIXTURE LOADED IN SHEAR AND CONTAINING FASTENERS WITH HOLE CLEARANCE LOCATED CLOSE TO AN EDGE.

The characteristic resistance of a single fastener or fastener group to concrete edge failure is calculated as follows –

$$V_{Rk,c} = V^{0}_{Rk,c}\left(\frac{A_{c,V}}{A^{0}_{c,V}}\right)\psi_{s,V}\psi_{h,V}\psi_{ec,V}\psi_{\alpha,V}\psi_{re,V} \tag{53}$$

where

$V^0_{Rk,c}$ = initial value of the characteristic shear strength of the fastener, given in Clause 7.2.2.2

$A_{c,V}$ = actual area of idealised concrete break-out body, given in Clause 7.2.2.3

$A^0_{c,V}$ = reference projected area of failure cone, given in Clause 7.2.2.3

$\psi_{s,V}$ = parameter accounting for the disturbance to the distribution of stresses in the concrete member, given in Clause 7.2.2.4

$\psi_{h,V}$ = parameter accounting for the influence of member thickness, given in Clause 7.2.2.5

$\psi_{ec,V}$ = parameter accounting for the eccentricity of the resultant load in a fastener group, given in Clause 7.2.2.6

$\psi_{\alpha,V}$ = parameter accounting for the angle of the applied load, given in Clause 7.2.2.7

$\psi_{re,V}$ = parameter accounting for the shell spalling effect, given in Clause 7.2.2.8

7.2.2.2 Basic characteristic shear strength

The basic characteristic shear strength of a single fastener loaded perpendicular to the edge of the concrete member is calculated as follows –

$$V^0_{Rk,c} = k_5 d_{nom}^{\alpha} l_f^{\beta} \sqrt{f'_c}\, c_1^{1.5} \quad (54)$$

where

k_5 = parameter accounting for the state of the concrete

= 1.7 for cracked concrete

= 2.4 for non-cracked concrete

d_{nom} = outside diameter of fastener, published in the Report of Assessment

$$\alpha = 0.1\left(\frac{l_f}{c_1}\right)^{0.5} \quad (55)$$

$$\beta = 0.1\left(\frac{d_{nom}}{c_1}\right)^{0.2} \quad (56)$$

l_f = parameter related to the length of the fastener, published in the Report of Assessment

= h_{ef} for headed fasteners with a uniform shank diameter and post-installed fastener with a uniform diameter

≤ $12d_{nom}$ where $d_{nom} \leq 24$ mm

≤ max($8d_{nom}$, 300 mm) where $d_{nom} > 24$ mm

≤ 60 mm

f'_c = characteristic compressive strength of concrete

c_1 = edge distance of fastener

7.2.2.3 Geometric effect of spacing and edge distance

The geometric effect of fastener spacing and concrete member thickness are accounted for by the ratio $A_{c,V}/A^0_{c,V}$ where –

$A_{c,V}$ = actual area of idealised concrete break-out body (refer to Figure 35), limited by:

i) overlapping areas from adjacent fasteners ($s \leq 3c_1$)
ii) edges parallel to the assumed loading direction ($c_2 \leq 1.5c_1$)
iii) member thickness ($h < 1.5c_1$)

$A^0_{c,V}$ = reference projected area of the break-out body (refer to Figure 34)

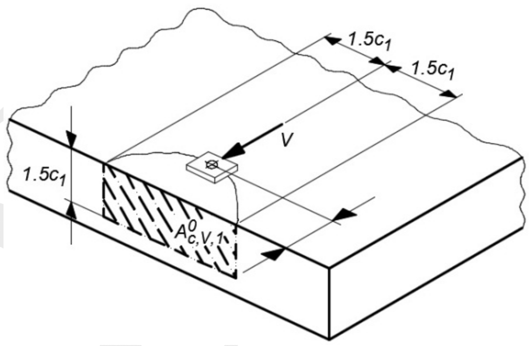
$$= 4.5c_1^2 \tag{57}$$

Where a fixture contains two fasteners and is loaded by a torsion moment such that the fasteners are loaded in opposing shear, the calculation of the basic characteristic strength, $V^0_{Rk,c}$ may be non-conservative for concrete edge failure where concrete break-out bodies overlap. If the ratio between the concrete edge break-out strength of the verified edge to the concrete break-out strength of the second fastener (either pry-out or edge break-out failure) is greater than 0.7 and $s_2 \leq s_{crit}$, Equation (54) should be multiplied by a factor equal to 0.8 which is assumed to be conservative.

The critical spacing under shear loading, s_{crit} is defined as follows –

s_{crit} = $1.5h_{ef} + 1.5c_1$ if the second fastener is governed by pry-out failure

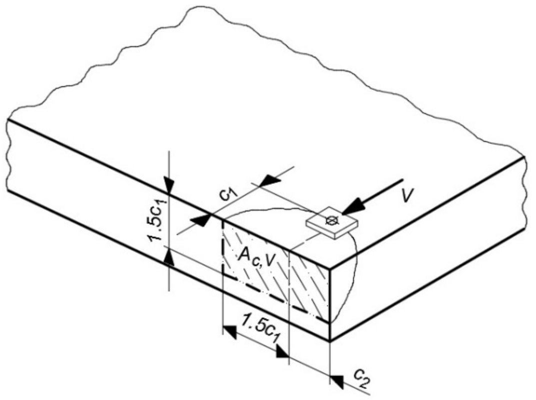
= $1.5h_{ef}$ if the second fastener is governed by concrete edge failure relative to a second edge that is perpendicular to the verified edge



$A^0_{c,V,1} = (2 \text{ x } 1.5c_1) \text{ x } 1.5c_1$

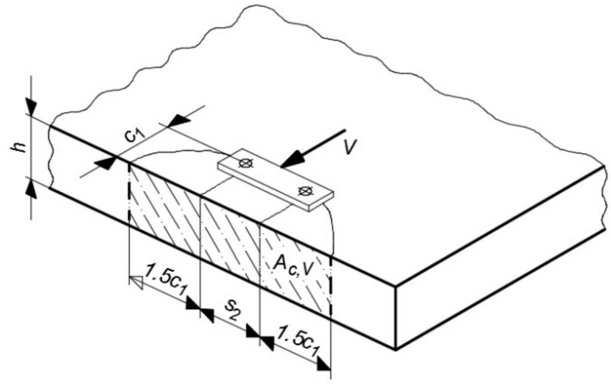
$= 4.5c_1^2$

FIGURE 34: FASTENER LOADED IN SHEAR CLOSE TO AN EDGE SHOWING IDEALISED BREAK-OUT BODY AND CALCULATION OF AREA, $A^0_{c,V,1}$.



$A_{c,V} = 1.5c_1(1.5c_1 + c_2)$
$h \geq 1.5c_1$
$c_2 \leq 1.5c_1$

(b) SINGLE FASTENER WITH BREAK-OUT BODY INFLUENCED BY CORNER.



$A_{c,V} = (2\text{x}1.5c_1 + s_2)\text{h}$
$h < 1.5c_1$
$s_2 \leq 3c_1$

(c) DOUBLE FASTENER IN A THIN MEMBER.

FIGURE 35: EXAMPLE PROJECTED AREAS, $A_{c,V}$ CALCULATED FOR BREAK-OUT BODIES FROM FASTENER ARRANGEMENTS LOADED IN SHEAR.

7.2.2.4 Disturbance to the distribution of stresses

The effect on the edge break-out strength of the disturbance to the distribution of stresses in the concrete is accounted for by the parameter $\psi_{s,V}$ as follows –

$$\psi_{s,V} \quad = \quad 0.7 + 0.3\frac{c_2}{1.5c_1} \leq 1 \qquad (58)$$

where

c_1 = edge distance of fastener in direction '1'

c_2 = edge distance of fastener in direction '2'

In a narrow member where there are two edges parallel to the direction of loading, the smaller of the two edge distances shall be adopted for c_2.

7.2.2.5 Influence of member thickness

The ratio $A_{c,V}/A^0_{c,V}$ does not accurately represent the proportional change in concrete edge strength with member thickness, thus the parameter $\psi_{h,V}$ is adopted to rectify this where –

$$\psi_{h,V} \quad = \quad \left(\frac{1.5c_1}{h}\right)^{0.5} \geq 1 \qquad (59)$$

where

c_1 = edge distance of fastener

h = concrete member thickness

7.2.2.6 Eccentricity of loading on a fastener group

The parameter $\psi_{ec,V}$ accounts for a group effect when there is different shear loads resisted by individual fasteners in the group as follows –

$$\psi_{ec,V} = \frac{1}{1 + 2.e_V / (3c_1)} \leq 1 \tag{60}$$

where

e_V = eccentricity of the resultant shear force acting on a group of fasteners relative to the centre of gravity of the fasteners loaded in shear (refer to Figure 36)

c_1 = edge distance of fastener

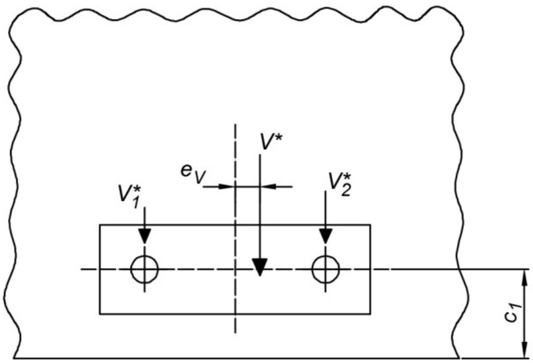


FIGURE 36: FIXTURE THAT HAS A SHEAR LOAD, V_{Ed} THAT HAS BEEN LOADED ECCENTRICALLY BY AN AMOUNT EQUAL TO e_V.

7.2.2.7 Direction of loading

The parameter $\psi_{\alpha,V}$ accounts for the influence on edge break-out strength of the shear load applied at an angle to the free edge under consideration and shall be calculated as –

$$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos\alpha_V)^2 + (0.5\sin\alpha_V)^2}} \geq 1 \tag{61}$$

where

α_V = angle between the applied load to the fastener or fastener group and the direction perpendicular to the free edge under consideration, $0 \leq \alpha_V \leq 90^o$

7.2.2.8 Edge reinforcement

The influence of edge reinforcement on the edge break-out strength is accounted for by the parameter $\psi_{re,V}$ as follows –

$\psi_{re,V}$ = 1.0 for fasteners in cracked concrete without edge reinforcement or stirrups or in non-cracked concrete

= 1.4 for fasteners in cracked concrete containing edge reinforcement that includes stirrups or wire mesh with spacing $a \leq 100$ mm and $a \leq 2c_1$. This factor may only be applied if the effective embedment depth, h_{ef} is at least equal to 2.5 times the cover of the edge reinforcement.

7.2.2.9 Narrow concrete member

For a narrow member, $c_{2,max} < 1.5c_1$ that is also deemed to be thin, $h < 1.5c_1$, Equation (53) provides a conservative estimation of the edge break-out strength, $V_{Rk,c}$. A more precise calculation of $V_{Rk,c}$ is achieved by substituting c'_1 for c_1 (refer to Figure 37) in Equations (54) – (60) including for the determination of $A_{c,V}$ and $A^0_{c,V}$, where –

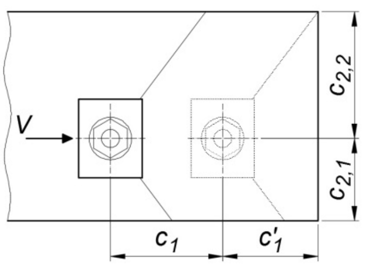
$$c'_1 = \max\{c_{2,\max}/1.5\,, h/1.5\} \quad \text{for single fasteners} \tag{62}$$

$$= \max\{c_{2,\max}/1.5\,, h/1.5\,, s_{c,\max}/3\} \quad \text{for fastener groups} \tag{63}$$

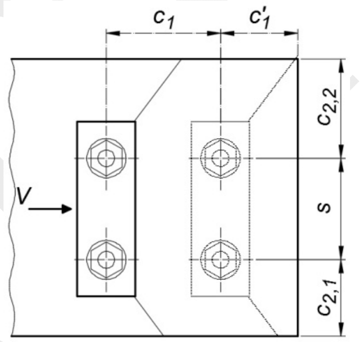
where

$c_{2,max}$ = largest of the two edge distances parallel to the direction of loading in the case of a single fastener

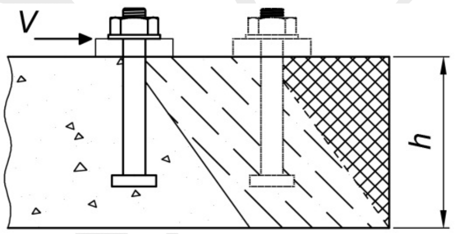
$s_{2,max}$ = maximum spacing between fasteners in a group in direction '2'



(a) SINGLE FASTENER.



(b) MULTIPLE FASTENERS.



max($c_{2,1}$ and $c_{2,2}$) < $1.5c_1$ and
$h < 1.5c_1$

(c) CROSS-SECTION VIEW OF FASTENER(S).

FIGURE 37: FASTENERS LOCATED IN THIN CONCRETE MEMBERS LOADED IN SHEAR SHOWING BREAK-OUT BODY AND REVISED BREAK-OUT BODY BASED ON THE REVISED EDGE DISTANCE, c'_1.

7.2.3 Concrete pry-out failure

Verification of the strength of the fastener or fastener group against concrete pry-out failure includes pry-out failure on the side opposite to the direction of loading, as well as a tension force that may be induced in the fastener as a result of shear loading.

The characteristic strength of a headed or mechanical post-installed fastener to pry-out failure is calculated as follows –

$$V_{Rk,cp} = k_3 N_{Rk,c} \text{ for fastenings without supplementary reinforcement} \tag{64}$$

$$= 0.75 k_3 N_{Rk,c} \text{ for fastenings with supplementary reinforcement} \tag{65}$$

where

k_3 = parameter published in the Report of Assessment

$N_{Rk,c}$ = characteristic concrete cone strength for a single fastener or fastener in a group, determined in accordance with Clause 6.3.2

The characteristic strength of a bonded post-installed fastener to pry-out failure is calculated as follows –

$V_{Rk,cp}$ = $k_3 \min(N_{Rk,c}, N_{Rk,p})$ for fastenings without supplementary reinforcement (66)

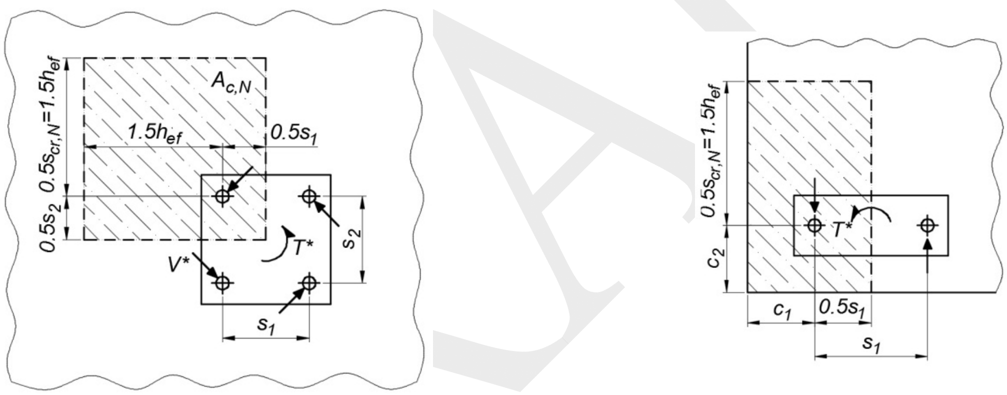
= $0.75 k_3 \min(N_{Rk,c}, N_{Rk,p})$ for fastenings with supplementary reinforcement (67)

where

$N_{Rk,p}$ = characteristic strength against pull-out failure for a single fastener or all fasteners in a group loaded in shear, determined in accordance with Clause 6.2.3

Where multiple fasteners are present in a group and opposing shear forces are applied, such as the condition where a torsion moment is applied, the most adverse condition shall be verified.

The determination of $A_{c,N}$ shall include a virtual edge equal to 0.5s in the direction of the neighbouring fastener(s) (refer to Figure 38).



(a) (b)

FIGURE 38: GROUP OF FASTENERS LOADED IN SHEAR SHOWING THE CALCULATION OF THE AREA, $A_{c,N}$ FOR PRY-OUT FAILURE DUE TO THE SHEAR COMPONENT OF THE LOAD ACTING ON ONE OF THE FASTENERS IN THE GROUP, ASSUMING $s_{cr,N} = 3h_{ef}$.

7.2.4 Supplementary reinforcement

Should the fastener design include provision for supplementary reinforcement, Clause 6.2.7 shall be followed.

7.3 CAST-IN ANCHOR CHANNEL

The verifications in Table 5 shall apply.

7.3.1 Steel failure

The presence of a lever arm for the purpose of design for shear load is determined in accordance with Clause 4.2.2.3 and Clause 4.2.2.4.

7.3.1.1 General

The following strengths are published in the Report of Assessment –

(a) Characteristic shear strength of anchor against steel fracture, $V_{Rk,s,a}$
(b) Characteristic shear strength of anchor against failure of the connection between anchor and channel, $V_{Rk,s,c}$
(c) Basic characteristic shear strength of anchor against local failure by flexure of the channel lips, $V^0_{Rk,s,l}$
(d) Characteristic shear strength of channel bolt, $V_{Rk,s}$
(e) Characteristic flexural strength of an anchor channel, $M_{Rk,s,flex}$

7.3.1.2 Flexural failure of channel lips

The characteristic strength against flexural failure of the channel lips shall be calculated as follows –

$$V_{Rk,s,l} = V^0_{Rk,s,l}\psi_{l,V} \tag{68}$$

where

$$\psi_{l,V} = 0.5\left(1+\frac{s_{cbo}}{s_{l,V}}\right) \le 1$$

s_{cbo} = actual spacing of anchor channel bolts

$s_{l,V}$ = characteristic spacing for channel lip failure under shear loading, published in the Report of Assessment. A value of $s_{l,V} = 2b_{ch}$ may be adopted if no further guidance is available.

7.3.1.3 Shear force with lever arm

Where the fastener is considered to include a lever arm (refer to Clause 4.2.2.3) the characteristic steel shear strength, $V_{Rk,s,M}$ shall be calculated in accordance with Clause 7.2.1.2.

The Report of Assessment includes information addressing the influence of a shear load with lever arm on channel lip failure.

7.3.2 Concrete edge failure

7.3.2.1 General

The strength against concrete edge failure, $V_{Rk,c}$ may be calculated as follows –

$$V_{Rk,c} = V^0_{Rk,c}\psi_{ch,s,V}\psi_{ch,c,V}\psi_{ch,h,V}\psi_{ch,90^o,V} \quad (69)$$

where

$V^0_{Rk,c}$ = basic characteristic shear strength of fastener, given in Clause 7.3.2.2

$\psi_{ch,s,V}$ = parameter accounting for the disturbance to the distribution of stresses in the concrete, given in Clause 7.3.2.3

$\psi_{ch,c,V}$ = parameter accounting for the influence of a corner, given in Clause 7.3.2.4

$\psi_{ch,h,V}$ = parameter accounting for the influence of member thickness, given in Clause 7.3.2.5

$\psi_{ch,90^o,V}$ = parameter accounting for the influence of shear loads acting parallel to the free edge of the concrete member, given in Clause 7.3.2.6

7.3.2.2 Basic characteristic shear strength

The basic characteristic shear strength of a single fastener loaded perpendicular to the edge of the concrete member, $V^0_{Rk,c}$ is calculated as follows –

$$V^0_{Rk,c} = k_{10}\sqrt{f'_c}\,c_1^{4/3} \quad (70)$$

where

k_{10} = parameter related to the state of concrete that is published in the Report of Assessment where

i) $k_{10} = k_{cr,V}$ for cracked concrete and $k_{cr,V} = 4.0$ may be used if $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$

ii) $k_{10} = k_{ucr,V}$ for uncracked concrete and $k_{ucr,V} = 5.6$ may be used if $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$

f'_c = characteristic compressive strength of concrete

c_1 = edge distance of fastener

7.3.2.3 Disturbance to the distribution of stresses

The disturbance to the distribution of stresses in the concrete is accounted for by the parameter $\psi_{ch,s,V}$ as follows –

$$\psi_{ch,s,V} = \frac{1}{1+\sum_{i=1}^{n}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5}\frac{V_i}{V_o}\right]} \leq 1 \quad (71)$$

where

n = number of anchors that are within a distance $s_{cr,V}$ to the anchor under consideration

s_i = distance between the anchor under consideration and neighbouring anchors

$\leq$ $s_{cr,V}$

$s_{cr,V}$ = characteristic spacing of fasteners to ensure the transmission of the characteristic shear strength of a single fastener, published in the Report of Assessment

$\geq$ $4c_1 + 2b_{ch}$ when $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$ (72)

V_i = shear force applied to an influencing anchor

V_o = shear force applied to the anchor under consideration

Equation (71) assumes only shear forces acting towards the edge are considered. Shear forces acting away from the edge may be neglected.

7.3.2.4 Influence of a corner

The parameter $\psi_{ch,c,V}$ accounts for the influence of a corner on the characteristic edge strength of a fastener (refer to Figure 39(a)) as follows –

$$\psi_{ch,c,V} = \left(\frac{c_2}{c_{cr,V}}\right)^{0.5} \leq 1 \tag{73}$$

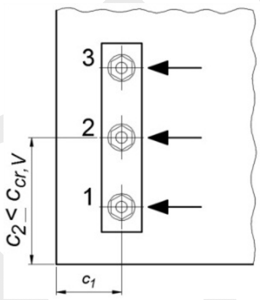
where

c_2 = edge distance of fastener in direction ‘2’

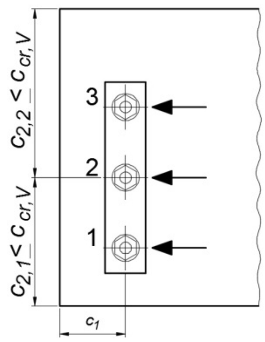
$c_{cr,V}$ = characteristic edge distance

= $0.5s_{cr,V}$ (74)

If a fastener is influenced by two corners (refer to Figure 39(b)), $\psi_{ch,c,V}$ shall be determined individually for the two directions and the product of the respective $\psi_{ch,c,V}$ values shall be inserted in Equation (69).



(a) ANCHOR CHANNEL CLOSE TO CORNER



(b) ANCHOR CHANNEL IN NARROW MEMBER

FIGURE 39: ANCHOR CHANNEL LOCATED CLOSE TO AN EDGE OR IN A NARROW MEMBER WITH ANCHOR ‘2’ UNDER CONSIDERATION.

7.3.2.5 Influence of member thickness

The parameter $\psi_{ch,h,V}$ accounts for the influence of member thickness on the characteristic edge strength of the fastener as follows –

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0.5} \leq 1 \quad (75)$$

where

h = member thickness when $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$

$h_{cr,V}$ = characteristic member thickness for a fastener taken from the Report of Assessment

$\geq$ $2c_1 + 2h_{ch}$ (refer to Figure 40) where $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$ (76)

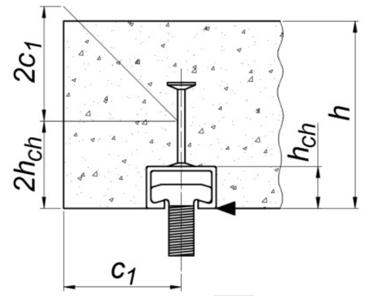


FIGURE 40: EXAMPLE OF THE SHEAR RESISTANCE OF ANCHOR CHANNEL INFLUENCED BY CONCRETE MEMBER THICKNESS.

7.3.2.6 Direction of loading

The parameter $\psi_{ch,90^o,V}$ accounts for the presence of a shear load acting parallel to the edge (refer to Figure 41) such that –

$$\psi_{ch,90^o,V} = 2.5 \quad (77)$$

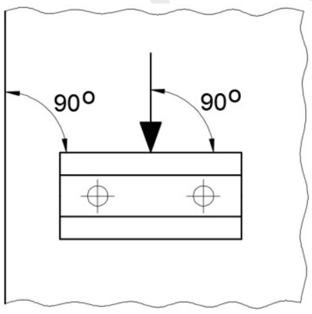


FIGURE 41: EXAMPLE OF ANCHOR CHANNEL LOADED IN SHEAR PARALLEL TO THE EDGE OF THE CONCRETE MEMBER.

7.3.2.7 Narrow concrete member

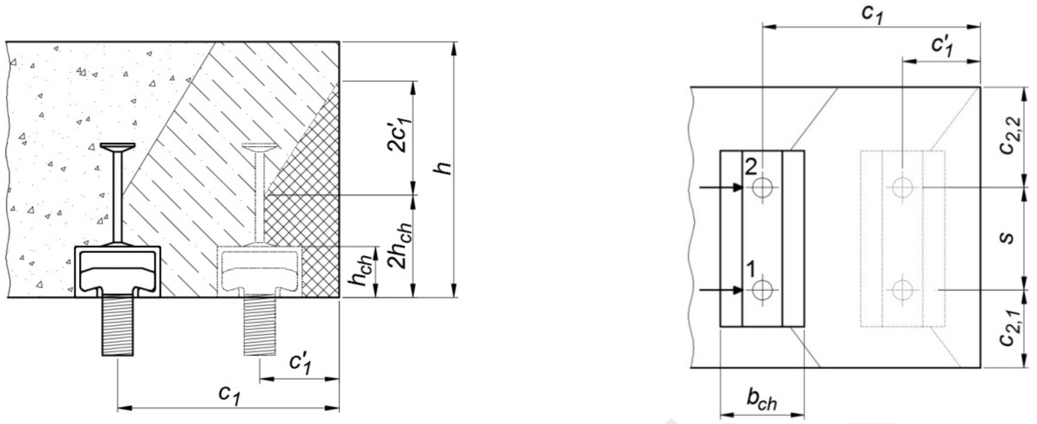
For a narrow member, $c_{2,max} \leq c_{cr,V}$ (refer to Equation (74)) that is also deemed to be thin, $h < h_{cr,V}$ (refer to Equation (76)), Equation (69) provides a conservative estimation of the concrete edge strength, $V_{Rk,c}$. A more precise calculation of $V_{Rk,c}$ is achieved by substituting c'_1 for c_1 in Equations (70), (72), and (76) (also refer to Figure 42). The value of c'_1 may be calculated as follows –

$$c'_1 = \max((c_{2,max} - b_{ch})/2, (h - 2h_{ch})/2) \quad (78)$$

where

$c_{2,max}$ = greatest edge distance parallel to the direction of the applied load

	=	max($c_{1,1}$, $c_{2,2}$)	(79)
b_{ch}	=	width of the anchor channel	



(a) CROSS-SECTION OF BREAK-OUT BODY AND REFINED BREAK-OUT BODY.

(b) PLAN VIEW OF ANCHOR CHANNEL.

FIGURE 42: EXAMPLE ILLUSTRATION OF ANCHOR CHANNEL STRENGTH INFLUENCED BY EDGE EFFECTS AND MEMBER THICKNESS WITH ANCHOR '2' UNDER CONSIDERATION AND c'_1 DETERMINED ON THE BASIS OF $c_{2,2}$ BEING DECISIVE.

7.3.3 Concrete pry-out failure

The strength against pry-out shall be determined for the most unfavourable fastener with the characteristic strength against pry-out failure, $V_{Rk,cp}$ determined as follows –

$$V_{Rk,cp} = k_3 N_{Rk,c} \tag{80}$$

where

k_3	=	parameter published in the Report of Assessment for concrete without supplementary reinforcement
	=	0.75 for concrete containing supplementary reinforcement
$N_{Rk,c}$	=	characteristic strength of a single fastener to concrete cone failure, determined in accordance with Clause 6.3.2.

7.3.4 Supplementary reinforcement

Should the fastener design include provision for supplementary reinforcement, Clause 6.2.7 shall be followed.

8 DESIGN FOR COMBINED TENSION AND SHEAR LOADING

8.1 STEEL FAILURE

8.1.1 Post-installed fasteners and cast-in headed fasteners

An assessment of the performance under combined tension and shear loading of the fastener should be performed in accordance with AS 4100 based upon characteristic strength of the headed fastener or post-installed fastener published in the Report of Assessment.

8.1.2 Cast-in Anchor channel

8.1.2.1 Steel failure of the channel bolt

An assessment of the performance under combined tension and shear loading of the channel bolt should be performed in accordance with AS 4100 based upon characteristic strength of the channel bolt published in the Report of Assessment.

8.1.2.2 Anchor channel without supplementary reinforcement

8.1.2.2.1 Channel lip and flexural failure of channel

Verification of the steel failure modes including channel lip and flexural failure of the channel is calculated according to the following equation –

$$\max\left(\left(\frac{N_{cb}*}{\phi_{s.l}N_{Rk,s,l}}\right);\left(\frac{M_{ch}*}{\phi_{Ms.flex}M_{Rk,s,flex}}\right)\right)^{k_{71}}+\left(\frac{V_{cb}*}{\phi_{s,l}V_{Rk,s,l}}\right)^{k_{71}}=1 \tag{81}$$

where

$N_{cb}*$	=	design tensile load acting on one channel bolt in the anchor channel
$M_{ch}*$	=	design bending moment experienced by anchor channel due to the application of design tensile load, $N_{ch}*$
$V_{cb}*$	=	design shear load acting on one channel bolt in the anchor channel
$N_{Rk,s,l}$	=	characteristic tensile strength for local flexural failure of channel lips
$M_{Rk,s,flex}$	=	characteristic flexural strength of anchor channel
$V_{Rk,s,l}$	=	characteristic shear strength for local flexural failure of channel lip
$\phi_{s.l}$	=	capacity reduction factor for steel failure of anchor channel
$\phi_{Ms,flex}$	=	capacity reduction factor for steel failure of channel in flexure
k_{71}	=	parameter to be taken from the Report of Assessment if $(\phi_{s.l}V_{Rk,s,l}) > (\phi_{s.l}N_{Rk,s,l})$
	=	2.0 if $(\phi_{s.l}V_{Rk,s,l}) \leq (\phi_{s.l}N_{Rk,s,l})$
	=	1.0 as a simplification

8.1.2.3 Anchor and anchor-channel connection modes of failure

Verification of the steel failure modes including fracture of the anchor and fracture of the connection between the anchor and channel is performed according to the following equation –

$$\max\left(\frac{N_a*}{\phi_{s.l}N_{Rk,s,a}};\frac{N_a*}{\phi_{s.l}N_{Rk,s,c}}\right)^{k_{72}}+\left(\frac{V_a*}{\phi_{s.l}V_{Rk,s,a}}\right)^{k_{72}}=1 \quad (82)$$

where

N_a* = design tensile load acting on one anchor in the anchor channel

V_a* = design shear load acting on one anchor in anchor channel

$N_{Rk,s,a}$ = characteristic tensile strength of one anchor in anchor channel to steel fracture

$N_{Rk,s,c}$ = characteristic tensile strength of anchor-channel connection

$V_{Rk,s,a}$ = design shear strength of one anchor in anchor channel to steel fracture

$\phi_{s.l}$ = capacity reduction factor for steel failure of anchor channel

k_{72} = parameter to be taken from the Report of Assessment if $(\phi_{s.l}V_{Rk,s,a}) > \min(\phi_{s.l}N_{Rk,s,a}, \phi_{s.l}N_{Rd,s,c})$

= 2.0 if $\phi_{s.l}V_{Rk,s,a} \le \min(\phi_{s.l}N_{Rk,s,a}, \phi_{s.l}N_{Rk,s,c})$

= 1.0 as a simplification

8.2 FAILURE MODES OTHER THAN STEEL

8.2.1 Post-installed mechanical and chemical fasteners and cast-in headed fasteners

A fastener required to resist the design shear, $V*$ and the design tension, $N*$ simultaneously shall satisfy either of the following –

$$\left(\frac{N*}{\phi_i N_{Rk,i}}\right)^{1.5}+\left(\frac{V*}{\phi_i V_{Rk,i}}\right)^{1.5}\le 1 \quad (83)$$

or

$$\left(\frac{N*}{\phi_i N_{Rk,i}}\right)+\left(\frac{V*}{\phi_i V_{Rk,i}}\right)\le 1.2 \quad (84)$$

where

$N*/(\phi_i N_{Rk,i}) \le 1$ and $V*/(\phi_i V_{Rk,i}) \le 1$

$N*$ = design tension force applied to a single fastener or group

$V*$ = design shear force applied to a single fastener or group

$N_{Rk,i}$ = characteristic tensile strength of fastener or group to failure mode 'i'

$V_{Rk,i}$ = characteristic shear strength of fastener or group to failure mode 'i'

ϕ_i = capacity reduction factor for strength of fastener for failure mode 'i'

The largest value of $N^*/(\phi_i N_{Rk,i})$ and $V^*/(\phi_i V_{Rk,i})$ from the different failure modes shall be adopted in Equation (83) or (84).

If the design of the fastening includes supplementary reinforcement, $N^*/(\phi_i N_{Rk,i})$ for concrete cone failure and $V^*/(\phi_i V_{Rk,i})$ for concrete edge failure are omitted and replaced by failure of supplementary reinforcement as per Clause 8.3.1.

8.2.2 Cast-in Anchor channel

An anchor channel required to resist the design shear, V^* and the design tension, N^* simultaneously shall satisfy either Equation (85) or (86) whereby –

$$\left(\frac{N_a^*}{\phi_i N_{Rk,i}}\right)^{1.5} + \left(\frac{V_a^*}{\phi_i V_{Rk,i}}\right)^{1.5} \leq 1 \tag{85}$$

or

$$\left(\frac{N_a^*}{\phi_i N_{Rk,i}}\right) + \left(\frac{V_a^*}{\phi_i V_{Rk,i}}\right) \leq 1.2 \tag{86}$$

$N^*/N_{Rk,i} \leq 1$

$V^*/V_{Rk,i} \leq 1$

The largest value of $N^*/\phi_i N_{Rk,i}$ and $V^*/\phi_i V_{Rk,i}$ from the different failure modes shall be adopted in Equation (85) or (86).

8.3 ADDITIONAL VERIFICATION FOR FASTENERS WITH SUPPLEMENTARY REINFORCEMENT

8.3.1 Post-installed fasteners and cast-in headed fasteners

In addition to the requirements of Clause 8.2.1, post-installed fasteners and cast-in headed fasteners with supplementary reinforcement to resist either tension or shear loads only, the following verification shall be made with the largest value of $N^*/\phi_i N_{Rk,i}$ and $V^*/\phi_i V_{Rk,i}$ for the modes of failure other than steel failure –

$$\left(\frac{N^*}{\phi_i N_{Rk,i}}\right)^{k_7} + \left(\frac{V^*}{\phi_i V_{Rk,i}}\right)^{k_7} \leq 1 \tag{87}$$

where

$N^*/\phi_i N_{Rk,i}$ and $V^*/\phi_i V_{Rk,i} \leq 1$

N^* = design tension force applied to a single fastener or group

V^* = design shear force applied to a single fastener or group

$N_{Rk,i}$ = characteristic tensile strength of fastener for each failure mode including $N_{Rk,p}$, $N_{Rk,sp}$, $N_{Rk,cb}$, $N_{Rk,re}$ and $N_{Rk,a}$, as well as $N_{Rk,c}$ if supplementary reinforcement resists shear loads only

$V_{Rk,i}$ = design shear strength of fastener for each failure mode including $V_{Rk,c}$ and $V_{Rk,cp}$

ϕ_i = capacity reduction factor for strength of fastener for failure mode 'i'

k_7 = parameter published in the Report of Assessment that may be conservatively taken as k_7 = 2/3

If supplementary reinforcement is included to resist shear loads only, $N_{Rk,i}$ includes $N_{Rk,c}$, $N_{Rk,p}$, $N_{Rk,sp}$ and $N_{Rk,cb}$, and $V_{Rk,i}$ includes $V_{Rk,cp}$, $N_{Rk,re}$ and $N_{Rk,a}$.

8.3.2 Cast-in anchor channel

An anchor channel design including supplementary reinforcement to resist tension and shear loads requires verification for the following failure modes:

- Steel failure of the channel bolt, refer to Clause 8.1.2.1
- Other steel failure modes, refer to Clause 8.1.2.2
- Failure modes other than steel, refer to Clause 8.2.2, except $N^*/(\phi_i N_{Rk,i})$ for concrete cone failure and $V^*/(\phi_i V_{Rk,i})$ for concrete edge failure are replaced by failure of supplementary reinforcement outlined below.

In addition to the above verifications, anchor channel located close to an edge with supplementary reinforcement included to resist shear loads, the following verification shall be made –

$$\left(\frac{N_a^*}{\phi_i N_{Rk,i}}\right)+\left(\frac{V_a^*}{\phi_i V_{Rk,i}}\right)\leq 1 \qquad (88)$$

where

N_a^* = design tensile load acting on one anchor in the anchor channel

V_a^* = design shear load acting on one anchor in the anchor channel

$N_{Rk,i}$ = characteristic tensile strength of a single anchor in the anchor channel

$V_{Rk,i}$ = characteristic shear strength of a single anchor in the anchor channel

ϕ_i = capacity reduction factor for failure of fastener for mode 'i'

If supplementary reinforcement is included to resist tension loads only, $N_{Rk,i}$ includes $N_{Rk,p}$, $N_{Rk,sp}$, $N_{Rk,re}$, $N_{Rk,cb}$ and $N_{Rk,a}$ and $V_{Rk,i}$ includes $V_{Rk,cp}$, $N_{Rk,re}$ and $N_{Rk,a}$.

9 DESIGN FOR SERVICEABILITY

9.1 VERIFICATIONS

In order to satisfy serviceability requirements, Clauses 9.2 and 9.3 shall be met.

9.2 DISPLACEMENT

The permissible displacement of the fastener, δ_d shall be considered. It may be assumed that the system remains linear-elastic such that displacements are directly proportional to the applied load. Displacements under combined tension and shear loading shall be calculated from the vector sum of the tension and shear components of the applied load.

The magnitude of the displacement of the fastener under a given tension or shear load in cracked or uncracked concrete shall be taken from the Report of Assessment.

9.3 LIMITING CRACK WIDTH

Where a fastener system includes supplementary reinforcement, a check shall be performed on the design of the supplementary reinforcement to ensure that detailing requirements of the supplementary reinforcement satisfy limitations on crack width.

10 DESIGN FOR FATIGUE LOADING

10.1 GENERAL

This part of the Standard addresses design considerations for applications for post-installed fasteners and cast-in headed fasteners subjected to pulsating tension or shear load, alternating shear load, and combinations thereof. Typical applications involving the fatigue loading of fasteners include restraint of cranes, reciprocating machinery, bridge connections, etc.

Verification of fastener strength under fatigue loading shall be performed in accordance with the requirements for static loading (refer to Sections 6, 7 and 8) and fatigue loading (refer to Clause 10.2).

The design for fatigue loading shall ensure the following –

(i) The fastener has prequalification for fatigue loading recognised in the accompanying Report of Assessment.
(ii) A permanent prestress shall be present throughout the design life of the fastener to avoid loosening of the clamping force.

The determination of loads acting on fasteners shall be performed in accordance with Section 4 with the following restrictions –

(i) Fasteners subjected to shear loading and considered to include a lever arm (refer to Clause 4.2.2.4) shall not be permitted.
(ii) Fixtures containing annular gaps shall not be permitted.

10.2 STRENGTH OF FASTENER

The verification for strength of a fastener to fatigue loading shall consider tension loading, shear loading and combined tension and shear loading.

10.2.1 Tension loading

The verifications that shall be considered for fatigue tensile loading of a fastener are included in Table 7.

TABLE 7: VERIFICATIONS REQUIRED FOR TENSILE FATIGUE LOADS APPLIED TO FASTENERS.

Mode of failure	**Single fastener**	**Fastener group**	
		Most loaded fastener	**Fastener group**
Steel failure	$\chi_{F,fat}\Delta N_{fat} \leq \phi_{Ms,N,fat}\Delta N_{Rk,s}$	$\chi_{F,fat}\Delta N_{fat}^{h} \leq \phi_{Ms,N,fat}\psi_{F,N}\Delta N_{Rk,s}$	
Pull-out failure	$\chi_{F,fat}\Delta N_{fat} \leq \phi_{Mp,fat}\Delta N_{Rk,p}$	$\chi_{F,fat}\Delta N_{fat}^{h} \leq \phi_{Mp,fat}\psi_{F,N}\Delta N_{Rk,p}$	
Concrete cone failure	$\chi_{F,fat}\Delta N_{fat} \leq \phi_{Mc,fat}\Delta N_{Rk,c}$		$\chi_{F,fat}\Delta N_{fat}^{g} \leq \phi_{Mc,fat}\Delta N_{Rk,c}$
Concrete splitting failure	$\chi_{F,fat}\Delta N_{fat} \leq \phi_{Mc,fat}\Delta N_{Rk,sp}$		$\chi_{F,fat}\Delta N_{fat}^{g} \leq \phi_{Mc,fat}\Delta N_{Rk,sp}$
Blow-out failure	$\chi_{F,fat}\Delta N_{fat} \leq \phi_{Mc,fat}\Delta N_{Rk,cb}$		$\chi_{F,fat}\Delta N_{fat}^{g} \leq \phi_{Mc,fat}\Delta N_{Rk,cb}$

$\chi_{F,fat}$, $\chi_{Mc,fat}$, $\phi_{Mp,fat}$ = provided in Clause 3.2.4

$\phi_{Ms,N,fat}$ = $\phi_{Ms,fat}$ in accordance with Clause 3.2.4

$\psi_{F,N}$ ≤ 1, factor applied to the tensile strength of the fastener to account for the uneven distribution of loads, provided in the Report of Assessment

ΔN_{fat} = peak-to-peak amplitude of the fatigue tensile action

$N_{fat,max} - N_{fat,min}$

$\Delta N_{Rk,s}$ = fatigue tensile strength for steel failure provided in the Report of Assessment

$\Delta N_{Rk,c}$ = fatigue tensile strength for concrete cone failure at 2x10^6 load cycles
= $0.5N_{Rk,c}$ with $N_{Rk,c}$ determined from Equation (7)

$\Delta N_{Rk,p}$ = fatigue tensile strength for pull-out failure provided in the Report of Assessment

$\Delta N_{Rk,sp}$ = fatigue tensile strength to splitting failure for 2x10^6 load cycles
= $0.5N_{Rk,sp}$ with $N_{Rk,sp}$ determined from Equation (29)

$\Delta N_{Rk,cb}$ = fatigue tensile strength to blow-out failure for 2x10^6 load cycles
= $0.5N_{Rk,cb}$ with $N_{Rk,cb}$ determined from Equation (32)

10.2.2 Shear loading

The verifications that shall be considered for fatigue shear loading of a fastener are included in Table 8.

TABLE 8: VERIFICATIONS REQUIRED FOR SHEAR FATIGUE LOADS APPLIED TO FASTENERS.

Mode of failure	Single fastener	Fastener group	
		Most loaded fastener	Fastener group
Steel failure - without lever arm	$\chi_{F,fat}\Delta V_{fat} \leq \phi_{Ms,V,fat}\Delta V_{Rk,s}$	$\chi_{F,fat}\Delta V_{fat}^{h} \leq \phi_{Ms,V,fat}\psi_{F,V}\Delta V_{Rk,s}$	
Pry-out failure	$\chi_{F,fat}\Delta V_{fat} \leq \phi_{Mc,fat}\Delta V_{Rk,cp}$		$\chi_{F,fat}\Delta V_{fat}^{g} \leq \phi_{Mc,fat}\Delta V_{Rk,cp}$
Edge failure	$\chi_{F,fat}\Delta V_{fat} \leq \phi_{Mc,fat}\Delta V_{Rk,c}$		$\chi_{F,fat}\Delta V_{fat}^{g} \leq \phi_{Mc,fat}\Delta V_{Rk,c}$

$\chi_{F,fat}$, $\gamma_{Mc,fat}$ = provided in Clause 3.2.4

$\phi_{Ms,V,fat}$ = $\phi_{Ms,fat}$ in accordance with Clause 3.2.4

$\psi_{F,V}$ ≤ 1, factor applied to the shear strength of the fastener to account for the uneven distribution of loads, provided in the Report of Assessment

ΔV_{fat} = peak-to-peak amplitude of the fatigue shear action

$V_{Ek,max} - V_{Ek,min}$

$\Delta V_{Rk,s}$ = fatigue shear strength for steel failure provided in the Report of Assessment

$\Delta V_{Rk,c}$ = fatigue shear strength to concrete cone failure at $2x10^6$ load cycles

= $0.5V_{Rk,c}$ with $V_{Rk,c}$ determined from Equation (53)

$\Delta V_{Rk,cp}$ = fatigue shear strength to concrete pry-out failure provided in the Report of Assessment

= $0.5V_{Rk,cp}$ with $V_{Rk,cp}$ determined from Equation (64) or (65)

10.2.3 Combined tension and shear loading

The verification for fatigue combined tension and shear loading shall be performed as follows –

$$\left(\beta_{N,fat}\right)^{\alpha} + \left(\beta_{V,fat}\right)^{\alpha} \leq 1 \tag{89}$$

where

$$\beta_{N,fat} = \frac{\chi_{F,fat}\Delta N_{fat}}{\psi_{F,N}\left(\phi_{M,fat}\Delta N_{Rk}\right)} \leq 1 \tag{90}$$

$$\beta_{V,fat} = \frac{\chi_{F,fat}\Delta V_{fat}}{\psi_{F,V}\left(\phi_{M,fat}\Delta V_{Rk}\right)} \leq 1 \tag{91}$$

α	=	α_s for verification of steel failure, given in the Report of Assessment
	=	α_c for verification of modes of failure other than steel, given in the Report of Assessment
ΔN_{fat}, ΔN_{Rk}	=	found in Table 7
ΔV_{fat}, ΔV_{Rk}	=	found in Table 8

From the different modes of failure being considered, the greatest values of $\beta_{N,fat}$ and $\beta_{V,fat}$ shall be adopted in Equation (89).

11 REFERENCES

The following normative references have been made in this Standard –

AEFAC Standard Part 2

AS/NZS 1170 Structural design actions

AS/NZS 1170.0 Part 0: General principles

AS/NZS 3678 Structural steel – hot-rolled plates, floorplates and slabs

AS/NZS 4671 Steel reinforcing materials

AS 1379 Specification and supply of concrete

AS 1554.2 Structural steel welding, Part 2: Stud welding (steel studs to steel)

AS 3600 Concrete structures

AS 4291.1 Mechanical properties of fasteners made of carbon steel and alloy steel, Part 1: Bolts, screws and studs

AS 4100 Steel structures

EOTA Technical Report No. 020 "Evaluation of anchorages in concrete concerning resistance to fire"

ETAG 001 Part 1 "Guideline for European Technical Approval of metal anchors for use in concrete, part one: anchors in general", European Organisation for Technical Approvals, 2nd Amended April 2013

ETAG 001 Part 2 "Guideline for European Technical Approval of metal anchors for use in concrete, part two: torque-controlled expansion anchors", European Organisation for Technical Approvals, 2nd Amended April 2013

ETAG 001 Part 3 "Guideline for European Technical Approval of metal anchors for use in concrete, part three: undercut anchors", European Organisation for Technical Approvals, 2nd Amended April 2013

ETAG 001 Part 4 "Guideline for European Technical Approval of metal anchors for use in concrete, part four: deformation-controlled expansion anchors", European Organisation for Technical Approvals, 2nd Amended April 2013

ETAG 001 Part 5 "Guideline for European Technical Approval of metal anchors for use in concrete, part five: bonded anchors", European Organisation for Technical Approvals, 3rd Amended April 2013

ETAG 001 Annex A "Guideline for European Technical Approval of metal anchors for use in concrete, Details of test", European Organisation for Technical Approvals, 2nd Amendment November 2006

ETAG 001 Annex E "Assessment of metal anchors under seismic action", EOTA, April 2013

Handbook HB 18.67 – 2005 "Conformity assessment – fundamentals of product certification", Standards Australia

ISO 898-1 Mechanical properties of fasteners made of carbon steel and alloy steel – Part 1: Bolts, screws and studs with specified property classes – coarse thread and fine pitch thread

ISO 898-2 Mechanical properties of fasteners made of carbon steel and alloy steel – Part 2: Nuts with specified property classes – coarse thread and fine pitch thread

ISO 4506 Hardmetals – compression test

ISO 5922 Malleable cast iron

prEN 1992-4:2013 “Eurocode 2: Design of concrete structures – Part 4: Design of Fastenings for Use in Concrete” CEN/TC 250

The following informative references have been made in this Standard –

DIN 8035 Masonry drills – hammer drills with hardmetal tip

ISO 5468 Rotary and rotary impact masonry drill bits with hardmetal tips - dimensions

APPENDIX A (INFORMATIVE) ASSUMPTIONS FOR THE DESIGN AND EXECUTION OF FASTENERS

A.1 GENERAL

This Appendix outlines the assumptions in inherent in this Standard with respect to installation and execution of the relative type of fastener and welding design of the headed fasteners. The manufacturer's installation instructions should support the information provided herein.

A.2 POST-INSTALLED FASTENERS

The concrete is assumed to be correctly compacted in the region designated for fastening and should be checked prior to installation, typically by visual methods.

A number of assumptions are made regarding the drilling operation as follows –

(i) Drilling is performed in accordance with the manufacturer's installation instructions.
(ii) Suitably qualified personnel should perform the drilling.
(iii) Drilling is performed perpendicular to the surface of the concrete member unless directed otherwise in the manufacturer's installation instructions.
(iv) Hammer drill bits adopted should conform to the dimensional requirements of ISO 5468 for drill bit diameters up to 25 mm and DIN 8035 for drill bit diameters greater than 25 mm but not exceeding 40 mm. A conformity mark to the relevant standard should demonstrate conformity, otherwise evidence of suitability should be demonstrated.
(v) Diamond core drilling should comply with the prescribed hole diameter.
(vi) Hole cleaning should be performed in accordance with the manufacturer's installation instructions as noted in the Report of Assessment.
(vii) Holes that have been aborted (e.g. due to hitting reinforcement) should be filled with a non-shrink mortar with a strength no less than that of the substrate and at least 40 MPa.

Unless explicit permission has been granted, reinforcement should not be damaged during drilling. Drilling should not be performed closer than 50 mm to the nearest reinforcement. In the event that drilling hits reinforcement, permission should be sought in writing before drilling through the reinforcement.

A.3 CAST-IN HEADED FASTENERS

A quality control system should be in place for welding of headed fasteners to include the following –

(i) A welding procedure consistent with the requirements of AS 1554.2 and additional provisions provided in the Report of Assessment.
(ii) Fastener secured for the placement of the reinforcement and concrete (including compaction) such that no movement will occur.
(iii) Adequate compaction of the concrete achieved in the region of the fasteners, particularly under the fixture and around the head of fasteners. Fixtures with dimensions greater than 400 mm x 400 mm will typically require vent openings that should also have careful compaction.
(iv) An appropriately qualified person inspects and approves that the installation has been performed correctly.

Fasteners may be punched and vibrated into wet concrete immediately after pouring subject to the following provisions –

(i) Proper compaction of concrete is achieved under the head of the fastener or fixture.
(ii) The fastener is not moved once vibration has been completed.
(iii) All fasteners in a fixture should be inserted simultaneously during vibrating, typically achievable for fixtures with dimensions 200 mm x 200 mm or less with up to four fasteners.

A.4 ANCHOR CHANNEL

The anchor channel should be secured for the placement of the reinforcement and concrete (including compaction) such that no movement will occur.

Adequate compaction of the concrete should be achieved, particularly under the channel and around the head of the anchors.

An anchor channel should not be inserted into wet concrete (except as noted below).

Anchor channel may be vibrated into wet concrete provided the following conditions are met –

(i) One person should not insert an anchor channel of length greater than one metre. For longer lengths of anchor channel at least two personnel are required.
(ii) The anchor channel should not be moved once vibration has been completed.
(iii) Proper compaction of concrete is achieved under the head of anchors and the anchor channel.

Where required, inspection and verification of correct installation should be performed by an appropriately qualified individual.

APPENDIX B (INFORMATIVE) METHOD OF DESIGN FOR POST-INSTALLED FASTENERS

B.1 GENERAL

The design assumes that an elastic analysis has been used to establish the forces acting on fasteners for the purpose of design, and that the requirements of Appendix A have been met.

Three different methods exist for design such that the greater the simplification, the greater the conservatism in design. Each method also addresses the condition of the concrete (cracked vs. non-cracked) and the concrete compressive strength. The design method is dependent on the testing and assessment procedures which correspond to a given Option number that is presented in ETAG 001 and reproduced in Table 9.

Technical data for design is unique to a particular design method and is found in the Report of Assessment.

TABLE 9: ASSESSMENT OPTIONS FOR POST-INSTALLED FASTENERS COVERED BY ETAG 001.

Option No.	Concrete condition		Concrete strength (MPa)		Characteristic resistance, F_{Rk}		c_{cr}	s_{cr}	c_{min}	s_{min}	Design method as per AEFAC Standard Appendix B)
	Cracked & non-cracked	Non-cracked	$f'_c = 20$	$20 < f'_c \leq 50$	One value for all directions	Different value for different directions					
1	•			•		•	•	•	•	•	A
2	•		•			•	•	•	•	•	
3	•			•	•		•	•	•	•	B
4	•		•		•		•	•	•	•	
5	•			•	•		•	•			C
6	•		•		•		•	•			
7		•		•		•	•	•	•	•	A
8		•	•			•	•	•	•	•	
9		•		•	•		•	•	•	•	B
10		•	•		•		•	•	•	•	
11		•		•	•		•	•			C

B.2 DESIGN METHOD A

Under the most detailed design procedure, Method A, the strength of the fastener is established for loads applied in all directions and all modes of failure. Actual values for spacing of fasteners in a group, *s* and edge distance, *c* are adopted in the design. The design provisions are included for tensile strength in Clause 6.2, for shear strength in Clause 7.2, and for combined tension and shear loading in Clauses 8.1.1

(steel failure), Clause 8.2.1 (failure modes other than steel) and Clause 8.3.1 (additional verifications for fasteners with supplementary reinforcement).

The data required for design Method A is provided in the Report of Assessment.

B.3 DESIGN METHOD B

Design Method B requires the identification of a single value for basic characteristic strength, F^0_{Rk} for a given concrete compressive strength and that is adopted for all load directions and all modes of failure.

B.3.1 Basic design strength

The characteristic values for spacing, s_{cr} and edge distance, c_{cr} are adopted such that the design becomes –

$$S^* \leq \phi_M F^0_{Rk} \tag{92}$$

where

S^* = design action effect (refer to Equation (1))

ϕ_M = capacity reduction factor for material

F^0_{Rk} = basic characteristic strength of fastener

B.3.2 Characteristic strength with reduced spacing or edge distance

If the spacing and edge distance are less than the characteristic value ($s < s_{cr}$ and $c < c_{cr}$) the characteristic strength is calculated as follows –

$$F_{Rk} = \frac{F^0_{Rk}}{n}\frac{A_c}{A^0_c}\psi_s \psi_{re} \psi_c \tag{93}$$

where

F^0_{Rk} = basic characteristic strength of fastener

n = number of loaded fasteners

A_c = actual projected area of the failure cone of the fastener, calculated in accordance with Clause 6.2.2.1 by replacing $A_{c,N}$ with A_c.

A^0_c = reference projected area of the failure cone of the fastener, calculated according to Clause 6.2.2.1 by replacing $A^0_{c,N}$, $s_{cr,N}$ and $c_{cr,N}$ with A^0_c, s_{cr} and c_{cr}, respectively.

ψ_s = parameter related to the distribution of stresses in the concrete due to the proximity of the fastener to an edge, calculated in accordance with Clause 6.2.2.4 and replacing $c_{cr,N}$ with c_{cr}.

ψ_{re} = parameter accounting for the shell spalling factor, calculated according to Clause 6.2.2.5

ψ_c = parameter accounting for the influence of the concrete compressive strength on the strength of the fastener provided in the Report of Assessment.

B.3.3 Additional provisions

Additional provisions for fastener design using Method B include –

(i) The greatest design load on a fastener in a group should not exceed the value calculated by Equation (93).

(ii) For a fastener loaded in shear that has a lever arm, the characteristic shear strength, $V_{Rk,s,M}$ should be calculated according to Clause 7.2.1.2, replacing $N_{Rk,s}$ with F^0_{Rk}.

(iii) The design shear strength shall not exceed F_{Rk} calculated from Equation (93) ($V_{Rk,s} \leq F_{Rk}$).

(iv) The basic characteristic strength for bonded anchors, F^0_{Rk} should be multiplied by the factor accounting for the effects of sustained loading on bond strength, ψ_{sus} as defined in Clause 6.2.4.2.

The Report of Assessment includes values for c_{min}, c_{cr}, s_{cr}, s_{min}, F^0_{Rk}, $M^0_{Rk,s}$, ϕ_M, ϕ_{Ms} and ψ_c.

B.4 DESIGN METHOD C

The design with the greatest simplification, Method C requires the calculation of a single value for the characteristic strength, F^0_{Rk} that is based on the characteristic spacing (s_{cr}) and edge distance (c_{cr}). The actual values of spacing and edge distance adopted in the design should not be less than their characteristic values (i.e. $s \geq s_{cr}$ and $c \geq c_{cr}$). The design strength is calculated as follows –

$$S^* \leq \phi_M F^0_{Rk}$$

where

ϕ_M = capacity reduction factor for material

F^0_{Rk} = basic characteristic strength of fastener

Additional provisions include –

(i) For a fastener loaded in shear that has a lever arm, the characteristic shear strength, $V_{Rk,s,M}$ should be calculated according to Clause 7.2.1.2, replacing $N_{Rk,s}$ with F_{Rk}.

(ii) The design shear strength (without a lever arm) should not exceed F^0_{Rk} ($V_{Rk,s} \leq F_{Rk}$).

(iii) The basic characteristic strength for bonded anchors, F^0_{Rk} should be multiplied by the factor accounting for the effects of sustained loading on bond strength, ψ_{sus} as defined in Clause 6.2.4.2.

APPENDIX C (NORMATIVE) VERIFICATION OF RESISTANCE OF CONCRETE ELEMENTS TO LOADS APPLIED BY FASTENERS

C.1 GENERAL

This appendix provides additional design procedures to ensure the safe transmission of fastener loads to the concrete member under ultimate limit state and serviceability limit state loading. The provisions provided herein are intended as an addition to the requirements of AS 3600 for the design for shear strength of a concrete member, including the transmission of fastener loads to the supports.

When a fastener is installed in a composite member comprising a precast element with a structural topping, it assumed that the load is applied to the entire member under the following conditions –

(i) Adequate shear reinforcement is provided between the topping and precast member when the fastener is installed only in the precast member, or

(ii) The effective embedment depth, h_{ef} is limited to the depth of the fastener embedded in the topping.

C.2 LIGHTLY LOADED APPLICATIONS

The following provisions for the verification of shear strength of the concrete member apply to applications involving fasteners located in the bottom of a precast element with a unit load not exceeding 1 kPa.

It is assumed that fasteners are applied in the tension face of the concrete element.

C.2.1 No additional verification for transmission of loads required

No additional verification for local transmission of loads to the concrete element is required if one of the following conditions is fulfilled –

a) Design actions (including loading on fastener) at the support of the concrete element are less than design shear capacity of concrete member:

$$V^* \leq \phi V_u \qquad (94)$$

where

V^* = design shear load at the support of the concrete member including loads imposed by the fastener

ϕ = capacity reduction factor for shear

V_u = shear capacity of concrete element determined in accordance with AS 3600

b) The design tensile load applied to the tensioned fasteners, $N^* \leq 30$ kN and the spacing of fasteners, a between the outermost fasteners of adjacent groups or between the outermost fasteners of a group and an individual fastener satisfies the following –

$$a \geq \sqrt{N^*}$$

where

a = spacing between the outermost fasteners of adjacent fastener groups or between the outermost fasteners and an individual fastener (refer to Figure 5)

c) Hanger (supplementary) reinforcement is included in the design to resist the tensile load applied to the fastener which may be additional reinforcement or underutilized existing reinforcement already present in the structure. The hanger reinforcement should enclose tensile reinforcement in the member and be anchored on the opposite side of the concrete member. The distance between the hanger reinforcement and fastener shall be not greater than h_{ef}.

d) The effective embedment depth of the fastener, h_{ef} exceeds 0.8 times the depth of the member, h as follows –

$$h_{ef} \geq 0.8h \tag{95}$$

where

h = Total depth of concrete member

C.2.2 Verification for local transmission of fastener loads required

If none of the conditions in Clause D.2.1 are fulfilled, the shear forces in the concrete member due to loads applied by the fastener, the following condition shall be fulfilled –

$$V^* \leq 0.4V_u \tag{96}$$

where

V^* = design shear forces in concrete element due to fastener

ϕ = capacity reduction factor

V_u = ultimate shear strength determined in accordance with AS 3600

The fastener loads shall be assumed to act as point loads with a width of application of $t_1 = a_1 + h_{ef}$ and $t_2 = a_2 + h_{ef}$ in orthogonal directions as per Figure 5.

C.2.3 High load applications

If the design load(s) applied to the fixture causes a resultant applied tension load that is greater than 60 kN, then conditions (c) and (d) in Clause D.2.1 shall be complied with.