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ILNAS-EN 1992-4:2018

Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

Eurocode 2 - Calcul des structures en béton - Partie 4 : Conception et calcul des éléments de fixation pour béton

Eurocode 2 - Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 4: Bemessung der Verankerung von Befestigungen in Beton

07/2018

National Foreword

This European Standard EN 1992-4:2018 was adopted as Luxembourgish Standard ILNAS-EN 1992-4:2018 in July 2018.

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EUROPEAN STANDARD

NORME EUROPÉENNE

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EN 1992-4

July 2018

ICS 91.010.30; 91.080.40

Supersedes CEN/TS 1992-4-1:2009, CEN/TS 1992-4-2:2009, CEN/TS 1992-4-3:2009, CEN/TS 1992-4-4:2009, CEN/TS 1992-4-5:2009

English Version

Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

Eurocode 2 - Calcul des structures en béton - Partie 4 : Conception et calcul des éléments de fixation pour béton

Eurocode 2 - Bemessung und Konstruktion von Stahlbeton- und Spannbetontragwerken - Teil 4: Bemessung der Verankerung von Befestigungen in Beton

This European Standard was approved by CEN on 9 March 2018.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the CEN-CENELEC Management Centre has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
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European foreword

This document (EN 1992-4:2018) has been prepared by Technical Committee CEN/TC 250 “Structural Eurocodes”, the secretariat of which is held by BSI.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2019 and conflicting national standards shall be withdrawn at the latest by January 2019.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document supersedes CEN/TS 1992-4-1:2009, CEN/TS 1992-4-2:2009, CEN/TS 1992-4-3:2009, CEN/TS 1992-4-4:2009 and CEN/TS 1992-4-5:2009.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association.

EN 1992 is composed of the following parts:

— EN 1992-1-1, *Eurocode 2: Design of concrete structures — Part 1-1: General rules and rules for buildings*;

— EN 1992-1-2, *Eurocode 2: Design of concrete structures — Part 1-2: General rules — Structural fire design*;

— EN 1992-2, *Eurocode 2 — Design of concrete structures — Concrete bridges — Design and detailing rules*;

— EN 1992-3, *Eurocode 2 — Design of concrete structures — Part 3: Liquid retaining and containment structures*;

— EN 1992-4, *Eurocode 2 — Design of concrete structures — Part 4: Design of fastenings for use in concrete*.

The numerical values for partial factors and other reliability parameters are recommended values. The recommended values apply when:

a) the fasteners comply with the requirements of 1.2 (3), and

b) the installation complies with the requirements of 4.6.

National Annex for EN 1992-4

This EN gives values with Notes indicating where national choices may have to be made. When this EN is made available at national level it may be followed by a National Annex containing all Nationally Determined Parameters to be used for the design of fastenings according to this EN for use in the relevant country.

National choice of the partial factors and reliability parameters is allowed in design according to this EN in the following sections:

4.4.1(2);

4.4.2.2(2);

4.4.2.3;

4.4.2.4;

4.7(2);

C.2(2);

C.4.4(1);

C.4.4(3);

D.2(2).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

1 Scope

1.1 General

(1) This European Standard provides a design method for fastenings (connection of structural elements and non-structural elements to structural components), which are used to transmit actions to the concrete. This design method uses physical models which are based on a combination of tests and numerical analysis consistent with EN 1990:2002, 5.2.

Additional rules for the transmission of the fastener loads within the concrete member to its supports are given in EN 1992-1-1 and Annex A of this EN.

Inserts embedded in precast concrete elements during production, under Factory Production Control (FPC) conditions and with the due reinforcement, intended for use only during transient situations for lifting and handling, are covered by CEN/TR 15728.

(2) This EN is intended for safety related applications in which the failure of fastenings may result in collapse or partial collapse of the structure, cause risk to human life or lead to significant economic loss. In this context it also covers non-structural elements.

(3) The support of the fixture can be either statically determinate or statically indeterminate. Each support can consist of one fastener or a group of fasteners.

(4) This EN is valid for applications which fall within the scope of the EN 1992 series. In applications where special considerations apply, e.g. nuclear power plants or civil defence structures, modifications can be necessary.

(5) This EN does not cover the design of the fixture. Rules for the design of the fixture are given in the appropriate Standards meeting the requirements on the fixture as given in this EN.

(6) This document relies on characteristic resistances and distances which are stated in a European Technical Product Specification (see Annex E). At least the characteristics of Annex E are given in a European Technical Product Specification for the corresponding loading conditions providing a basis for the design methods of this EN.

1.2 Type of fasteners and fastening groups

(1) This EN uses the fastener design theory[1)] (see Figure 1.1) and applies to:

a) cast-in fasteners such as headed fasteners, anchor channels with rigid connection (e.g. welded, forged) between anchor and channel;

b) post-installed mechanical fasteners such as expansion fasteners, undercut fasteners and concrete screws;

c) post-installed bonded fasteners and bonded expansion fasteners.

(2) For other types of fasteners, modifications of the design provisions can be necessary.

(3) This EN applies to fasteners with established suitability for the specified application in concrete covered by provisions, which refer to this EN and provide data required by this EN. The suitability of the fastener is stated in the relevant European Technical Product Specification.

1) In fastener design theory the concrete tensile capacity is directly used to transfer loads into the concrete component.

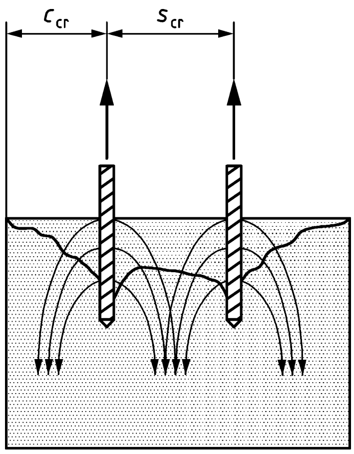


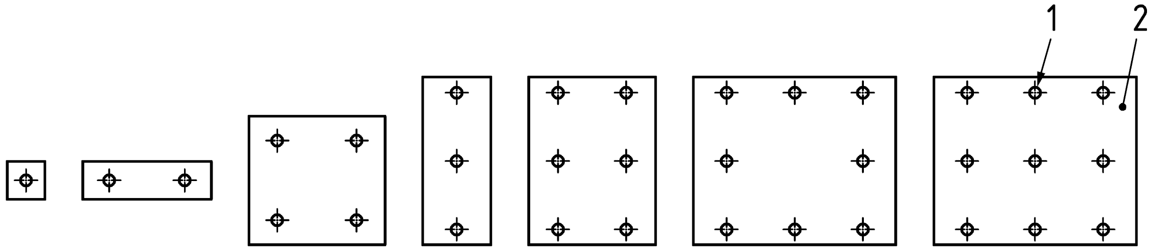
Figure 1.1 — Fastener design theory — Example

(4) This EN applies to single fasteners and groups of fasteners. In a group of fasteners, the loads are applied to the individual fasteners of the group by means of a common fixture. In a group of fasteners, this European Standard applies only if fasteners of the same type and size are used.

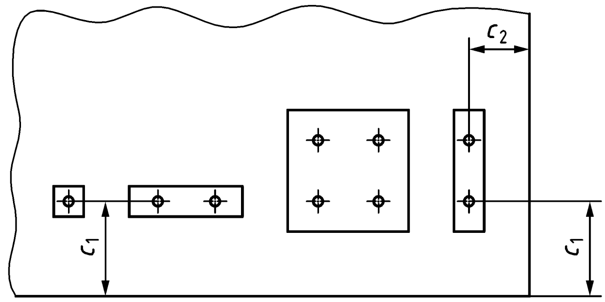
(5) The configurations of fastenings with cast-in place headed fasteners and post-installed fasteners covered by this EN are shown in Figure 1.2.

(6) For anchor channels, the number of anchors is not limited.

a)



b)



Key

1 fastener

2 steel plate

a) Fastenings without hole clearance for all edge distances and for all load directions, and fastenings with hole clearance according to Table 6.1 situated far from edges $\left(c_i \geq \max\left\{10h_{ef}\,;\,60d_{nom}\right\}\right)$ for all load directions and fastenings with hole clearance according to Table 6.1 situated near to an edge $\left(c_i < \max\left\{10h_{ef}\,;\,60d_{nom}\right\}\right)$ loaded in tension only

b) Fastenings with hole clearance according to Table 6.1 situated near to an edge $\left(c_i < \max\left\{10h_{ef}\,;\,60d_{nom}\right\}\right)$ for all load directions

Figure 1.2 — Configuration of fastenings with headed and post-installed fasteners covered by this EN

(7) Post-installed ribbed reinforcing bars used to connect concrete members are covered by a European Technical Product Specification.

1.3 Fastener dimensions and materials

(1) This EN applies to fasteners with a minimum diameter or a minimum thread size of 6 mm (M6) or a corresponding cross section. In case of fasteners for fastening statically indeterminate non-structural systems as addressed in 7.3, the minimum thread size is 5 mm (M5). The maximum diameter of the fastener is not limited for tension loading but is limited to 60 mm for shear loading.

(2) EN 1992-4 applies to fasteners with embedment depth $h_{ef} \geq 40$ mm. Only for fastening statically indeterminate non-structural systems as addressed in 7.3 fasteners with effective embedment depth of at least 30 mm are considered, which may be reduced to 25 mm in internal exposure conditions. For fastenings with post-installed bonded anchors, only fasteners with an embedment depth $h_{ef} \leq 20d$ are covered. The actual value for a particular fastener may be found in the relevant European Technical Product Specification.

(3) This EN covers metal fasteners made of either carbon steel (EN ISO 898-1 and EN ISO 898-2, EN 10025-1, EN 10080), stainless steel (EN 10088-2 and EN 10088-3, EN ISO 3506-1 and EN ISO 3506-2) or malleable cast iron (ISO 5922). The surface of the steel can be coated or uncoated. This EN is valid for fasteners with a nominal steel tensile strength $f_{uk} \leq 1\,000\ \mathrm{N/mm^2}$. This limit does not apply to concrete screws.

1.4 Fastener loading

(1) Loading on the fastenings covered by this document can be static, quasi-static, fatigue and seismic. The suitability of the fastener to resist fatigue and seismic loadings is specifically stated in the relevant European Technical Product Specification. Anchor channels subjected to fatigue loading or seismic loading are not covered by this EN.

(2) The loading on the fastener resulting from the actions on the fixture (e.g. tension, shear, bending or torsion moments or any combination thereof) will generally be axial tension and/or shear. When the shear force is applied with a lever arm a bending moment on the fastener will arise. EN 1992-4 only considers axial compression on the fixture which is transmitted to the concrete either directly to the concrete surface without acting on the embedded fastener load transfer mechanism or via fasteners suitable for resisting compression.

(3) In case of anchor channels, shear in the direction of the longitudinal axis of the channel is not covered by this EN.

NOTE Design rules for anchor channels with loads acting in the direction of the longitudinal axis of the anchor channel can be found in CEN/TR 17080, *Design of fastenings for use in concrete — Anchor channels — Supplementary rules*.

(4) Design of fastenings under fire exposure is covered by this EN (see informative Annex D).

1.5 Concrete strength and type

This EN is valid for fasteners installed in members made of compacted normal weight concrete without fibres with strength classes in the range C12/15 to C90/105 all in accordance with EN 206. The range of concrete strength classes in which particular fasteners may be used is given in the relevant European Technical Product Specification and may be more restrictive than stated above.

1.6 Concrete member loading

In general, fasteners are prequalified for applications in concrete members under static loading. If the concrete member is subjected to fatigue or seismic loading, prequalification of the fastener specific to this type of loading and a corresponding European Technical Product Specification are required.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 206, *Concrete - Specification, performance, production and conformity*

EN 1990:2002, *Eurocode - Basis of structural design*

EN 1991 (all parts), *Eurocode 1: Actions on structures*

EN 1992-1-1:2004, *Eurocode 2: Design of concrete structures - Part 1-1: General rules and rules for buildings*

EN 1992-1-2, *Eurocode 2: Design of concrete structures - Part 1-2: General rules - Structural fire design*

EN 1998 (all parts), *Eurocode 8: Design of structures for earthquake resistance*

3 Terms, definitions, symbols and abbreviations

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1.1
anchor
fastener
element made of steel or malleable iron either cast into concrete or post-installed into a hardened concrete member and used to transmit applied loads (see Figures 3.1 to 3.3)

Note 1 to entry: The term anchor is used in the context of anchor channels.

3.1.2
anchor channel
steel profile with rigidly connected anchors (see Figure 3.2) installed prior to concreting

Note 1 to entry: In the case of anchor channels, two or more steel anchors are rigidly connected to the back of the channel and embedded in concrete.

3.1.3
attached element
structural or non-structural component that is connected to the attachment

3.1.4
attachment
fixture
assembly that transmits loads to the fastener or anchor channel

3.1.5
base material
concrete member in which the fastener or anchor channel is installed

3.1.6
bending
bending effect induced by a shear load applied with a lever arm with respect to the surface of the concrete member

3.1.7
bonded expansion fastener
bonded fastener designed such that the fastener element can move relative to the hardened bonding compound resulting in follow-up expansion (see Figure 3.3 h))

3.1.8
bonded fastener
fastener placed into a hole in hardened concrete, which derives its resistance from a bonding compound placed between the wall of the hole in the concrete and the embedded portion of the fastener (see Figure 3.3 g))

3.1.9
cast-in fastener
headed bolt, headed stud, internal threaded socket with head at the embedded end or anchor channel installed before placing the concrete, see also headed fastener

3.1.10
channel bolt
screw or bolt which connects the element to be fixed to the anchor channel (see Figure 3.2)

3.1.11
characteristic edge distance
edge distance required to ensure that the edge does not influence the characteristic resistance of a fastening

3.1.12
characteristic resistance
5 % fractile of the resistance (value with a 95 % probability of being exceeded, with a confidence level of 90 %)

3.1.13
characteristic spacing
spacing required to ensure the characteristic resistance of a single fastener

3.1.14
combined pull-out and concrete failure of bonded fasteners
failure mode in which failure occurs at the interface between the bonding material and the base material or between the bonding material and the fastener element (bond failure) and contains a concrete cone at the top end

3.1.15
combined tension and shear loads
oblique load
tension and shear load applied simultaneously

3.1.16
concrete blow-out failure
spalling of the concrete on the side face of the concrete element at the level of the embedded head with no major breakout at the top concrete surface

Note 1 to entry: This is usually associated with fasteners with small side cover and deep embedment.

3.1.17
concrete breakout failure
failure that corresponds to a wedge or cone of concrete surrounding the fastener, group of fasteners or anchor of an anchor channel being separated from the base material

3.1.18
concrete pry-out failure
failure that corresponds to the formation of a concrete spall opposite to the loading direction under shear loading

3.1.19
concrete related failure modes

3.1.19.1
failure modes under tension loading
pull-out failure, combined pull-out and concrete failure (bonded fasteners), concrete cone failure, concrete blow-out failure, concrete splitting failure, anchorage failure of supplementary reinforcement

3.1.19.2
failure modes under shear loading
concrete pry-out failure, concrete edge failure

3.1.20
concrete screw
threaded fastener screwed into a predrilled hole where threads create a mechanical interlock with the concrete (see Figure 3.3 f))

3.1.21
concrete splitting failure
concrete failure mode in which the concrete fractures along a plane passing through the axis of the fastener or fasteners or anchors of an anchor channel

3.1.22
deformation-controlled expansion fastener
post-installed fastener that derives its tensile resistance by expansion against the side of the drilled hole through movement of an internal plug in the sleeve (see Figure 3.3 c)) or through movement of the sleeve over an expansion element (plug), and with which, once set, no further expansion can occur

3.1.23
displacement
movement of the loaded end of the fastener relative to the concrete member into which it is installed in the direction of the applied load; or, in the case of anchor channels, movement of a channel bolt (see Figure 3.2) or the anchor channel relative to the concrete element

Note 1 to entry: In tension tests, displacement is measured parallel to the axis of the fastener; in shear tests, displacement is measured perpendicular to the axis of the fastener.

3.1.24
ductile steel element
element with sufficient ductility

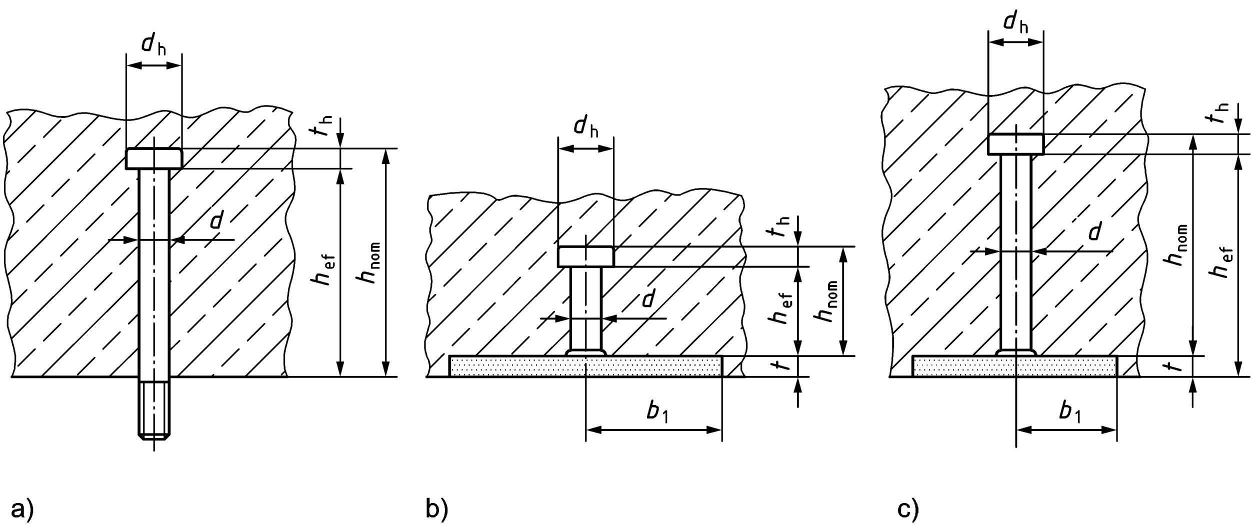
Note 1 to entry: The ductility conditions are given in the relevant subclauses.

3.1.25
edge distance
distance from the edge of the concrete member to the centre of the fastener or anchor of an anchor channel

3.1.26
effective embedment depth
overall depth through which the fastener or anchor of an anchor channel transfers force to the surrounding concrete; see Figures 3.1 to 3.3

3.1.27
European Technical Product Specification
European Standard (EN), European Technical Assessment (ETA) for fastener or anchor channel based on a European Assessment Document (EAD) or a transparent and reproducible assessment that complies with all requirements of the relevant EAD

3.1.28
fastening
assembly of fixture and fasteners or anchor channel used to transmit loads to concrete



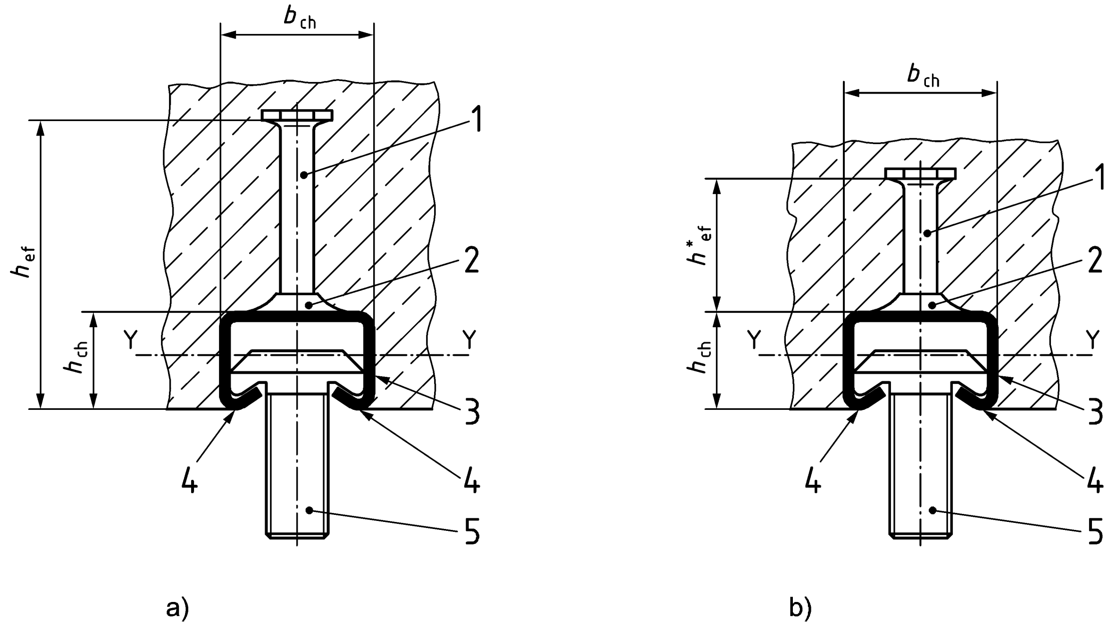
Key

a) without anchor plate

b) with a large anchor plate at least in one direction, $b_1 > 0,5\ h_{nom}$ or $t > 0,2\ h_{nom}$

c) with a small anchor plate in both directions, $b_1 \leq 0,5\ h_{nom}$ and $t \leq 0,2\ h_{nom}$

Figure 3.1 — Definition of effective embedment depth h_{ef} for headed fasteners



Key

1 anchor

2 connection between anchor and channel

3 channel

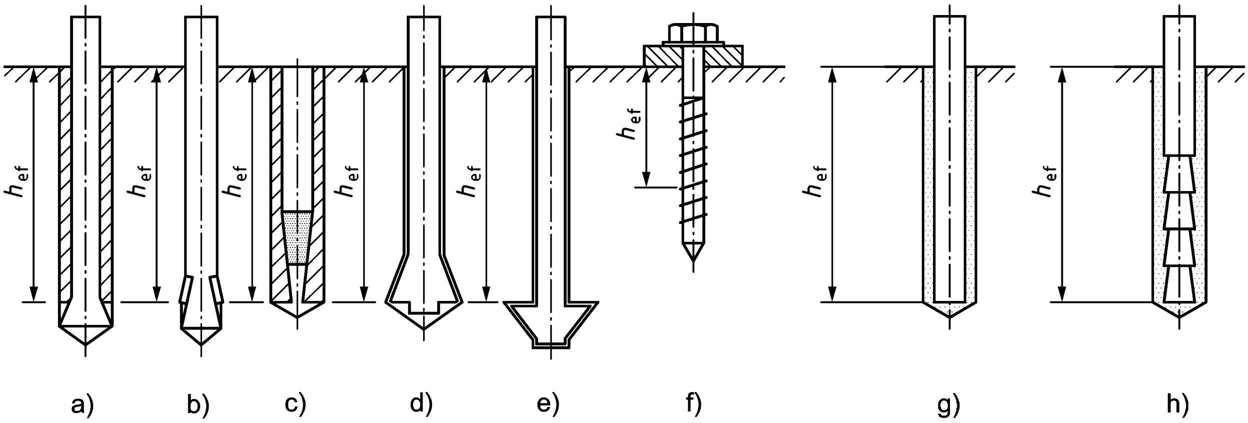
4 channel lip

5 channel bolt

a) h_{ef} for anchor channels (see 7.4.1.5 (1) and 7.4.1.5 (1) b))

b) h_{ef}^{*} for anchor channels (see 7.4.1.5 (1) a))

Figure 3.2 — Definitions for anchor channels



Key

a) torque-controlled fastener, sleeve type
b) torque-controlled fastener, wedge type
c) deformation-controlled fastener
d) undercut fastener, type 1
e) undercut fastener, type 2
f) concrete screw
g) bonded fastener
h) bonded expansion fastener

Figure 3.3 — Definition of effective embedment depth h_{ef} for post-installed fasteners – Examples

3.1.29
flexure
bending effect in the channel of an anchor channel induced by a tension load

3.1.30
group of fasteners
number of fasteners with identical dimensions and characteristics acting together to support a common attachment, where the spacing of the fasteners does not exceed the characteristic spacing

3.1.31
headed fastener
cast-in steel fastener with a head at the embedded end (see Figure 3.1) that derives its tensile resistance from mechanical interlock at the head of the fastener

3.1.32
mechanical interlock
load transfer to a concrete member via interlocking surfaces

3.1.33
minimum edge distance
smallest allowable distance to allow adequate placing and compaction of concrete (cast-in place fasteners) and to avoid damage to the concrete during installation (post-installed fasteners), given in the European Technical Product Specification

3.1.34
minimum member thickness
smallest value for member thickness, in which a fastener or an anchor channel is allowed to be installed, given in the European Technical Product Specification

3.1.35
minimum spacing
smallest value for distance between two fasteners to allow adequate placing and compaction of concrete (cast-in fasteners) and to avoid damage to the concrete during installation (post-installed fasteners), measured centreline to centreline, given in the European Technical Product Specification

3.1.36
post-installed fastener
fastener installed in hardened concrete (see Figure 3.3)

3.1.37
pull-out failure
both pull-out failure of mechanical fasteners and combined pull-out and concrete failure of bonded fasteners

3.1.38
pull-out failure of mechanical fasteners
failure mode in which the fastener pulls out of the concrete without development of the full concrete resistance or in case of post-installed mechanical fasteners a failure mode in which the fastener body pulls through the expansion sleeve without development of the full concrete resistance

3.1.39
shear load
load acting parallel to the concrete surface and transversely with respect to the longitudinal axis of the channel; load applied perpendicular to the longitudinal axis of a fastener

3.1.40
spacing
distance between the centre lines of fasteners; distance between centre lines of channel bolts as well as anchors of anchor channels

3.1.41
steel failure of fastener
failure mode characterized by fracture of the steel fastener parts

3.1.42
supplementary reinforcement
anchor reinforcement
reinforcement tying a potential concrete breakout body to the concrete member

3.1.43
tension load
load applied perpendicular to the surface of the base material (for anchor channels) and along the axis of a fastener

3.1.44
torque-controlled expansion fastener
post-installed expansion fastener that derives its tensile resistance from the expansion of one or more sleeves or other components against the sides of the drilled hole through the application of torque, which pulls the cone(s) into the expansion sleeve(s) during installation

Note 1 to entry: After setting, tensile loading larger than the existing pre-stressing force causes additional expansion (follow-up expansion), see Figure 3.3 a) and b)).

3.1.45
undercut fastener
post-installed fastener that develops its tensile resistance from the mechanical interlock provided by undercutting of the concrete at the embedded end of the fastener

Note 1 to entry: The undercutting is achieved with a special drill before installing the fastener or alternatively by the fastener itself during its installation, see Figure 3.3 d) and e)).

3.2 Symbols and abbreviations

3.2.1 Indices

a	acceleration
adm	admissible
b	bond
c	concrete
ca	connection
cb	blow-out
cbo	channel bolt
ch	channel
cp	concrete pry-out
cr	cracked; characteristic
d	design value
E	action effects
Ed	design action
el	elastic
eq	seismic (earthquake)
F	action
fat	fatigue
fi	fire
fix	fixture
flex	bending
ind	indirect
k	characteristic value
L	load

l	local
M	material
max	maximum
min	minimum
N	normal force
nom	nominal
p	pull-out
pl	plastic
pr	prying
R	resistance, restraint
Rd	design resistance
re	reinforcement
s	steel
sp	splitting
u	ultimate
ucr	uncracked
V	shear force
y	yield

3.2.2 Superscripts

a	anchor
cb	channel bolt
ch	channel
g	load on or resistance of a group of fasteners
h	highest loaded (most stressed) fastener in a group
0	basic value

3.2.3 Actions and resistances (listing in alphabetical order)

NOTE In general, only those terms which are used in more than one section of this EN are defined. If a term is used only in one section, it may be defined in that section only.

a_g	design ground acceleration on type A ground
a_{vg}	vertical design ground acceleration on type A ground
A_a	seismic amplification factor (see Formula (C.4) and Table C.2)
A_h	load bearing area of the head of a headed fastener
A_i'	ordinate of a triangle with the height 1 at the position of the load N_{Ed} or V_{Ed} and the base length 2 l_i at the position of the anchor i of an anchor channel
α	ratio of the design ground acceleration on type A ground, a_g, to the acceleration of gravity g
α_{eq}	reduction factor to take into account the influence of large cracks and scatter of load displacement curves under seismic loading
α_{gap}	reduction factor to take into account inertia effects due to an annular gap between fastener and fixture in case of seismic shear loading, given in the relevant European Technical Product Specification
α_v	ratio of the vertical design ground acceleration on type A ground, a_{vg}, to the acceleration of gravity g (see Formula (C.6))
α_V	angle between design shear load V_{Ed} (single fastener) or V_{Ed}^g (group of fasteners) and a line perpendicular to the edge verified for concrete edge failure, $0° \le \alpha_V \le 90°$, see Figure 7.12 and Formula (7.48)
α_1, α_2	influencing factors according to EN 1992–1–1:2004, 8.4.4
C_d	nominal value, e.g. limiting displacement
C_{Ed}	resultant design compression force beneath the fixture (see Figure 6.2) and compression resulting from bending (see Figure 6.8)
C_{pr}	prying force
E	effect of action
E_d	design value of effect of actions
F	force in general
F_{va}	vertical effects of the seismic action for non-structural elements
g	acceleration of gravity
γ	partial factor
γ_a	importance factor of the non-structural element

γ_{inst}	factor accounting for the sensitivity to installation of post-installed fasteners
γ_{M}	partial factor for material
γ_{Mc}	partial factor for concrete cone, concrete edge, concrete blow-out and concrete pry-out failure modes
γ_{Ms}	partial factor for steel failure
H	building height, measured from the foundation or from the top of a rigid basement
M	moment
$M_{\text{Ed}}^{\text{ch}}$	design value of bending moment acting on the anchor channel due to tension loads $N_{\text{Ed}}^{\text{cb}}$ (see 6.3.2 (4))
$M_{\text{Rd,s,flex}}$	design resistance in case of steel failure in terms of flexure of channel under tension load
$M_{\text{Rk,s,flex}}$	characteristic resistance in case of steel failure in terms of flexure of channel under tension load
N	axial force (positive = tension force, negative = compression force)
N_{Ed}	resultant design tension force of the tensioned fastener
N_{Ed}^{a}	design value of tension load acting on an anchor of an anchor channel
$N_{\text{Ed}}^{\text{cb}}$	resultant design tension force acting on a channel bolt
$N_{\text{Ed}}^{\text{h}} \left(V_{\text{Ed}}^{\text{h}}\right)$	design value of tensile load (shear load) acting on the most stressed fastener of a group
$N_{\text{Ed}}^{\text{g}} \left(V_{\text{Ed}}^{\text{g}}\right)$	design value of the resultant tensile (shear) loads of the fasteners in a group effective in taking up tension (shear) loads
$N_{\text{Ed,re}}$	design value of tension load acting on the supplementary reinforcement
$N_{\text{Ed,re}}^{\text{a}}$	design value of tension load acting on the supplementary reinforcement of one anchor of the anchor channel
$N_{\text{Rd,a}}$	design resistance of supplementary reinforcement associated with anchorage failure
$N_{\text{Rd,c}}$	design resistance in case of concrete cone failure under tension load
$N_{\text{Rd,cb}}$	design resistance in case of concrete blow-out failure under tension load
$N_{\text{Rd,p}}$	design resistance in case of pull-out failure under tension load
$N_{\text{Rd,re}}$	design resistance in case of steel failure of supplementary reinforcement
$N_{\text{Rd,s}}$	design value of steel resistance of a fastener or a channel bolt under tension load
$N_{\text{Rd,s,a}}$	design value of steel resistance of one anchor of an anchor channel under tension load

$N_{Rd,s,c}$	design value of steel resistance of the connection between anchor and channel of an anchor channel under tension load
$N_{Rd,s,l}$	design resistance in case of steel failure in terms of local flexure of channel lip under tension load
$N_{Rd,sp}$	design resistance in case of concrete splitting failure under tension load
$N_{Rk,c}$	characteristic resistance in case of concrete cone failure under tension load
$N_{Rk,cb}$	characteristic resistance in case of concrete blow-out failure under tension load
$N_{Rk,p}$	characteristic resistance in case of pull-out failure under tension load
$N_{Rk,p,fi}$	characteristic tension resistance in case of pull-out failure under fire exposure
$N_{Rk,re}$	characteristic resistance in case of steel failure of supplementary reinforcement
$N_{Rk,s}$	characteristic value of steel resistance of a fastener or a channel bolt under tension load
$N_{Rk,s,a}$	characteristic value of steel resistance of one anchor of an anchor channel under tension load
$N_{Rk,s,c}$	characteristic value of steel resistance of the connection between anchor and channel of an anchor channel under tension load
$N_{Rk,s,fi}$	characteristic tension resistance in case of steel failure under fire exposure
$N_{Rk,s,l}$	characteristic resistance in case of steel failure in terms of local flexure of channel lip under tension load
$N_{Rk,sp}$	characteristic resistance in case of concrete splitting failure under tension load
ϕ_m	mandrel diameter of reinforcing bar
$\psi_{ch,c,N}$	factor taking into account the influence of a corner on the concrete cone resistance for an anchor channel
$\psi_{ch,c,Nb}$	factor taking into account the influence of a corner on the concrete blow-out resistance for an anchor channel
$\psi_{ch,c,V}$	factor taking into account the influence of a corner on the concrete edge resistance for an anchor channel
$\psi_{ch,e,N}$	factor taking into account the influence of an edge on the concrete cone resistance for an anchor channel
$\psi_{ch,h,Nb}$	factor taking into account the effect of the thickness of the concrete member on the concrete blow-out resistance for an anchor channel
$\psi_{ch,h,V}$	factor taking into account the influence of the thickness of the concrete member on the concrete edge resistance for an anchor channel
$\psi_{ch,s,N}$	factor taking into account the influence of neighbouring anchors on the concrete cone resistance for an anchor channel

$\psi_{ch,s,Nb}$	factor taking into account the influence of neighbouring anchors on the concrete blow-out resistance for an anchor channel
$\psi_{ch,s,V}$	factor taking into account the influence of neighbouring anchors on the concrete edge resistance for an anchor channel
$\psi_{ch,90°,V}$	factor taking into account the influence of shear loads acting parallel to the edge on the concrete edge resistance for an anchor channel
$\psi_{ec,N}$	factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of concrete cone failure
$\psi_{ec,Nb}$	factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of concrete blow-out failure
$\psi_{ec,Np}$	factor taking into account the group effect when different tension loads are acting on the individual fasteners of a group in case of combined pull-out and concrete failure of bonded fasteners
$\psi_{ec,V}$	factor taking into account the group effect when different shear loads are acting on the individual fasteners of a group in case of concrete edge failure
$\psi_{g,Nb}$	factor taking into account a group effect of a number of fasteners in a row parallel to the edge in case of concrete blow-out failure
$\psi_{g,Np}$	factor taking into account a group effect for closely spaced bonded fasteners
$\psi_{h,sp}$	factor taking into account the influence of the actual member thickness on the splitting resistance
$\psi_{h,V}$	factor taking into account the fact that concrete edge resistance does not increase proportionally to the member thickness
$\psi_{M,N}$	factor taking into account the effect of a compression force between the fixture and concrete in case of bending moments with or without axial force
$\psi_{re,N}$	shell spalling factor
$\psi_{re,V}$	factor taking into account the effect of reinforcement located on the edge in case of concrete edge failure
$\psi_{s,N}$	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of concrete cone failure
$\psi_{s,Nb}$	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of concrete blow-out failure
$\psi_{s,Np}$	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of an edge in the concrete member in case of combined pull-out and concrete failure of bonded fasteners
$\psi_{s,V}$	factor taking into account the disturbance of the distribution of stresses in the concrete due to the proximity of further edges in the concrete member in case of concrete edge failure

$\psi_{\alpha,V}$	factor taking into account the influence of a shear load inclined to the edge in case of concrete edge failure
q	behaviour factor
q_a	behaviour factor for non-structural elements
Q_{ind}	indirect variable action
R	resistance
R_d	design value of resistance
R_k	characteristic value of resistance
δ	displacement of fastener
S	soil factor
S_a	horizontal seismic coefficient applicable to non-structural elements
S_{Va}	vertical seismic coefficient applicable to non-structural elements
$s_{l,N}$	characteristic spacing of channel bolts for channel lip failure under tension load
$s_{l,V}$	characteristic spacing of channel bolts for channel lip failure under shear load
$\sigma_{Rk,s,fi}$	characteristic tension strength of a fastener in case of steel failure under fire exposure
T_a	fundamental period of vibration of the non-structural element
T_{Ed}	design value of applied torsional moment on fixture (see Figure 6.4 and Figure 7.11)
T_1	fundamental period of vibration of the building in the relevant direction
τ_{Rk}	characteristic bond resistance of a post-installed bonded fastener, depending on the concrete strength class, in uncracked $\left(\tau_{Rk,ucr}\right)$ or cracked concrete $\left(\tau_{Rk,cr}\right)$
$\tau_{Rk,s,fi}$	characteristic shear strength of a fastener in case of steel failure under fire exposure
V	shear force
V_a	shear force on fastener (see Figure 6.4)
V_{Ed}	design shear force
$V_{Rd,c}$	design resistance in case of concrete edge failure under shear load
$V_{Rd,cp}$	design resistance in case of concrete pry-out failure under shear load
$V_{Rd,s}$	design value of steel resistance of a fastener or a channel bolt under shear load
$V_{Rd,s,a}$	design value of steel resistance of one anchor of an anchor channel under shear load
$V_{Rd,s,c}$	design value of steel resistance of the connection between anchor and channel of an anchor channel under shear load

$V_{Rd,s,M}$	design resistance in case of steel failure with lever arm under shear load
$V_{Rd,s,l}$	design resistance in case of steel failure in terms of local flexure of channel lip under shear load
$V_{Rk,c}$	characteristic resistance in case of concrete edge failure under shear load
$V_{Rk,cp}$	characteristic resistance in case of concrete pry-out failure under shear load
$V_{Rk,cp,fi}$	characteristic resistance in case of concrete pry-out failure under shear load and fire exposure
$V_{Rk,s}$	characteristic value of steel resistance of a fastener or a channel bolt under shear load
$V_{Rk,s,a}$	characteristic value of steel resistance of one anchor of an anchor channel under shear load
$V_{Rk,s,c}$	characteristic value of steel resistance of the connection between anchor and channel of an anchor channel under shear load
$V_{Rk,s,fi}$	characteristic shear resistance in case of steel failure under fire exposure
$V_{Rk,s,l}$	characteristic resistance in case of steel failure in terms of local flexure of channel lip under shear load
$V_{Rk,s,M}$	characteristic resistance in case of steel failure with lever arm under shear load
W_a	weight of the non-structural element
z	height of the non-structural element above the level of application of the seismic action

3.2.4 Concrete and steel

A_s	stressed cross section of a fastener
$A_{s,re}$	cross section of a reinforcing bar
ε	strain
f_{bd}	design bond strength of supplementary reinforcement
f_{ck}	nominal characteristic compressive cylinder strength (150 mm diameter by 300 mm height)
f_{uk}	nominal characteristic steel ultimate tensile strength
f_{yk}	nominal characteristic steel yield strength
$f_{yk,re}$	nominal characteristic steel yield strength of reinforcement
I_p	radial moment of inertia of the fastening
I_y	moment of inertia of the channel relative to the y-axis of the channel (see Figure 3.2)
σ	stress in the concrete (to determine cracked vs uncracked concrete state)
w_k	crack width
W_{el}	elastic section modulus calculated from the stressed cross section

3.2.5 Fasteners and fastenings, reinforcement

a	spacing between outer fasteners in adjoining fastenings
$a_1(a_2)$	spacing between outer fasteners in adjoining fastenings in direction 1 (direction 2) (see Figure 3.4)
a_3	distance between concrete surface and point of assumed restraint of a fastener loaded by a shear force with lever arm (see Figure 6.6)
α	factor accounting for degree of restraint of the fastening
b_1	width of anchor plate (see Figure 3.1)
b_{ch}	width of the channel (see Figure 3.2)
b_{fix}	width of fixture
c	edge distance from the axis of a fastener or the axis of an anchor channel
c_1	edge distance in direction 1 (see Figure 3.4)
c_2	edge distance in direction 2 (see Figure 3.4), where direction 2 is perpendicular to direction 1
c_{cr}	characteristic edge distance to ensure the characteristic resistance of a single fastener
$c_{cr,N}$ ($c_{cr,V}$)	characteristic edge distance for ensuring the transmission of the characteristic resistance of a single fastener or anchor of an anchor channel in case of concrete break-out under tension loading (concrete edge failure under shear loading)
$c_{cr,Np}$	characteristic edge distance for ensuring the transmission of the characteristic resistance of a single bonded fastener under tension load in case of combined concrete and pull-out failure
c_{min}	minimum allowable edge distance
d	diameter of fastener bolt or thread diameter, diameter of the stud or shank of headed studs, effective depth to supplementary reinforcement (see Figure 6.8)
d_a	diameter of an anchor of an anchor channel (round anchor)
d_f	diameter of clearance hole in the fixture
d_h	diameter of the head of a headed fastener (see Figure 3.1)
d_{nom}	outside diameter of a fastener
E	modulus of elasticity
e_1	distance between shear load and concrete surface (see Figure 6.6)
e_N	eccentricity of resultant tension force of tensioned fasteners in respect to the centre of gravity of the tensioned fasteners (see Figure 6.3)
e_s	distance between the line of the shear load and the axis of the supplementary reinforcement for shear (see Figure 6.8)

e_V eccentricity of resultant shear force of sheared fasteners in respect to the centre of gravity of the sheared fasteners (see Figure 7.15)

h thickness of concrete member in which the fastener or anchor channel is installed (see Figure 3.4)

h_{ch} height of the channel (see Figure 3.2)

h_{ef} effective embedment depth (see Figures 3.1 to 3.3)

h_{min} minimum allowed thickness of concrete member

h_{nom} nominal length of the headed fastener welded to the anchor plate

l_1 anchorage length of the reinforcing bar in the assumed concrete break-out body (see Figures 7.2 and 7.10)

l_a effective lever arm of the shear force acting on a fastener or on an anchor channel (see Figure 6.6) used in the calculation

l_{bd} design anchorage length of reinforcement

l_i influence length of an external load N_{Ed} or V_{Ed} along an anchor channel (see Figure 6.7 and Formula (6.5))

n number of fasteners in a group

n_{re} number of legs of the supplementary reinforcement effective for one fastener

ϕ diameter of reinforcing bar

s centre to centre spacing of fasteners in a group (see Figure 3.4) or anchors of an anchor channel (see Figure 6.7) or spacing of reinforcing bars

s_1 (s_2) spacing of fasteners in a group in direction 1 (direction 2), (see Figure 3.4)

s_{cbo} spacing of channel bolts of an anchor channel

s_{cr} characteristic spacing for ensuring the transmission of the characteristic resistance of a single fastener or anchor of an anchor channel

$s_{cr,N}$ ($s_{cr,V}$) characteristic spacing of fasteners or anchors of anchor channels to ensure the characteristic resistance of the individual fasteners or anchors of an anchor channel in case of concrete cone failure under tension load (concrete edge failure under shear load)

s_{min} minimum allowable spacing

t thickness of anchor plate (see Figure 3.1)

t_{fix} thickness of the fixture

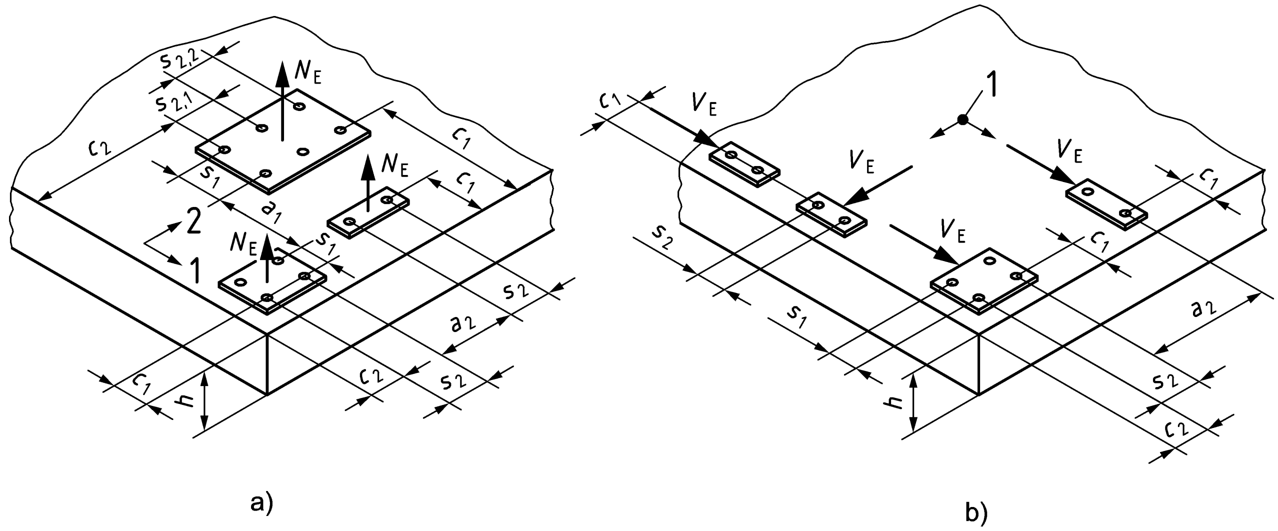
t_{grout} thickness of grout layer

t_h thickness of head of headed fastener

z internal lever arm of a fastening calculated according to the theory of elasticity (see Figure 6.2 and Formula (7.7)); internal lever arm of concrete member (see Figure 6.8)

3.2.6 Units

In this EN SI-units are used. Unless stated otherwise in the formulae, the following units are used: dimensions are given in mm, cross sections in mm², section modulus in mm³, moment of inertia in mm⁴, forces and loads in N and stresses, strengths and moduli of elasticity in N/mm².



Key

1 indices 1 and 2: For fastenings close to an edge under tension loads, index 1: direction perpendicular to the edge, index 2: direction parallel to the edge. For shear loads the indices depend on the edge for which the verification of concrete edge failure is performed (index 1: direction perpendicular to the edge for which verification is made; index 2: perpendicular to direction 1)

a) fastenings subjected to tension load

b) fastenings subjected to shear load in the case of fastenings near an edge

Figure 3.4 — Definitions related to concrete member dimensions, fastener spacing and edge distance

4 Basis of design

4.1 General

(1) With appropriate degrees of reliability fasteners and anchor channels shall sustain all actions and influences likely to occur during execution and use (ultimate limit state). They shall not deform to an inadmissible degree (serviceability limit state) and remain fit for the use for which they are required (durability). They shall not be damaged by accidental events to an extent disproportional to the original cause.

(2) Fastening and anchor channel shall be designed according to the same principles and requirements valid for structures given in EN 1990 including load combinations and EN 1992-1-1.

NOTE A design using the partial factors given in this EN and the partial factors given in the EN 1990 Annexes is considered to lead to a structure associated with reliability class RC2, i.e. a β-value of 3,8 for a 50 year reference period. For further information, see EN 1990.

(3) The design working life of the fasteners or anchor channels shall not be less than that of the fixture. The partial factors for resistance and durability in this EN are based on a design working life of 50 years for the fastening or anchor channel.

(4) Values of actions shall be obtained from the relevant parts of the EN 1991 series and EN 1998 series in the case of seismic actions (see Annex C).

(5) If the fastening is subjected to fatigue or seismic actions, only fasteners suitable for this application shall be used (see relevant European Technical Product Specification).

(6) The design of the concrete member to which the fixture transfers loads shall comply with the EN 1992-1 series and the requirements of Annex A for safe transmission of loads to the supports of the member.

(7) For the design and execution of fastenings and anchor channels the same quality requirements are valid as for the design and execution of structures and the attachment:

— the design of the fastening and of an anchor channel shall be performed by qualified personnel;

— the execution shall comply with the requirements stated in Annex F.

4.2 Required verifications

(1) Fasteners shall be verified in accordance with EN 1992-1-1 and EN 1998-1 (where applicable).

(2) In the ultimate limit state, verifications are required for all appropriate load directions and all relevant failure modes.

(3) In the serviceability limit state, it shall be shown that the displacements occurring under the relevant actions are not larger than the admissible displacement.

(4) The material of the fastener and the corrosion protection shall be selected and demonstrated taking into account the environmental conditions at the place of installation, and whether the fasteners are inspectable, maintainable and replaceable. Information is given in informative Annex B.

(5) Where applicable the fastening shall have an adequate fire resistance. For the purpose of this EN it is assumed that the fire resistance of the fixture is adequate. Annex D describes the principles, requirements and rules for the design of fastenings exposed to fire.

4.3 Design format

(1) At the ultimate limit state it shall be shown that:

$$E_{\mathrm{d}} \leq R_{\mathrm{d}} \quad (4.1)$$

and at the serviceability limit state it shall be shown that

$$E_{\mathrm{d}} \leq C_{\mathrm{d}} \quad (4.2)$$

(2) The forces in the fasteners shall be derived using appropriate combinations of actions on the fixture in accordance with EN 1990. Forces Q_{ind} resulting from restraint to deformation, intrinsic (e.g. shrinkage) or extrinsic (e.g. temperature variations), of the attached member shall be taken into account in the design of fasteners. The design action shall be taken as $\gamma_{\mathrm{ind}} \cdot Q_{\mathrm{ind}}$.

(3) In general actions on the fixture may be calculated ignoring the displacement of the fasteners or of the anchor channels. However, the effect of displacement of the fasteners or of the anchor channels should be considered when a statically indeterminate stiff element is fastened.

(4) In the ultimate limit state the value of the design resistance is obtained from the characteristic resistance of the fastener, the group of fasteners or anchor channels as follows:

$$R_{\mathrm{d}} = R_{\mathrm{k}} / \gamma_{\mathrm{M}} \quad (4.3)$$

(5) In the serviceability limit state the value E_d, which is the design value of fastener or anchor channel displacement, shall be evaluated from the information given in the relevant European Technical Product Specification. Furthermore, cracking of the concrete for fastening with supplementary reinforcement and for embedded base plates close to an edge loaded in shear shall be considered. For C_d, see Clause 11.

4.4 Verification by the partial factor method

4.4.1 Partial factors for actions

(1) Partial factors shall be in accordance with EN 1990.

(2) For the verification of indirect and fatigue actions the values of the partial factors γ_{ind} and $\gamma_{F,fat}$ shall be used.

NOTE The values of γ_{ind} and $\gamma_{F,fat}$ for use in a Country may be found in its National Annex. The recommended values for ultimate limit state are $\gamma_{ind} = 1{,}2$ for concrete failure and $\gamma_{ind} = 1{,}0$ for other modes of failure, and in case of fatigue loading $\gamma_{F,fat} = 1{,}0$.

4.4.2 Partial factors for resistance

4.4.2.1 General

The factor to account for the sensitivity to installation of post-installed fasteners, γ_{inst}, has been included as part of γ_{Mc} (see Table 4.1). It has its origin in the prequalification of the product. The factor γ_{inst} is product dependent and is given in the relevant European Technical Product Specification. Therefore γ_{inst} shall not be modified.

Table 4.1 — Recommended values of partial factors

Failure modes	Partial factor		
		Permanent and transient design situations	Accidental design situation
Steel failure – fasteners			
Tension	γ_{Ms}	$= 1{,}2 \cdot f_{uk}/f_{yk} \geq 1{,}4$	$= 1{,}05 \cdot f_{uk}/f_{yk} \geq 1{,}25$
Shear with and without lever arm	γ_{Ms}	$= 1{,}0 \cdot f_{uk}/f_{yk} \geq 1{,}25$ when $f_{uk} \leq 800$ N/mm² <u>and</u> $f_{yk}/f_{uk} \leq 0{,}8$	$= 1{,}0 \cdot f_{uk}/f_{yk} \geq 1{,}25$ when $f_{uk} \leq 800$ N/mm² <u>and</u> $f_{yk}/f_{uk} \leq 0{,}8$
		$= 1{,}5$ when $f_{uk} > 800$ N/mm² <u>or</u> $f_{yk}/f_{uk} > 0{,}8$	$= 1{,}3$ when $f_{uk} > 800$ N/mm² <u>or</u> $f_{yk}/f_{uk} > 0{,}8$
Steel failure – anchor channels			
Tension in anchors and channel bolts	γ_{Ms}	$= 1{,}2 \cdot f_{uk}/f_{yk} \geq 1{,}4$	$= 1{,}05 \cdot f_{uk}/f_{yk} \geq 1{,}25$
Shear with and without lever arm in channel bolts	γ_{Ms}	$= 1{,}0 \cdot f_{uk}/f_{yk} \geq 1{,}25$ when $f_{uk} \leq 800$ N/mm² <u>and</u> $f_{yk}/f_{uk} \leq 0{,}8$	$= 1{,}0 \cdot f_{uk}/f_{yk} \geq 1{,}25$ when $f_{uk} \leq 800$ N/mm² <u>and</u> $f_{yk}/f_{uk} \leq 0{,}8$
		$= 1{,}5$ when $f_{uk} > 800$ N/mm² <u>or</u> $f_{yk}/f_{uk} > 0{,}8$	$= 1{,}3$ when $f_{uk} > 800$ N/mm² <u>or</u> $f_{yk}/f_{uk} > 0{,}8$
Connection between anchor and channel in tension and shear	$\gamma_{Ms,ca}$	= 1,8	= 1,6
Local failure of anchor channel by bending of lips in tension and shear	$\gamma_{Ms,l}$	= 1,8	= 1,6
Bending of channel	$\gamma_{Ms,flex}$	= 1,15	= 1,0
Steel failure – supplementary reinforcement			
Tension	$\gamma_{Ms,re}$	= 1,15 [a]	= 1,0

Concrete related failure			
Concrete cone failure, concrete edge failure, concrete blow-out failure, concrete pry-out failure	γ_{Mc}	= $\gamma_c \cdot \gamma_{inst}$	= $\gamma_c \cdot \gamma_{inst}$
	γ_c	= 1,5[a] for seismic repair and strengthening of existing structures see the EN 1998 series	= 1,2[a] for seismic repair and strengthening of existing structures see the EN 1998 series
	γ_{inst}	= 1,0 for headed fasteners and anchor channels satisfying the requirements of 4.6 (in tension and shear) ≥ 1,0 for post-installed fasteners in tension, see relevant European Technical Product Specification = 1,0 for post-installed fasteners in shear	
Concrete splitting failure	γ_{Msp}	= γ_{Mc}	
Pull-out and combined pull-out and concrete failure	γ_{Mp}	= γ_{Mc}	
[a] The values are in accordance with EN 1992-1-1.			

4.4.2.2 Ultimate limit state (static, quasi static and seismic loading)

(1) Partial factors for fastenings under static, quasi static and seismic loading shall be applied to characteristic resistances.

(2) The recommended values for the partial factors for fastenings under seismic loading are identical to the corresponding values for quasi static loading. For accidental loads the partial factors according to Table 4.1 are recommended.

NOTE The value of a partial factor for use in a Country under static, quasi static, seismic and accidental loading may be found in its National Annex, when the partial factor is not product dependent. The recommended values are given in Table 4.1. They take into account that the characteristic resistance for steel failure is based on f_{uk}, except f_{yk} should be used for bending of the channel of anchor channels and steel failure of supplementary reinforcement.

4.4.2.3 Ultimate limit state (fatigue loading)

Partial factors for fastenings under fatigue loading $\gamma_{Ms,fat}$, $\gamma_{Mc,fat}$, $\gamma_{Msp,fat}$ and $\gamma_{Mp,fat}$ shall be applied to characteristic resistances.

NOTE The values of the partial factors for fastenings under fatigue loading for use in a Country may be found in its National Annex. For the partial factor for material, the following values are recommended: $\gamma_{Ms,fat} = 1{,}35$ (steel failure) and $\gamma_{Mc,fat} = \gamma_{Msp,fat} = \gamma_{Mp,fat} = 1{,}5 \cdot \gamma_{inst}$ (concrete related failure modes).

4.4.2.4 Serviceability limit state

The partial factor for resistance is γ_M and shall be applied to characteristic resistances.

NOTE The value of the partial factor for serviceability limit state for use in a Country may be found in its National Annex. For the partial factor γ_M the value $\gamma_M = 1{,}0$ is recommended.

4.5 Project specification

(1) The project specification shall typically include the following.

a) Strength class of the concrete used in the design and indication as to whether the concrete is assumed to be cracked or not cracked. If uncracked concrete is assumed, verification is required (see 4.7).

b) Environmental exposure assumed in design (see EN 206).

c) A note indicating that the number, manufacturer, type and geometry of the fasteners or manufacturer, type and geometry of anchor channel or channel bolts shall not be changed unless verified and approved by the responsible designer.

d) Construction drawings or supplementary design documents should include:

   1) location of the fasteners or anchor channels in the structure, including tolerances;

   2) number and type of fasteners (including embedment depth) or type of anchor channels and channel bolts;

   3) spacing and edge distance of the fastenings or anchor channels including tolerances (normally these should be specified with positive tolerances only);

   4) thickness of fixture and diameter of the clearance holes (if applicable);

5) position of the attachment on the fixture including tolerances;

6) maximum thickness of a possible intervening layer e.g. grout or insulation between the fixture and surface of the concrete;

7) (special) installation instructions (if applicable). These shall not contradict the manufacturer's installation instructions.

e) Reference to the manufacturer's installation instructions.

f) A note that the fasteners shall be installed ensuring the specified embedment depth.

(2) For additional quality assurance of the installation project specification may call for proof loading of installation on site.

4.6 Installation of fasteners

The resistance and reliability of fastenings are significantly influenced by the manner in which the fasteners are installed. The partial factors given in 4.4 are valid only when the conditions and the assumptions given in Annex F are fulfilled.

4.7 Determination of concrete condition

(1) In the region of the fastening the concrete may be cracked or uncracked. The condition of the concrete for the service life of the fastening shall be determined by the designer.

NOTE In general, it is conservative to assume that the concrete is cracked over its service life.

(2) Uncracked concrete may be assumed if it is proven that under the characteristic combination of loading at serviceability limit state the fastener with its entire embedment depth is located in uncracked concrete. This will be satisfied if Formula (4.4) is observed (compressive stresses are negative):

$$\sigma_L + \sigma_R \leq \sigma_{adm} \tag{4.4}$$

where

σ_L is the stress in the concrete induced by external loads including fastener loads

σ_R is the stress in the concrete due to restraint of intrinsic imposed deformations (e.g. shrinkage of concrete) or extrinsic imposed deformations (e.g. due to displacement of support or temperature variations). If no detailed analysis is conducted, then $\sigma_R = 3\ \text{N/mm}^2$ should be assumed;

σ_{adm} is the admissible tensile stress for the definition of uncracked concrete.

The stresses σ_L and σ_R should be calculated assuming that the concrete is uncracked. For concrete members which transmit loads in two directions (e.g. slabs, walls and shells) Formula (4.4) should be fulfilled for both directions.

NOTE The value of σ_{adm} may be found in a Country's National Annex. The recommended value is $\sigma_{adm} = 0$ and is based on the characteristic combination of loading at the serviceability limit state.

5 Durability

Fasteners and fixtures shall be chosen to have adequate durability taking into account the environmental conditions for the structure (such as exposure classes) as given in EN 1992-1-1.

NOTE 1 Product specific information might be stated in the relevant European Technical Product Specification.

NOTE 2 Further information is given in informative Annex B.

6 Derivation of forces acting on fasteners – analysis

6.1 General

(1) Clause 6 applies to static and quasi static loading. The requirements for fatigue and seismic loading are given in Clauses 8 and 9, respectively.

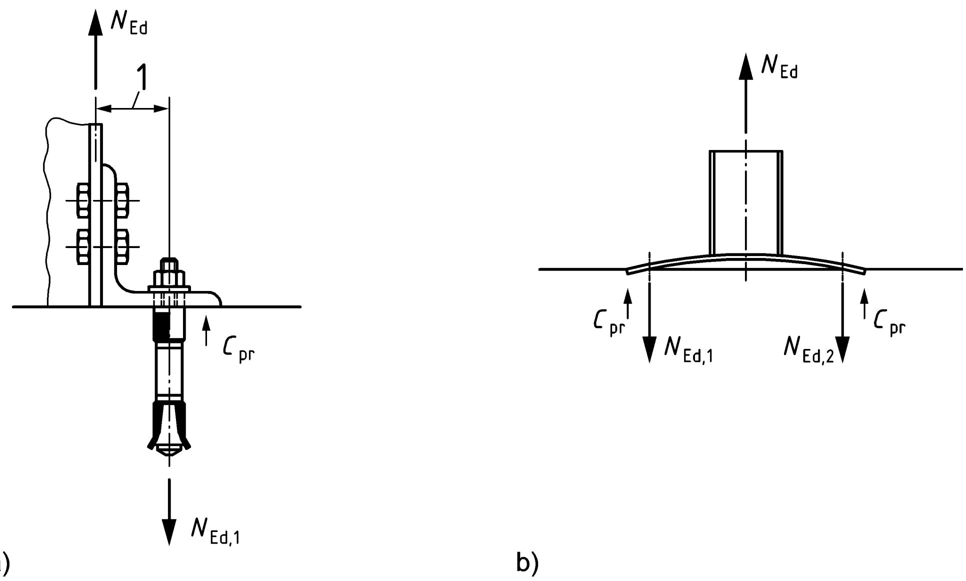
(2) The actions acting on a fixture shall be transferred to the fasteners as statically equivalent tension and shear forces.

(3) When a bending moment and/or a compression force act on a fixture, which is in contact with concrete or mortar, a friction force will develop. If a shear force is also acting on a fixture, this friction will reduce the shear force on the fastener. However, in this EN friction forces are neglected in the design of the fastenings.

(4) Eccentricities and prying effects shall be explicitly considered in the design of the fastening (see Figure 6.1). Prying forces C_{pr} arise with deformation of the fixture and displacement of the fasteners.

(5) In general, elastic analysis may be used for establishing the loads on individual fasteners both at ultimate and serviceability limit states.

For ultimate limit states plastic analysis for headed and post-installed fasteners may be used, if the conditions of CEN/TR 17081, *Design of fastenings for use in concrete — Plastic design of fastenings with headed and post-installed fasteners*, are observed.



Key

1 eccentricity

C_{pr} prying force

a) $N_{Ed,1} = N_{Ed} + C_{pr}$

b) $N_{Ed,1} = N_{Ed,2} = 0{,}5 N_{Ed} + C_{pr}$

Figure 6.1 — Eccentricity and prying action – Examples for amplification of tension forces acting on fastener a) due to eccentricity and b) due to prying action

6.2 Headed fasteners and post-installed fasteners

6.2.1 Tension loads

(1) The design value of tension loads acting on each fastener due to the design values of normal forces and bending moments acting on a rigid fixture may be calculated assuming a linear distribution of strains as shown in Figure 6.2 and a linear relationship between strains and stresses. If the fixture bears on the concrete with or without a grout layer, the compression forces are transmitted to the concrete by the fixture. The load distribution to the fasteners may be calculated analogous to the elastic analysis of reinforced concrete using the following assumptions (see Figure 6.2).

a) The fixture is sufficiently rigid such that linear strain distribution will be valid (analogous to Bernoulli hypothesis).

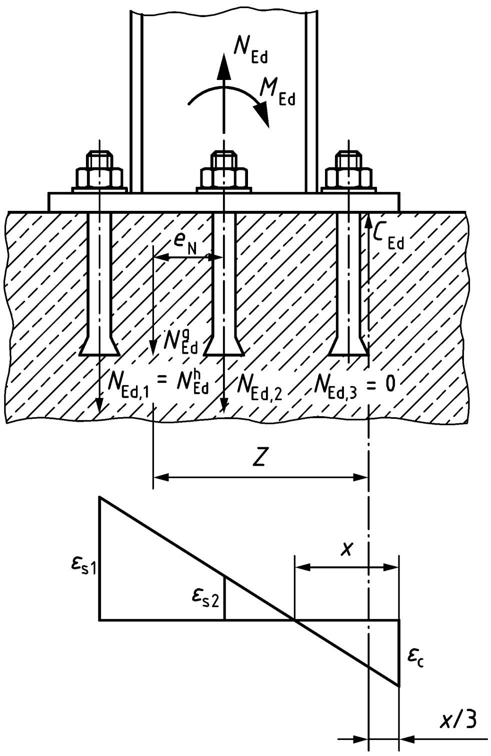
b) The axial stiffness of all fasteners is equal. The stiffness should be determined on the basis of the elastic steel strains in the fastener.

c) The modulus of elasticity of the concrete is taken from EN 1992-1-1. As a simplification, the modulus of elasticity of concrete may be assumed as $E_c = 30\ 000\ \text{N/mm}^2$. If no specific information is available in the relevant European Technical Product Specification, the modulus of elasticity of steel of the fastener may, as a simplification, be assumed as $E_s = 210\ 000\ \text{N/mm}^2$.

d) In the zone of compression under the fixture the fasteners do not take up normal forces.

(2) The assumption in 6.2.1 (1) a) may be considered to be satisfied if the base plate remains elastic under design actions $\left(\sigma_{\mathrm{Ed}} \leq \sigma_{\mathrm{Rd}}\right)$ and its deformation remains negligible in comparison with the axial displacement of the fasteners. If this requirement for the deformation is not fulfilled the elastic deformation behaviour of the fixture shall be taken into account adequately to determine the design value of tension loads acting on each fastener.

(3) For fastener groups with different levels of tension forces $N_{\mathrm{Ed,i}}$ acting on the individual fasteners of a group, the eccentricity e_{N} of the tension force $N_{\mathrm{Ed}}^{\mathrm{g}}$ of the group with respect to the centre of gravity of the tensioned fasteners influences the concrete related resistances of the group (i.e. resistances in case of concrete cone failure, combined pull-out and concrete failure of bonded fasteners, concrete splitting failure and concrete blow-out failure). Therefore this eccentricity shall be calculated (see Figures 6.2 and 6.3). If the tensioned fasteners do not form a rectangular pattern (see Figure 6.3 c)), for reasons of simplicity the group of tensioned fasteners may be shaped into a rectangular group to calculate the centre of gravity. It may be assumed as point '5' in Figure 6.3 c). This simplification will lead to a larger eccentricity and a reduced concrete resistance.

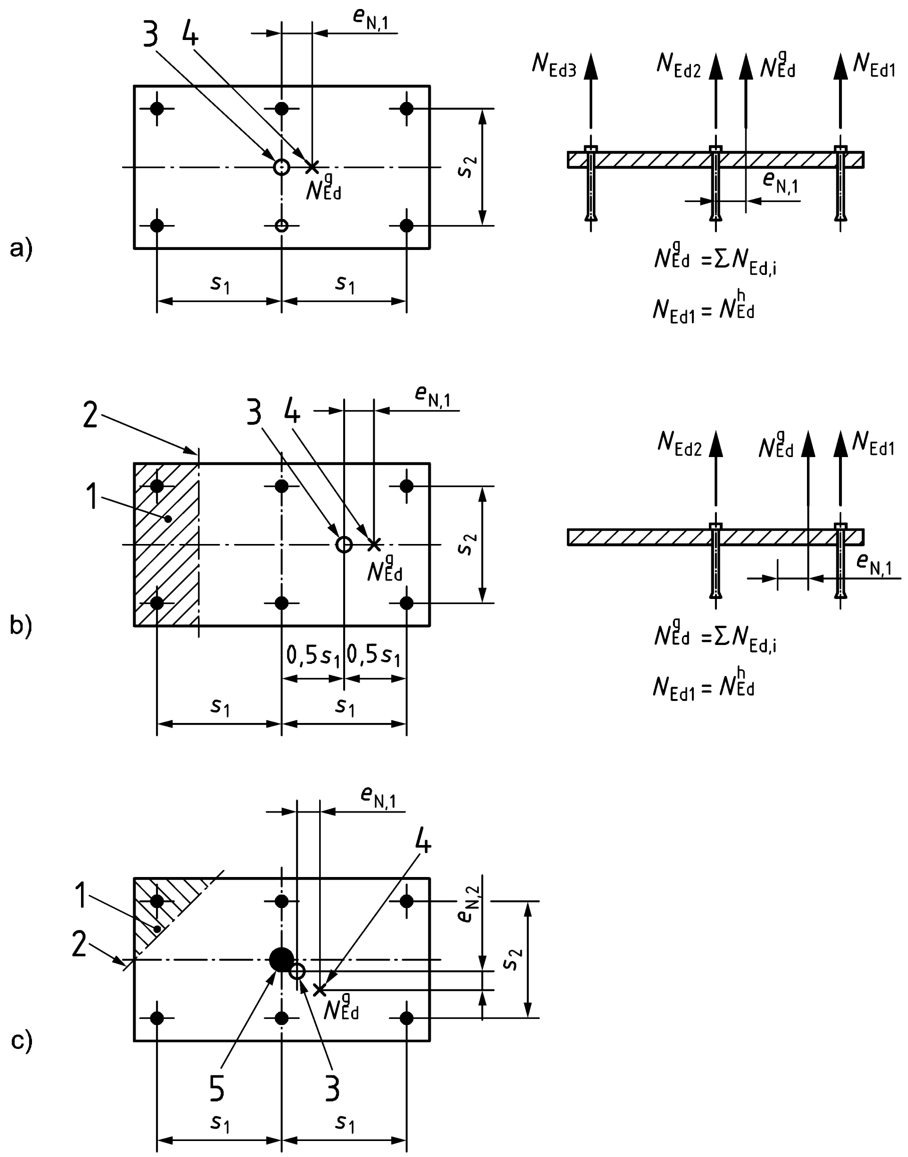


Key

$N_{\mathrm{Ed,\,i}} = \varepsilon_{\mathrm{s,\,i}} \cdot E_{\mathrm{s}} \cdot A_{\mathrm{s}}$

$C_{\mathrm{Ed}} = 0{,}5 \cdot b_{\mathrm{fix}} \cdot x \cdot \varepsilon_{\mathrm{c}} \cdot E_{\mathrm{c}}$

Figure 6.2 — Fastening with a rigid fixture bearing on the concrete loaded by a bending moment and a normal force — Example



Key

1 compressed area

2 neutral axis

3 geometric centre of gravity of tensioned fasteners

4 point of resultant tensile force of tensioned fasteners

5 centre of gravity in simplified approach

a) eccentricity in one direction, all fasteners are loaded by a tension force

b) eccentricity in one direction, only a part of the fasteners of the group are loaded by a tension force

c) eccentricity in two directions, only a part of the fasteners of the group are loaded by a tension force

Figure 6.3 — Fastenings subjected to an eccentric tensile force N_{Ed} — Examples

6.2.2 Shear loads

6.2.2.1 General

Only fastenings with no hole clearances or clearances in the direction of the shear load complying with Table 6.1 are covered by this EN.

6.2.2.2 Distribution of loads

(1) The load distribution depends on the effectiveness of fasteners to resist shear loads which is, e.g. influenced by the hole clearance and the edge distance. The following cases are distinguished.

a) All fasteners are considered to be effective for each of the following cases:

1) if the fastening is located far from an edge $\left(c_{\mathrm{i}} \geq \max\left\{10h_{\mathrm{ef}}\,;\,60d_{\mathrm{nom}}\right\}\right)$;

2) for verification of steel failure and pry-out failure;

3) if the fastening is loaded by a torsion moment (see Figure 6.4), or by a shear load parallel to the edge (see Figure 6.5 a)).

b) Only fasteners closest to the edge loaded in shear are assumed to be effective for the verification of concrete edge failure if the fastening is located close to the edge $\left(c < \max\left\{10h_{\mathrm{ef}}\,;60d_{\mathrm{nom}}\right\}\right)$ and loaded perpendicular to the edge (see Figure 6.5 b)).

(2) A fastener is not considered to resist shear loads if the hole is slotted in the direction of the shear force.

Table 6.1 — Hole clearance

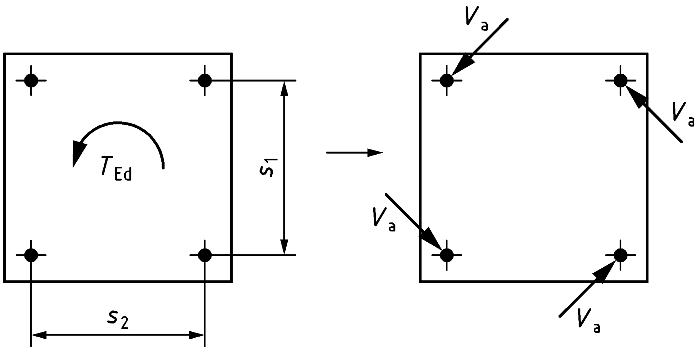
Dimensions in millimetres

1	external diameter of fastener d[a] or d_{nom}[b]	6	8	10	12	14	16	18	20	22	24	27	30	> 30
2	diameter d_{f} of clearance hole in the fixture	7	9	12	14	16	18	20	22	24	26	30	33	d + 3 or d_{nom} + 3

[a] If bolt bears against the fixture.

[b] If sleeve bears against the fixture.

NOTE 1 Applications where bolts are welded to the fixture or screwed into the fixture, or in the cases where any gap between the fastener and the fixture is filled with mortar of sufficient compressive strength (≥ 40N/mm^2) or eliminated by other suitable means may be considered to have no hole clearance.



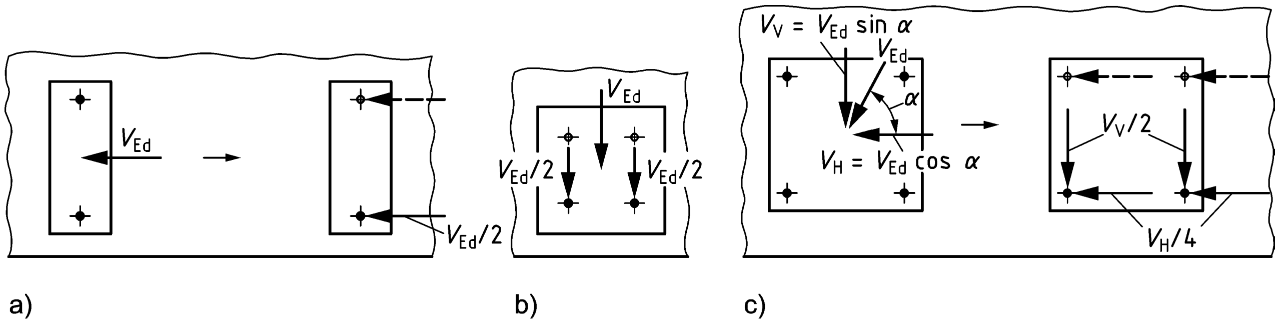
Key

$$V_a = \frac{T_{Ed}}{I_p}\left[\left(\frac{s_1}{2}\right)^2 + \left(\frac{s_2}{2}\right)^2\right]^{0,5}$$

where

$$I_p = s_1^2 + s_2^2$$

Figure 6.4 — Determination of shear loads when all fasteners are effective in verification – Example of torsion moment acting on a quadruple fastening



Key

a) group with two fasteners close to an edge loaded parallel to the edge

b) group with four fasteners close to an edge loaded perpendicular to the edge

c) quadruple fastening close to an edge loaded by an inclined shear load

Figure 6.5 — Determination of shear loads for verification of concrete edge failure; only the forces in the fasteners closest to the edge (solid lines) are considered in the verification – Examples

NOTE 2 In case of groups of fasteners where only the fasteners closest to the edge are effective, the component of the load acting perpendicular to the edge is taken up by the fasteners closest to the edge, while the components of the load acting parallel to the edge – due to reasons of equilibrium – are equally distributed to all fasteners of the group (see Figure 6.5 c)).

Shear loads acting away from the edge do not significantly influence the concrete edge resistance. Therefore, the component of a shear load acting away from the verified concrete edge may be neglected in the calculation of the shear forces on the fasteners close to the verified edge.

6.2.2.3 Shear loads with and without lever arm

(1) Shear loads acting on fastenings may be assumed to act without a lever arm if all of the following conditions are satisfied.

a) The fixture is made out of steel and is in contact with the fastener over a length of at least $0{,}5 \cdot t_{\mathrm{fix}}$.

b) The fixture is fixed:

1) either directly to the concrete without an intermediate layer; or

2) using a levelling mortar with a thickness $t_{\mathrm{grout}} \leq 0{,}5d$ under at least the full dimensions of the fixture on a rough concrete surface (see EN 1992-1-1:2004, 6.2.5) as intermediate layer; the strength of the mortar shall be at least that of the base concrete but not less than 30 N/mm².

When the above conditions are not satisfied, shear force on fastenings should be assumed to act with lever arm.

(2) If in 6.2.2.3 (1) only condition b) is not satisfied, a reduced steel shear capacity of the fasteners in accordance with 7.2.2.3.1 (3) may be used for fastenings in uncracked concrete instead of a design with lever arm provided all the following conditions are satisfied:

— there are at least two fasteners in the direction of the shear force;

— no bending moment or tension force is acting on the base plate;

— the fastener spacing in the direction of the shear force exceeds $10d$ (if inclined shear forces are acting this condition shall be fulfilled for both directions);

— the thickness of the mortar bed t_{grout} is less than or equal to 40 mm and $\leq 5d$ (fasteners without a sleeve) or $\leq 5d_{\mathrm{nom}}$ (fasteners with a sleeve);

— a mortar bed is applied at least to the full dimensions of the fixture on a rough concrete surface (see EN 1992-1-1:2004, 6.2.5);

— the strength of the mortar bed is at least that of the base concrete but not less than 30 N/mm².

(3) If the shear load acts with a lever arm, a bending moment acting on the fastener shall be accounted for. The design bending moment acting on the fastener is calculated according to Formula (6.1):

$$M_{\mathrm{Ed}} = V_{\mathrm{Ed}} \cdot \frac{l_{\mathrm{a}}}{\alpha_{\mathrm{M}}} \quad (6.1)$$

where

$$l_{\mathrm{a}} = a_3 + e_1 \quad (6.2)$$

V_{Ed} is the shear load acting on the fastener under consideration (see Figure 6.6)

where

e_1 is the distance between shear load and concrete surface neglecting the thickness of any levelling grout (see Figure 6.6)

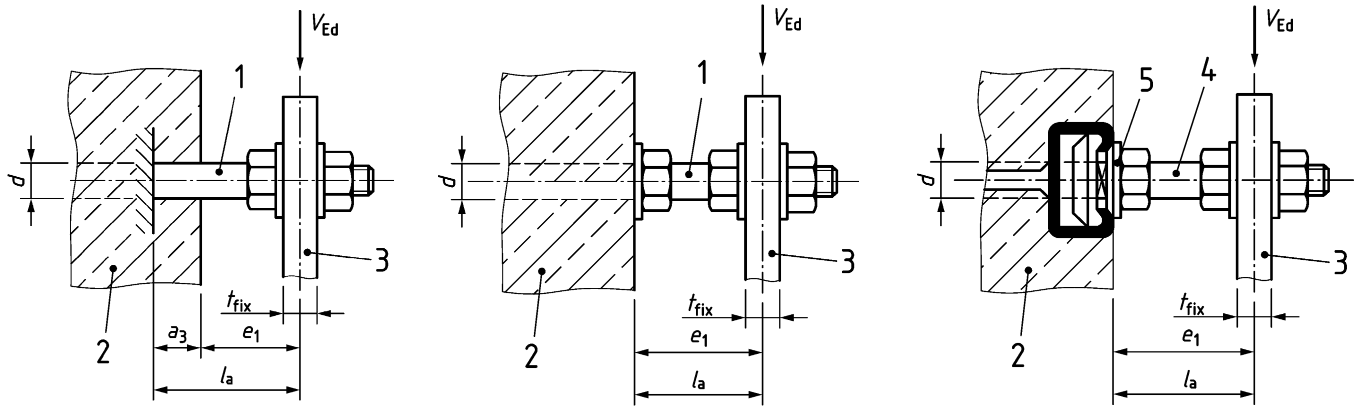
a_3 = 0,5 d_{nom}

= 0 if a washer and a nut are directly clamped to the concrete surface or to the surface of an anchor channel or if a levelling grout layer with a compressive strength $\geq 30\ \text{N/mm}^2$ and a thickness $t_{grout} \leq d/2$ is present.

α_M is the factor accounting for the degree of restraint of the fastener at the side of the fixture of the application in question. It should be determined according to good engineering practice.

No restraint $(\alpha_M = 1{,}0)$ shall be assumed if the fixture can rotate freely.

Full restraint $(\alpha_M = 2{,}0)$ may be assumed only if the fixture cannot rotate.



a) b) c)

Key

1 fastener
2 concrete element
3 attachment
4 channel bolt
5 special washer

a) stand-off installation
b) stand-off installation with nut and washer to prevent local concrete spalling
c) stand-off installation with anchor channels

Figure 6.6 — Definition of the lever arm

6.3 Anchor channels

6.3.1 General

(1) The distribution of tension loads acting on the channel to the anchors of the anchor channel may be calculated treating the channel as a beam on elastic support (anchors) with a partial restraint of the channel ends as statical system. The resulting anchor forces depend significantly on the assumed anchor stiffness and degree of restraint. For shear loads the load distribution is additionally influenced by the pressure distribution in the contact zone between channel and concrete.

(2) As a simplification for anchor channels with two anchors the loads on the anchors may be calculated assuming a simply supported beam with a span length equal to the anchor spacing.

(3) For anchor channels with two or more anchors as an alternative the triangular load distribution method to calculate the distribution of tension and shear loads to the anchors may be used (see 6.3.2 and 6.3.3).

(4) In the case of shear loads, this EN covers only shear loads acting on the channel perpendicular to its longitudinal axis.

NOTE Shear loads acting in direction of the longitudinal axis of the anchor channel are covered in CEN/TR 17080, *Design of fastenings for use in concrete — Anchor channels — Supplementary rules*.

6.3.2 Tension loads

(1) The tension in each anchor caused by a tension load acting on the channel is calculated according to Formula (6.3), which assumes a linear load distribution over the influence length l_i and takes into account the condition of equilibrium. The influence length l_i shall be calculated according to Formula (6.5). An example for the calculation of the forces acting on the anchors is given in Figure 6.7.

$$N_{\mathrm{Ed,i}}^{a} = k \cdot A_{\mathrm{i}}' \cdot N_{\mathrm{Ed}}^{\mathrm{cb}} \quad (6.3)$$

where

A_{i}' is the ordinate at the position of the anchor i of a triangle with the unit height at the position of load $N_{\mathrm{Ed}}^{\mathrm{cb}}$ and the base length $2l_i$

$$k = \frac{1}{\sum_{1}^{n} A_{\mathrm{i}}'} \quad (6.4)$$

$$l_{\mathrm{i}} = 13 \cdot I_{\mathrm{y}}^{0,05} \cdot s^{0,5} \geq s \quad (6.5)$$

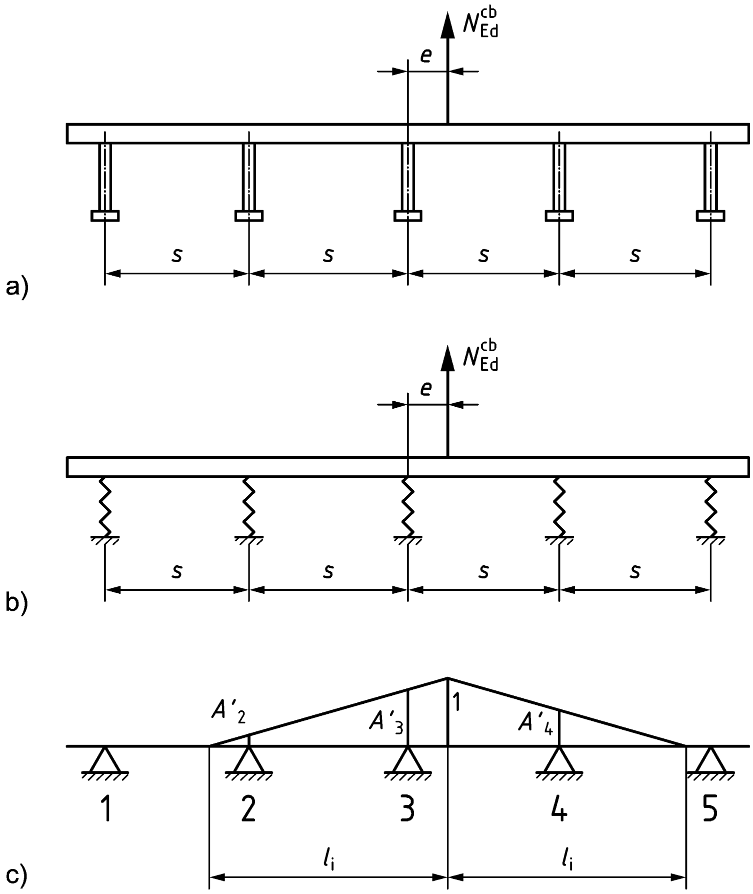
n is the number of anchors on the channel within the influence length l_i to either side of the applied load N_{Ed} (Figure 6.7)

(2) If several tension loads are acting on the channel a linear superposition of the anchor forces for all loads shall be assumed.

(3) If the exact position of the load on the channel is not known, the most unfavourable loading position shall be assumed for each failure mode (e.g. load acting over an anchor for the case of failure of an anchor by steel rupture or pull-out and load acting between anchors in the case of bending failure of the channel).

(4) The design bending moment $M_{\mathrm{Ed}}^{\mathrm{ch}}$ in the channel due to tension loads $N_{\mathrm{Ed}}^{\mathrm{cb}}$ acting on the channel bolts may be calculated assuming a simply supported single span beam with a span length equal to the anchor spacing.

The assumption of a simply supported beam to calculate the moments is a simplification which neglects the influence of partial end restraints, continuous beam action for channels with more than two anchors and catenary action after yielding of the channel. The characteristic values of the moments of the resistance given in the European Technical Product Specification take these effects into account. They may be larger than the plastic moment, calculated with the dimensions of the channel and nominal yield strength of the steel.



Key

a) anchor channel with 5 anchors

b) on elastic support

c) triangular load distribution method

$$A'_2 = \frac{l_i - e - s}{l_i}; \qquad N_{Ed,2}^{a} = A'_2 \cdot k \cdot N_{Ed}^{cb}$$

$$A'_3 = \frac{l_i - e}{l_i}; \qquad N_{Ed,3}^{a} = A'_3 \cdot k \cdot N_{Ed}^{cb}$$

$$A'_4 = \frac{l_i - s + e}{l_i}; \qquad N_{Ed,4}^{a} = A'_4 \cdot k \cdot N_{Ed}^{cb}$$

$$N_{Ed,1}^{a} = N_{Ed,5}^{a} = 0$$

Figure 6.7 — Calculation of anchor forces according to the triangular load distribution method for an anchor channel with five anchors – Example

6.3.3 Shear loads

(1) The provisions given in 6.2.2.3 shall be used to determine whether a shear load acts with or without a lever arm on the channel bolt.

(2) The shear forces of each anchor due to a shear load acting on the channel perpendicular to its longitudinal axis may be calculated in the same manner as described in 6.3.2.

NOTE Shear loads applied perpendicular to anchor channels are transferred as compression at the interface between channel and concrete and by the anchors. In addition for reasons of equilibrium the anchors are stressed by tension forces. Generally, the percentage of the shear load taken up by the channel and the anchors may vary depending on the geometry of the anchor channel. In the approach presented above it is assumed that shear forces are transferred by bending of the channel to the anchors and by the anchors into the concrete. This simplified approach has been chosen to allow for simple interaction between tension and shear forces acting on the channel.

(3) For verification of concrete edge failure components of shear loads acting away from the edge may be neglected when calculating the anchor forces.

6.4 Forces assigned to supplementary reinforcement

6.4.1 General

The design tension forces acting in the supplementary reinforcement shall be established using an appropriate strut and tie model. Examples see Figure 7.2 (tension load) and Figure 7.10 (shear load).

6.4.2 Tension loads

(1) The supplementary reinforcement shall be designed for N_{Ed} (single fastener) or N_{Ed}^{h} (group of fasteners). This reinforcement is then applied to all fasteners.

(2) For anchor channels the supplementary reinforcement of all anchors shall be designed for the force N_{Ed}^{a} of the most loaded anchor.

6.4.3 Shear loads

(1) When supplementary reinforcement is placed in the direction of the design shear force, the design tension force $N_{Ed,re}$ in the supplementary reinforcement caused by the design shear force V_{Ed} acting on a fixture perpendicular and towards to the edge shall be calculated according to Formula (6.6):

$$N_{Ed,re} = \left(\frac{e_s}{z} + 1 \right) \cdot V_{Ed} \tag{6.6}$$

where (see Figure 6.8):

e_s is the distance between axis of reinforcement and line of shear force acting on the fixture;

$z \approx 0,85 \cdot d$ with d not larger than min{2 h_{ef}; 2c_1}

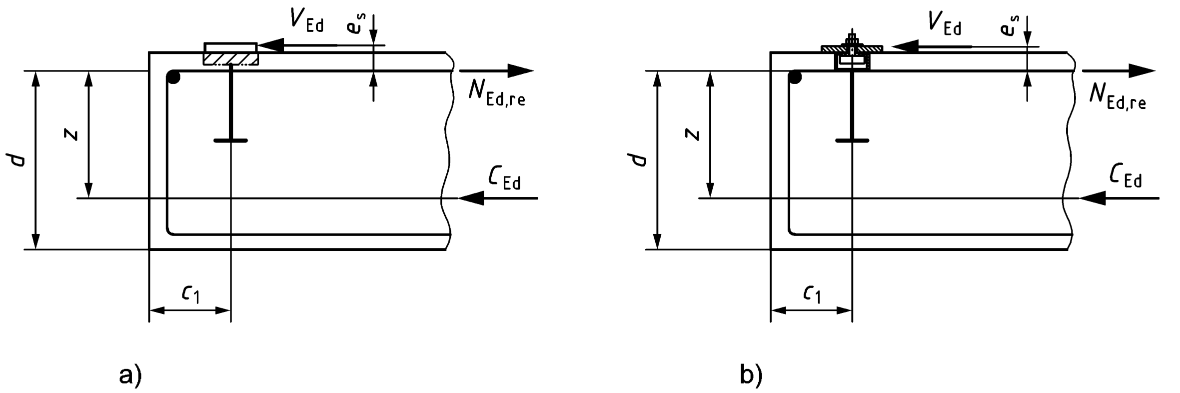
NOTE In case of deep sections the internal lever arm will be much smaller than the section. Therefore, the effective depth is limited to min{2 h_{ef}; 2 c_1}.

When the design shear force is inclined and towards the edge the supplementary reinforcement may be designed assuming that the total design shear force is acting perpendicular and towards to the edge. When the design shear force is parallel to the edge or inclined and away from the edge the supplementary reinforcement may conservatively be designed simply assuming that the component of the design shear force parallel to the edge is acting perpendicular and towards to the edge.

(2) In the case of different shear forces on the fasteners of a fixture, Formula (6.6) shall be solved for the shear load V_{Ed}^{h} of the most loaded fastener resulting in $N_{Ed,re}^{h}$. This force is then applied to the design of the supplementary reinforcement of all fasteners.

(3) If the supplementary reinforcement is not arranged in the direction of the shear force, this shall be taken into account in the calculation of the design tension force of the reinforcement to maintain equilibrium in the strut and tie model.

(4) For anchor channels the supplementary reinforcement of all anchors shall be designed for a force V_{Ed} that is the greater of the shear force on the most loaded anchor and on the most loaded channel bolt.



Key

a) base plate with headed fastener

b) anchor channel

Figure 6.8 — Surface reinforcement to take up shear forces — Forces in the reinforcement

7 Verification of ultimate limit state

7.1 General

(1) Clause 7 applies to static loading. The requirements for fatigue and seismic loading are given in Clauses 8 and 9, respectively.

(2) In the design of fastenings the values of f_{ck} used for calculation shall not exceed 60 N/mm² even if the structure uses a higher strength class.

(3) It shall be demonstrated that Formula (4.1) is fulfilled for all loading directions (tension, shear, combined tension and shear) as well as all failure modes for each load combination.

(4) The verification shall be performed for the fastener or group of fasteners considered effective for the specific failure mode for the loads resulting from the applied actions on the fixture.

(5) This section applies when forces on the fasteners have been calculated using elastic analysis.

(6) Both edge distance and spacing shall be specified only with positive tolerances.

(7) The formulae to calculate the characteristic resistances for concrete failure modes under tension loads as well as shear loads in case of pry-out failure are valid for a spacing between outer fasteners of adjoining groups or a distance between single fasteners or single fasteners and outer fasteners of adjoining groups of $a \geq s_{cr,N}$. For shear loads in case of concrete edge failure $a \geq 3c_1$ is valid.

(8) Aborted drill holes filled with non-shrinkage mortar with a strength at least equal to the base material and ≥ 40 N/mm^2 may be neglected in the design.

(9) The verifications given in 7.2 take into account all directions of load and all failure modes. As an alternative simplified design methods are given in informative Annex G.

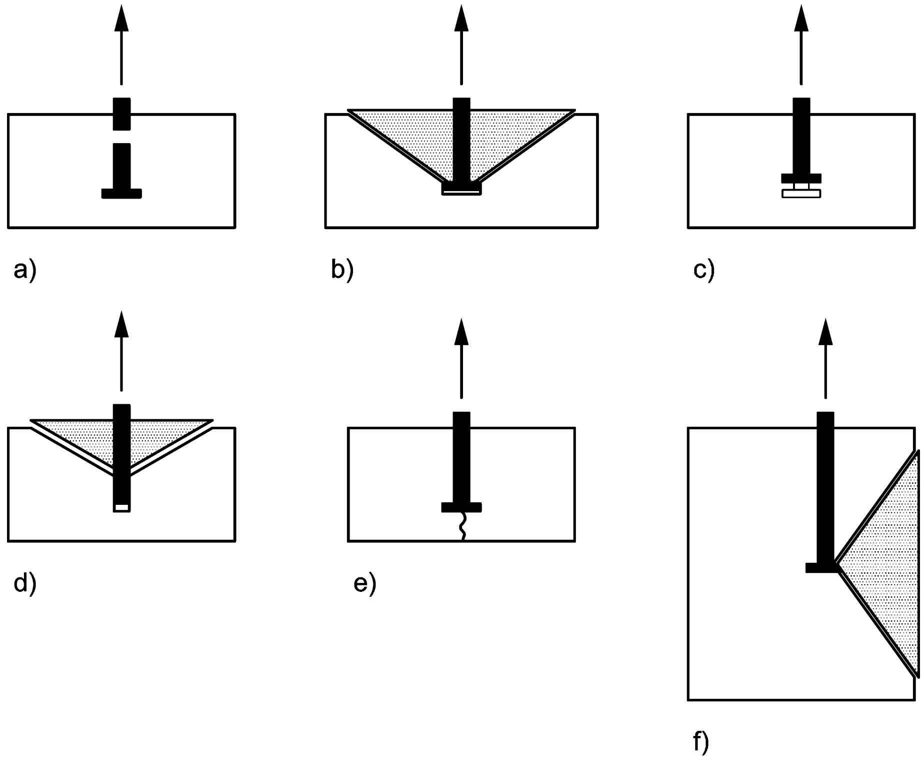
(10) In the calculation of the area of supplementary reinforcement, the area of any underutilized reinforcement provided in the member for other purposes may be included provided such reinforcement meets the detailing requirements in this document.

7.2 Headed and post-installed fasteners

7.2.1 Tension load

7.2.1.1 Required verifications

The verifications of Table 7.1 apply. The failure modes addressed are given in Figure 7.1.



Key

a) steel failure

b) concrete cone failure

c) pull-out failure

d) combined pull-out and concrete failure of bonded fasteners

e) concrete splitting failure

f) concrete blow-out failure

Figure 7.1 — Failure modes of headed or post-installed fasteners under tension load

7.2.1.2 Detailing of supplementary reinforcement

(1) When the design relies on supplementary reinforcement, concrete cone failure according to Table 7.1 and 7.2.1.4 need not be verified but the supplementary reinforcement shall be designed according to 7.2.1.9 to resist the total load.

(2) The supplementary reinforcement to take up tension loads shall comply with the following requirements (see also Figure 7.2).

a) The reinforcement shall consist of ribbed reinforcing bars $\left(f_{yk,re} \leq 600\ \mathrm{N/mm}^2\right)$ with a diameter ϕ not larger than 16 mm and shall be detailed as stirrups or loops with a mandrel diameter ϕ_m according to EN 1992-1-1.

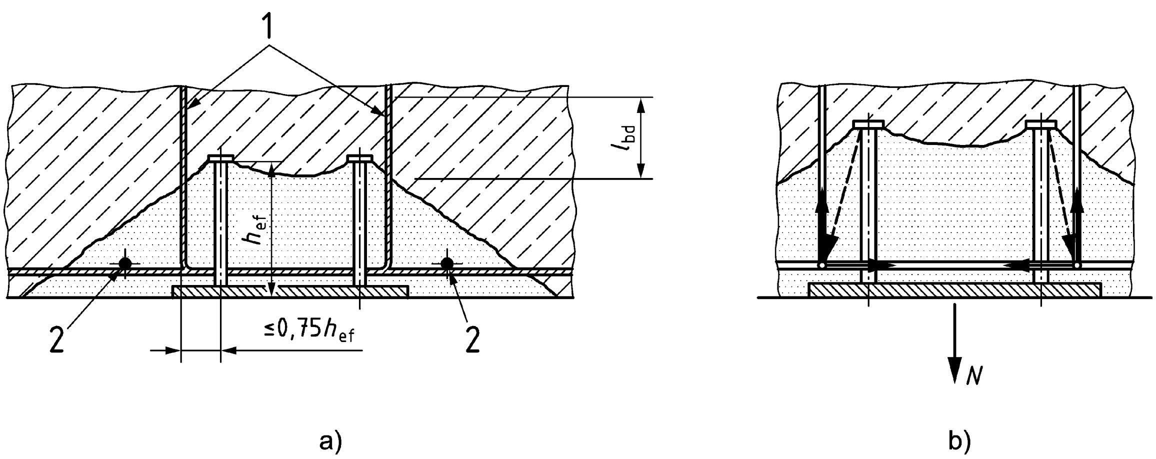
b) Where supplementary reinforcement has been sized for the most loaded fastener, the same reinforcement shall be provided around all fasteners.

c) The supplementary reinforcement should be placed symmetrically as close to the fasteners as practicable to minimize the effect of eccentricity associated with the angle of the failure cone. Preferably, the supplementary reinforcement should enclose the surface reinforcement. Only reinforcement bars with a distance $\leq 0{,}75h_{ef}$ from the fastener shall be assumed as effective.

d) Only supplementary reinforcement with an anchorage length in the concrete failure cone of $l_1 \geq 4\phi$ (anchorage with bends, hooks or loops) or $l_1 \geq 10\phi$ (anchorage with straight bars with or without welded transverse bars) shall be assumed as effective.

e) The supplementary reinforcement shall be anchored outside the assumed failure cone with an anchorage length l_{bd} according to EN 1992-1-1 (see Figure 7.2 a)). Concrete cone failure assuming an embedment length corresponding to the end of the supplementary reinforcement shall be verified using Formula (7.1) for $N_{Rk,c}$. This verification may be omitted if in reinforced structural elements the tension in the anchored reinforcing bar is transferred to the reinforcement in the structural element by adequate lapping.

f) Surface reinforcement should be provided as shown in Figure 7.2 designed to resist the forces arising from the assumed strut and tie model and the splitting forces according to 7.2.1.7 (2)b).



Key

1 supplementary reinforcement

2 surface reinforcement

Figure 7.2 — a) Fastening with supplementary reinforcement to take up tension loads; b) Corresponding strut and tie model – Example

Table 7.1 — Required verifications for headed and post-installed fasteners in tension

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	**Steel failure of fastener**	$N_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	$N^h_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	
2	**Concrete cone failure**	$N_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$		$N^g_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$
3	**Pull-out failure of fastener** [a]	$N_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$	$N^h_{Ed} < N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$	
4	**Combined pull-out and concrete failure** [b]	$N_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$		$N^g_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$
5	**Concrete splitting failure**	$N_{Ed} \le N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$		$N^g_{Ed} \le N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$
6	**Concrete blow-out failure** [c]	$N_{Ed} \le N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$		$N^g_{Ed} \le N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$
7	**Steel failure of reinforcement**	$N_{Ed,re} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N^h_{Ed,re} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
8	**Anchorage failure of reinforcement**	$N_{Ed,re} \le N_{Rd,a}$	$N^h_{Ed,re} \le N_{Rd,a}$	

[a] Not required for post-installed bonded fasteners.

[b] Not required for headed and post-installed mechanical fasteners.

[c] For cases which require verification see 7.2.1.8 (1).

7.2.1.3 Steel failure of fastener

The characteristic resistance of a fastener in case of steel failure $N_{Rk,s}$ is given in the relevant European Technical Product Specification. The characteristic resistance is based on f_{uk}.

7.2.1.4 Concrete cone failure

(1) The characteristic resistance of a fastener, a group of fasteners and the tensioned fasteners of a group of fasteners in case of concrete cone failure shall be obtained as given in Formula (7.1):

$$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N} \tag{7.1}$$

The different factors of Formula (7.1) are given below.

(2) The characteristic resistance of a single fastener placed in concrete and not influenced by adjacent fasteners or edges of the concrete member is obtained as follows:

$$N_{\mathrm{Rk,c}}^{0} = k_1 \cdot \sqrt{f_{\mathrm{ck}}} \cdot h_{\mathrm{ef}}^{1,5} \quad (7.2)$$

with

k_1 = $k_{\mathrm{cr,N}}$ for cracked concrete

= $k_{\mathrm{ucr,N}}$ for uncracked concrete

$k_{\mathrm{cr,N}}$ and $k_{\mathrm{ucr,N}}$ are given in the corresponding European Technical Product Specification.

NOTE Indicative values for $k_{\mathrm{cr,N}}$ and $k_{\mathrm{ucr,N}}$ are $k_{\mathrm{cr,N}} = 7{,}7$ and $k_{\mathrm{ucr,N}} = 11{,}0$ for post-installed fasteners and $k_{\mathrm{cr,N}} = 8{,}9$ and $k_{\mathrm{ucr,N}} = 12{,}7$ for cast-in headed fasteners.

(3) The geometric effect of axial spacing and edge distance on the characteristic resistance is taken into account by the value $A_{\mathrm{c,N}} / A_{\mathrm{c,N}}^{0}$

where

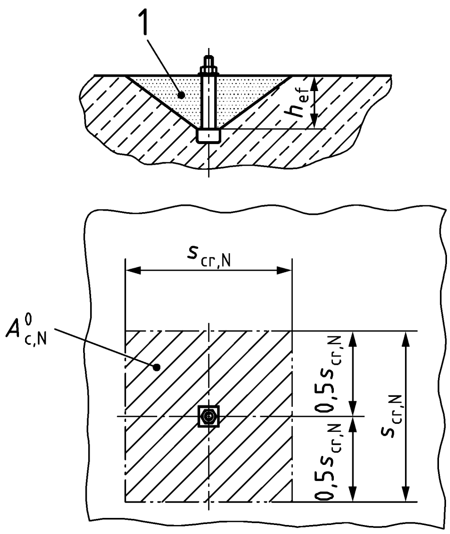
$$A_{\mathrm{c,N}}^{0} = s_{\mathrm{cr,N}} \cdot s_{\mathrm{cr,N}} \quad (7.3)$$

is the reference projected area, see Figure 7.3.

$A_{\mathrm{c,N}}$ is the actual projected area, limited by overlapping concrete cones of adjacent fasteners $(s \leq s_{\mathrm{cr,N}})$ as well as by edges of the concrete member $(c \leq c_{\mathrm{cr,N}})$. An example for the calculation of $A_{\mathrm{c,N}}$ is given in Figure 7.4.

$c_{\mathrm{cr,N}}$ is given in the corresponding European Technical Product Specification and $s_{\mathrm{cr,N}} = 2\, c_{\mathrm{cr,N}}$.

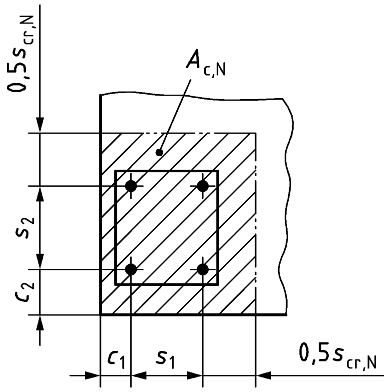
NOTE For headed and post-installed fasteners according to current experience $s_{\mathrm{cr,N}} = 2\, c_{\mathrm{cr,N}} = 3\, h_{\mathrm{ef}}$.



Key

1 concrete cone

Figure 7.3 — Idealized concrete cone and area $A_{\mathrm{c,N}}^{0}$ of concrete cone of an individual fastener



Key

$A_{c,N} = (c_1 + s_1 + 0,5s_{cr,N}) \cdot (c_2 + s_2 + 0,5s_{cr,N})$

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

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

When the fastening is close to one edge only, the value of c_1 (or c_2) parallel to the edge should be replaced by 0,5 $s_{cr,N}$ and the expression for $A_{c,N}$ should be modified accordingly.

Figure 7.4 — Actual area $A_{c,N}$ of the idealized concrete cone for a group of four fasteners – Example

(4) The factor $\psi_{s,N}$ takes account of the disturbance of the distribution of stresses in the concrete due to the proximity of an edge of the concrete member. For fastenings with several edge distances (e.g. fastening in a corner of the concrete member or in a narrow member), the smallest edge distance c shall be inserted in Formula (7.4).

$$\psi_{s,N} = 0,7 + 0,3 \cdot \frac{c}{c_{cr,N}} \leq 1 \quad (7.4)$$

(5) The shell spalling factor $\psi_{re,N}$ applies when $h_{ef} < 100$ mm and accounts for the effect of dense reinforcement between which the fastener is installed:

$$\psi_{re,N} = 0,5 + \frac{h_{ef}}{200} \leq 1 \quad (7.5)$$

The factor $\psi_{re,N}$ may be taken as 1,0 in the following cases:

a) reinforcement (any diameter) is present at a spacing ≥ 150 mm, or

b) reinforcement with a diameter of 10 mm or smaller is present at a spacing ≥ 100 mm.

The conditions a) or b) shall be fulfilled for both directions in case of reinforcement in two directions.

(6) The factor $\psi_{ec,N}$ takes account of a group effect when different tension loads are acting on the individual fasteners of a group.

$$\psi_{ec,N} = \frac{1}{1 + 2 \cdot \left(e_N / s_{cr,N}\right)} \leq 1 \tag{7.6}$$

Where there is an eccentricity in two directions, $\psi_{ec,N}$ shall be determined separately for each direction and the product of both factors shall be inserted in Formula (7.1).

(7) The factor $\psi_{M,N}$ takes into account the effect of a compression force between fixture and concrete in cases of bending moments with or without axial force.

$\psi_{M,N}$ = 1 for the following cases:

— fastenings with an edge distance $c < 1{,}5\ h_{ef}$;

— fastenings with $c \geq 1{,}5\ h_{ef}$ loaded by a bending moment and a tension force with $C_{Ed} / N_{Ed} < 0{,}8$, where C_{Ed} is the resultant compression force between fixture and concrete (taken as absolute value) and N_{Ed} is the resultant tension force of the tensioned fasteners ; or

— fastenings with $z / h_{ef} \geq 1{,}5$

$$= 2 - \frac{z}{1{,}5\ h_{ef}} \geq 1 \text{ for all other cases.} \tag{7.7}$$

In case of bending in two directions z shall be determined for the combined action of the moments in two directions and axial force.

(8) For the case of fasteners in an application with three or more edge distances less than $c_{cr,N}$ from the fasteners (see Figure 7.5) the calculation according to Formula (7.1) leads to conservative results. More precise results are obtained if in the case of single fasteners the value h_{ef} is substituted by

$$h'_{ef} = \frac{c_{max}}{c_{cr,N}} \cdot h_{ef} \tag{7.8}$$

or in the case of groups h_{ef} is substituted by

$$h'_{ef} = \max\left\{\frac{c_{max}}{c_{cr,N}} \cdot h_{ef} ; \frac{s_{max}}{s_{cr,N}} \cdot h_{ef}\right\} \tag{7.9}$$

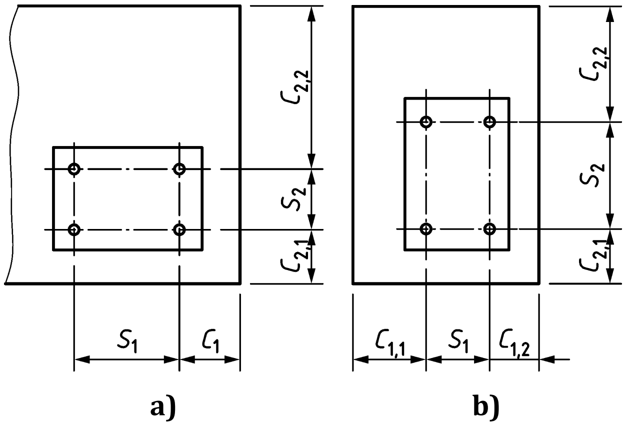
where

c_{max} is the maximum distance from centre of a fastener to the edge of concrete member $\leq c_{cr,N}$

s_{max} = $s_2 \left(\leq s_{cr,N}\right)$ for applications with three edges (see Figure 7.5 a));

= $\max(s_1; s_2) \leq s_{cr,N}$ (see Figure 7.5 b)).

For fastenings without hole clearance where three fasteners in a row close to an edge are allowed, s_{max} is the maximum centre to centre distance of outer fasteners $\leq 2s_{cr,N}$.



Key

a) $\left(c_1 ; c_{2,1} ; c_{2,2}\right) \le c_{cr,N}$

b) $\left(c_{1,1} ; c_{1,2} ; c_{2,1} ; c_{2,2}\right) \le c_{cr,N}$

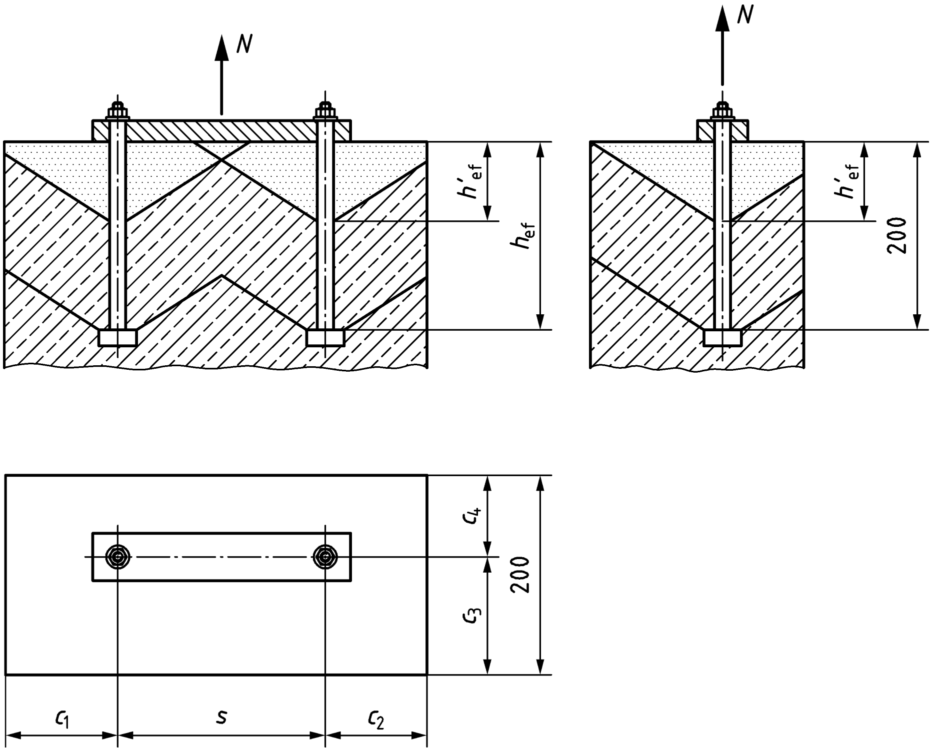
Figure 7.5 — Fastenings in concrete members where h'_{ef}, $s'_{cr,N}$ and $c'_{cr,N}$ may be used — Examples

The value h'_{ef} is inserted in Formula (7.2). In Formulae (7.3), (7.4) and (7.6) and for the determination of $A_{c,N}$ according to Figure 7.4 the values $s'_{cr,N}$ and $c'_{cr,N}$ defined as:

$$s'_{cr,N} = 2c'_{cr,N} = s_{cr,N}\frac{h'_{ef}}{h_{ef}} \tag{7.10}$$

are inserted for $s_{cr,N}$ and $c_{cr,N}$, respectively.

NOTE An example for the calculation of h'_{ef} is given in Figure 7.6.



Key

c_1 = 110 mm

c_2 = 100 mm

c_3 = 120 mm = c_{max}

c_4 = 80 mm

s = 210 mm

h_{ef} = 200 mm

$h'_{ef} = \max\left\{120 / 1,5;\ 210 / 3\right\} = 80 \text{ mm}$.

Figure 7.6 — Illustration of the calculation of h'_{ef} for a double fastening influenced by 4 edges

7.2.1.5 Pull-out failure of fastener

The characteristic resistance in case of pull-out failure $N_{Rk,p}$ of post-installed mechanical and headed fasteners is given in the relevant European Technical Product Specification.

For headed fasteners the characteristic resistance $N_{Rk,p}$ is limited by the concrete pressure under the head of the fastener according to Formula (7.11):

$$N_{Rk,p} = k_2 \cdot A_h \cdot f_{ck} \tag{7.11}$$

where

A_h is the load bearing area of the head of the fastener

$$= \frac{\pi}{4}\left(d_h^2 - d_a^2\right) \text{ for circular shaped heads} \tag{7.12}$$

k_2 = 7,5 for fasteners in cracked concrete

= 10,5 for fasteners in uncracked concrete

In Formula (7.12) d_h should not be taken larger than 6 t_h + d.

7.2.1.6 Combined pull-out and concrete failure in case of post-installed bonded fasteners

(1) The characteristic resistance of a fastener, a group of fasteners and the tensioned fasteners of a group of fasteners in case of combined pull-out and concrete failure shall be obtained as given in Formula (7.13).

$$N_{Rk,p} = N_{Rk,p}^{0} \cdot \frac{A_{p,N}}{A_{p,N}^{0}} \cdot \psi_{g,Np} \cdot \psi_{s,Np} \cdot \psi_{re,N} \cdot \psi_{ec,Np} \qquad (7.13)$$

The different factors of Formula (7.13) are given below.

(2) The characteristic resistance of a single bonded fastener $N_{Rk,p}^{0}$ not influenced by adjacent bonded fasteners or edges of the concrete member is calculated as:

$$N_{Rk,p}^{0} = \psi_{sus} \cdot \tau_{Rk} \cdot \pi \cdot d \cdot h_{ef} \qquad (7.14)$$

where

$$\psi_{sus} = 1 \text{ for } \alpha_{sus} \leq \psi_{sus}^{0} \qquad (7.14a)$$

$$\psi_{sus} = \psi_{sus}^{0} + 1 - \alpha_{sus} \text{ for } \alpha_{sus} > \psi_{sus}^{0} \qquad (7.14b)$$

ψ_{sus}^{0} is the product dependent factor that takes account of the influence of sustained load on the bond strength to be taken from the relevant European Technical Product Specification;

α_{sus} is the ratio between the value of sustained actions (comprising permanent actions and permanent component of variable actions) and the value of total actions all considered at ULS;

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

= $\tau_{Rk,ucr}$ for uncracked concrete;

$\tau_{Rk,cr}$ and $\tau_{Rk,ucr}$ are given in the relevant European Technical Product Specification.

NOTE The values $\tau_{Rk,cr}$ and $\tau_{Rk,ucr}$ may depend on the concrete strength class.

If no value is given in the European Product Specification for the product a value $\psi_{sus}^{0} = 0{,}6$ should be used. The value $\psi_{sus}^{0} = 0{,}6$ relates to sustained tension load being present during a design life of 50 years and a minimum of 10 years at a concrete temperature of 43 °C in the region of the fasteners. For fastenings with a long term temperature other than 43 °C different values will apply and these should be obtained by appropriate testing and assessment. In general, for a temperature in the concrete smaller than 43 °C the factor ψ_{sus}^{0} will be larger than 0,6.

The ratio α_{sus} should be determined by the designer for the fastening to be designed. Guidance may be given in national documents.

(3) The geometric effect of axial spacing and edge distance on the characteristic resistance is taken into account by the value $A_{p,N} / A^0_{p,N}$, where

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

$A_{p,N}$ is the actual bond influence area, limited by overlapping areas of adjacent fasteners $\left(s \leq s_{cr,Np}\right)$ as well as by edges of the concrete member $c \leq c_{cr,Np}$.

$$s_{cr,Np} = 7{,}3d\left(\psi_{sus}\tau_{Rk}\right)^{0,5} \leq 3h_{ef} \tag{7.15}$$

τ_{Rk} is the value $\tau_{Rk,ucr}$ for uncracked concrete C20/25

$$c_{cr,Np} = s_{cr,Np}\ /2 \tag{7.16}$$

NOTE $A^0_{p,N}$ and $A_{p,N}$ are calculated similar to the reference projected area $A^0_{c,N}$ and the actual projected area $A_{c,N}$ in case of concrete cone failure (Figures 7.3 and 7.4). However, the values $s_{cr,N}$ and $c_{cr,N}$ are replaced by the values $s_{cr,Np}$ and $c_{cr,Np}$, respectively. The value $s_{cr,Np}$ calculated according to Formula (7.15) is valid for cracked and uncracked concrete.

(4) The factor $\psi_{g,Np}$ takes account of a group effect for closely spaced bonded fasteners.

$$\psi_{g,Np} = \psi^0_{g,Np} - \left(\frac{s}{s_{cr,Np}}\right)^{0,5} \cdot \left(\psi^0_{g,Np} - 1\right) \geq 1 \tag{7.17}$$

where

$$\psi^0_{g,Np} = \sqrt{n} - \left(\sqrt{n} - 1\right) \cdot \left(\frac{\tau_{Rk}}{\tau_{Rk,c}}\right)^{1,5} \geq 1 \tag{7.18}$$

$$\tau_{Rk,c} = \frac{k_3}{\pi \cdot d}\sqrt{h_{ef} \cdot f_{ck}} \tag{7.19}$$

k_3 = 7,7 for cracked concrete

= 11,0 for uncracked concrete

In case of unequal spacing the mean value of the spacing should be used in Formula (7.17).

(5) The factor $\psi_{s,Np}$ takes account of the disturbance of the distribution of stresses in the concrete due to the proximity of an edge of the concrete member. For fastenings with several edge distances (e.g. fastening in a corner of the concrete member or in a narrow member), the smallest edge distance c shall be inserted in Formula (7.20).

$$\psi_{s,Np} = 0,7 + 0,3\left(\frac{c}{c_{cr,Np}}\right) \leq 1 \tag{7.20}$$

(6) For the shell spalling factor $\psi_{re,N}$ the corresponding provisions of 7.2.1.4(5) apply.

(7) The factor $\psi_{ec,Np}$ takes account of a group effect when different tension loads are acting on the individual fasteners of a group.

$$\psi_{ec,Np} = \frac{1}{1 + 2 \cdot \left(e_N \,/\, s_{cr,Np}\right)} \leq 1 \tag{7.21}$$

Where there is an eccentricity in two directions, $\psi_{ec,Np}$ shall be determined separately for each direction and the product of both factors shall be inserted in Formula (7.13).

(8) For the case of fasteners in applications with three or more edge distances less than $c_{cr,Np}$ from the fastener (Figure 7.5), the calculation according to Formula (7.13) leads to conservative results. More precise results are obtained if h_{ef} is substituted by h'_{ef}, which is determined according to Formulae (7.8) or (7.9) replacing $c_{cr,N}$ by $c_{cr,Np}$ and $s_{cr,N}$ by $s_{cr,Np}$.

The value h'_{ef} is inserted in Formulae (7.14) and (7.19). The value $s'_{cr,Np}$ is calculated according to Formula (7.15) replacing h_{ef} by h'_{ef}.

The values $s'_{cr,Np}$ and $c'_{cr,Np} = 0,5\, s'_{cr,Np}$ are used to determine $A^0_{p,N}$ and $A_{p,N}$ as well as in Formulae (7.17), (7.20) and (7.21).

7.2.1.7 Concrete splitting failure

(1) Concrete splitting failure during installation (e.g. when applying the installation torque on a fastener) is avoided by complying with minimum values for edge distances c_{min}, spacing s_{min}, member thickness h_{min} and requirements for reinforcement as given in the relevant European Technical Product Specification.

(2) Concrete splitting failure due to loading shall be taken into account according to the following rules.

a) The characteristic edge distance in the case of splitting under load, $c_{cr,sp}$, is given in the relevant European Technical Product Specification. The characteristic spacing is defined as $s_{cr,sp} = 2\, c_{cr,sp}$.

b) No verification is required if at least one of the following conditions is fulfilled.

   1) The edge distance in all directions is $c \geq 1,0\, c_{cr,sp}$ for single fasteners and $c \geq 1,2\, c_{cr,sp}$ for groups of fasteners and the member depth is $h \geq h_{min}$ in both cases, with h_{min} corresponding to $c_{cr,sp}$.

   2) The characteristic resistances for concrete cone failure and pull-out failure (headed and post-installed mechanical fasteners) or combined pull-out and concrete failure (bonded fasteners) are calculated for cracked concrete and reinforcement resists the splitting forces and limits the crack width to $w_k \leq 0,3$ mm.

In the absence of better information the cross-section of the reinforcement, $\sum A_{s,re}$, to resist the splitting forces can be determined as follows:

$$\sum A_{\mathrm{s,re}} = k_4 \frac{\sum N_{\mathrm{Ed}}}{f_{\mathrm{yk,re}} / \gamma_{\mathrm{Ms,re}}} \quad (7.22)$$

where

k_4 = 2,0 deformation-controlled expansion fasteners
= 1,5 torque-controlled expansion fasteners and bonded expansion fasteners
= 1,0 undercut fasteners and concrete screws
= 0,5 bonded fasteners, headed fasteners

$\sum N_{\mathrm{Ed}}$ is the sum of the design tensile force of the fasteners in tension under the design value of the actions

$f_{\mathrm{yk,re}}$ is the nominal yield strength of the reinforcing steel $\leq 600\ \mathrm{N/mm^2}$.

It is recommended that this reinforcement is placed symmetrically and close to the fastener or each fastener in case of a group.

c) If neither condition b) 1) or b) 2) is fulfilled, the characteristic resistance of a fastener or a group of fasteners in case of concrete splitting failure shall be calculated according to Formula (7.23).

$$N_{\mathrm{Rk,sp}} = N^0_{\mathrm{Rk,sp}} \cdot \frac{A_{\mathrm{c,N}}}{A^0_{\mathrm{c,N}}} \cdot \psi_{\mathrm{s,N}} \cdot \psi_{\mathrm{re,N}} \cdot \psi_{\mathrm{ec,N}} \cdot \psi_{\mathrm{h,sp}} \quad (7.23)$$

where

$N^0_{\mathrm{Rk,sp}}$ is given in the relevant European Technical Product Specification

$A_{\mathrm{c,N}}$, $A^0_{\mathrm{c,N}}$, $\psi_{\mathrm{s,N}}$, $\psi_{\mathrm{re,N}}$, $\psi_{\mathrm{ec,N}}$ according to 7.2.1.4, however the values $c_{\mathrm{cr,N}}$ and $s_{\mathrm{cr,N}}$ shall be replaced by $c_{\mathrm{cr,sp}}$ and $s_{\mathrm{cr,sp}}$, respectively, which correspond to the minimum member thickness h_{min}.

$\psi_{\mathrm{h,sp}}$ takes into account the influence of the actual member thickness h on the splitting resistance (see Formula (7.24))

$$\psi_{\mathrm{h,sp}} = \left(\frac{h}{h_{\mathrm{min}}}\right)^{2/3} \leq \max\left\{1; \left(\frac{h_{\mathrm{ef}} + 1{,}5c_1}{h_{\mathrm{min}}}\right)^{2/3}\right\} \leq 2 \quad (7.24)$$

d) If in the relevant European Technical Product Specification $c_{\mathrm{cr,sp}}$ is given for more than one minimum member thickness h_{min}, the minimum member thickness corresponding to $c_{\mathrm{cr,sp}}$ used in Formula (7.23) shall be inserted in Formula (7.24).

NOTE If $N^0_{\mathrm{Rk,sp}}$ is not available in the relevant European Technical Product Specification, this value can be conservatively calculated as $N^0_{\mathrm{Rk,sp}} = \min\left\{N_{\mathrm{Rk,p}}; N^0_{\mathrm{Rk,c}}\right\}$, with $N_{\mathrm{Rk,p}}$ according to 7.2.1.5 in case of post-installed mechanical and cast-in fasteners or replaced by $N^0_{\mathrm{Rk,p}}$ according to 7.2.1.6 in case of bonded fasteners. $N^0_{\mathrm{Rk,c}}$ is calculated according to Formula (7.2).

7.2.1.8 Concrete blow-out failure

(1) Verification of concrete blow-out failure is required in case of headed fasteners and for post-installed mechanical undercut fasteners acting as headed fasteners if the edge distance $c \leq 0{,}5\ h_{ef}$. Each edge shall be considered in turn. The characteristic resistance in case of concrete blow-out failure is calculated as follows:

$$N_{Rk,cb} = N^0_{Rk,cb} \cdot \frac{A_{c,Nb}}{A^0_{c,Nb}} \cdot \psi_{s,Nb} \cdot \psi_{g,Nb} \cdot \psi_{ec,Nb} \qquad (7.25)$$

For groups of fasteners perpendicular to the edge verification is only required for the fasteners closest to the edge. The different factors of Formula (7.25) are given below.

(2) The characteristic resistance of a single fastener, not influenced by adjacent fasteners or further edges is obtained as given in Formula (7.26):

$$N^0_{Rk,cb} = k_5 \cdot c_1 \cdot \sqrt{A_h} \cdot \sqrt{f_{ck}} \qquad (7.26)$$

where

k_5 = 8,7 for cracked concrete;

= 12,2 for uncracked concrete.

A_h as defined in Formula (7.12) or given in the relevant European Technical Product Specification.

(3) The geometric effect of axial spacing and edge distance on the characteristic resistance is taken into account by the value $A_{c,Nb} / A^0_{c,Nb}$,

where

$A^0_{c,Nb}$ is the reference projected area for an individual fastener with an edge distance c_1, see Figure 7.7

$$= (4\ c_1)^2 \qquad (7.27)$$

$A_{c,Nb}$ is the actual projected area, limited by overlapping concrete break-out bodies of adjacent fasteners $(s \leq 4\ c_1)$ as well as by proximity of edges of the concrete member $(c_2 \leq 2 \cdot c_1)$ or the member thickness.

Examples for the calculation of $A_{c,Nb}$ are given in Figure 7.8.

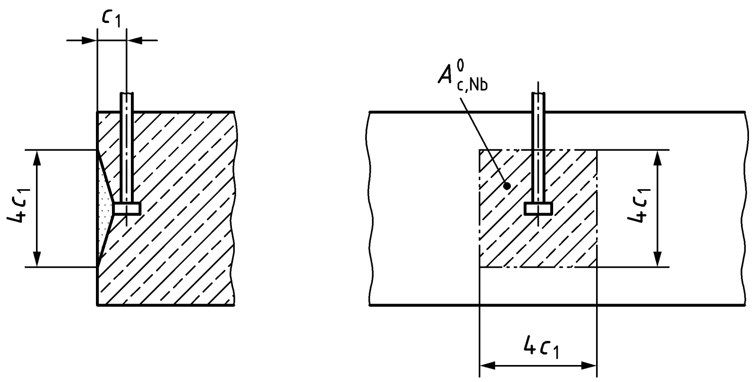
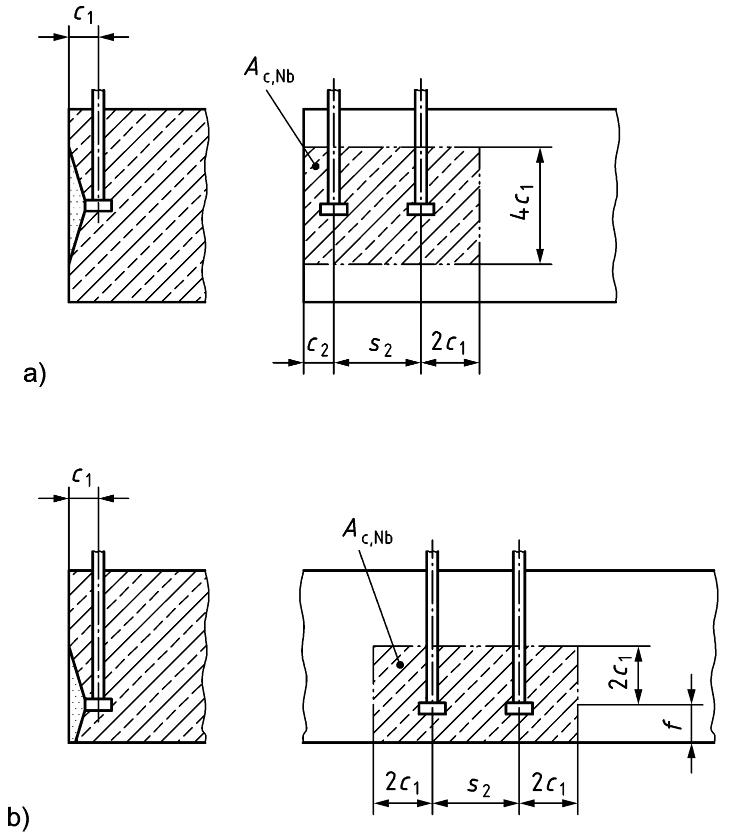


Figure 7.7 — Idealized concrete break-out body and area $A^0_{c,Nb}$ of an individual fastener in case of concrete blow-out failure



Key

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

$c_2 \leq 2\,c_1$

$s_2 \leq 4\,c_1$

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

$f \leq 2\,c_1$

$s_2 \leq 4\,c_1$

Figure 7.8 — Examples of actual areas $A_{c,Nb}$ of the idealized concrete break-out bodies for different arrangements of headed fasteners in case of concrete blow-out failures

(4) The factor $\psi_{\text{s,Nb}}$ takes account of the disturbance of the distribution of stresses in the concrete due to the proximity of a corner of the concrete member (see Figure 7.8 a)). For fastenings with several edge distances (e.g. fastening in a narrow concrete member), the smallest edge distance in direction 2, c_2, shall be inserted in Formula (7.28).

$$\psi_{\text{s,Nb}} = 0{,}7 + 0{,}3 \cdot \frac{c_2}{2c_1} \le 1 \tag{7.28}$$

(5) The factor $\psi_{\text{g,Nb}}$ accounts for the group effect of a number of fasteners n in a row parallel to the edge.

$$\psi_{\text{g,Nb}} = \sqrt{n} + \left(1 - \sqrt{n}\right) \cdot \frac{s_2}{4\,c_1} \ge 1 \tag{7.29}$$

with

$$s_2 \le 4c_1$$

(6) The factor $\psi_{\text{ec,Nb}}$ takes account of a group effect, when different loads are acting on the individual fasteners of a group.

$$\psi_{\text{ec,Nb}} = \frac{1}{1 + 2 \cdot e_{\text{N}} / \left(4c_1\right)} \tag{7.30}$$

7.2.1.9 Failure of supplementary reinforcement

7.2.1.9.1 Steel failure

The characteristic yield resistance of the supplementary reinforcement $N_{\text{Rk,re}}$ for one fastener is:

$$N_{\text{Rk,re}} = \sum_{i=1}^{n_{\text{re}}} A_{\text{s,re,i}} \cdot f_{\text{yk,re}} \tag{7.31}$$

where

$$f_{\text{yk,re}} \le 600\ \text{N/mm}^2$$

n_{re} is the number of bars of supplementary reinforcement effective for one fastener

7.2.1.9.2 Anchorage failure

The design resistance $N_{\text{Rd,a}}$ of the supplementary reinforcement provided for one fastener associated with anchorage failure in the concrete cone is:

$$N_{\text{Rd,a}} = \sum_{i=1}^{n_{\text{re}}} N^0_{\text{Rd,a,i}} \tag{7.32}$$

where

$$N^{0}_{\mathrm{Rd,a}} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{\mathrm{bd}}}{\alpha_1 \cdot \alpha_2} \leq A_{\mathrm{s,re}} \cdot f_{\mathrm{yk,re}} \cdot \frac{1}{\gamma_{\mathrm{Ms,re}}} \tag{7.33}$$

l_1 is the anchorage length in the break-out body (see Figure 7.2); l_1 shall be larger than the minimum anchorage length in 7.2.1.2 (2)d);

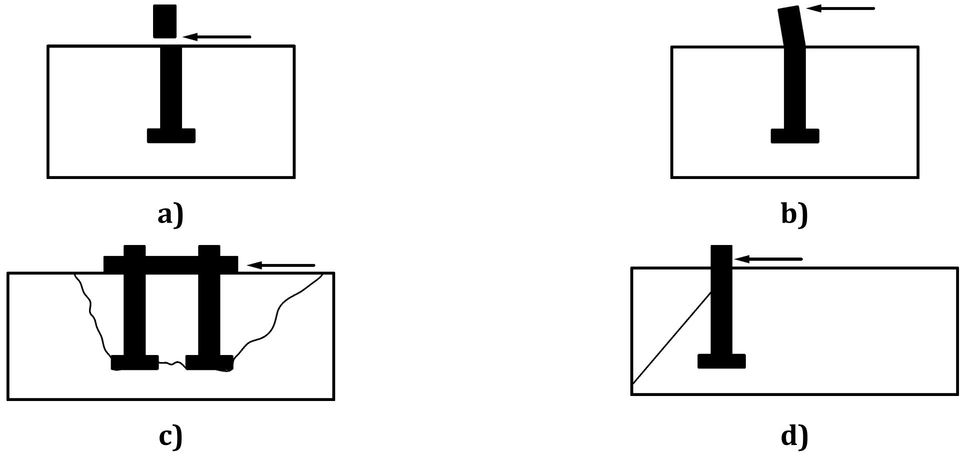
f_{bd} is the design bond strength according to EN 1992–1-1:2004, 8.4.2;

α_1, α_2 are the influencing factors according to EN 1992–1-1:2004, 8.4.4.

7.2.2 Shear load

7.2.2.1 Required verifications

The verifications of Table 7.2 apply. The failure modes addressed are given in Figure 7.9:



Key

a) steel failure without lever arm

b) steel failure with lever arm

c) concrete pry-out failure

d) concrete edge failure

Figure 7.9 — Failure modes of headed and post-installed fasteners under shear load

Table 7.2 — Required verifications for headed and post-installed fasteners in shear

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	**Steel failure of fastener without lever arm**	$V_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	$V^h_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	
2	**Steel failure of fastener with lever arm**	$V_{Ed} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V^h_{Ed} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	
3	**Concrete pry-out failure**	$V_{Ed} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$		$V^g_{Ed} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$ [a]
4	**Concrete edge failure**	$V_{Ed} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$		$V^g_{Ed} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$
5	**Steel failure of supplementary reinforcement** [b]	$N_{Ed,re} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N^h_{Ed,re} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
6	**Anchorage failure of supplementary reinforcement** [b]	$N_{Ed,re} \leq N_{Rd,a}$	$N^h_{Ed,re} \leq N_{Rd,a}$	

[a] Exception see 7.2.2.4 (4).

[b] The tension force acting on the reinforcement is calculated from V_{Ed} according to Formula (6.6).

7.2.2.2 Detailing of supplementary reinforcement

(1) When the design relies on supplementary reinforcement, concrete edge failure according to Table 7.2 and 7.2.2.5 need not to be verified but the supplementary reinforcement shall be designed according to 7.2.2.6 to resist the total load. The supplementary reinforcement may be in the form of a surface reinforcement (see Figure 7.10 a)) or in the shape of stirrups or loops (see Figure 7.10 b) and c)).

(2) The supplementary reinforcement shall be anchored outside the assumed failure body with an anchorage length l_{bd} according to EN 1992-1-1. In reinforced concrete members the tension in the anchored reinforcing bar shall be transferred to the reinforcement in the member by adequate lapping. Otherwise the load transfer from the supplementary reinforcement to the structural member shall be verified by an appropriate model, e.g. strut and tie model.

(3) If the shear force is taken up by a reinforcement according to Figure 7.10 a), the bars shall only be assumed to be effective if the following requirements are fulfilled.

a) Where supplementary reinforcement has been sized for the most loaded fastener, the same reinforcement is provided around all fasteners considered effective for concrete edge failure.

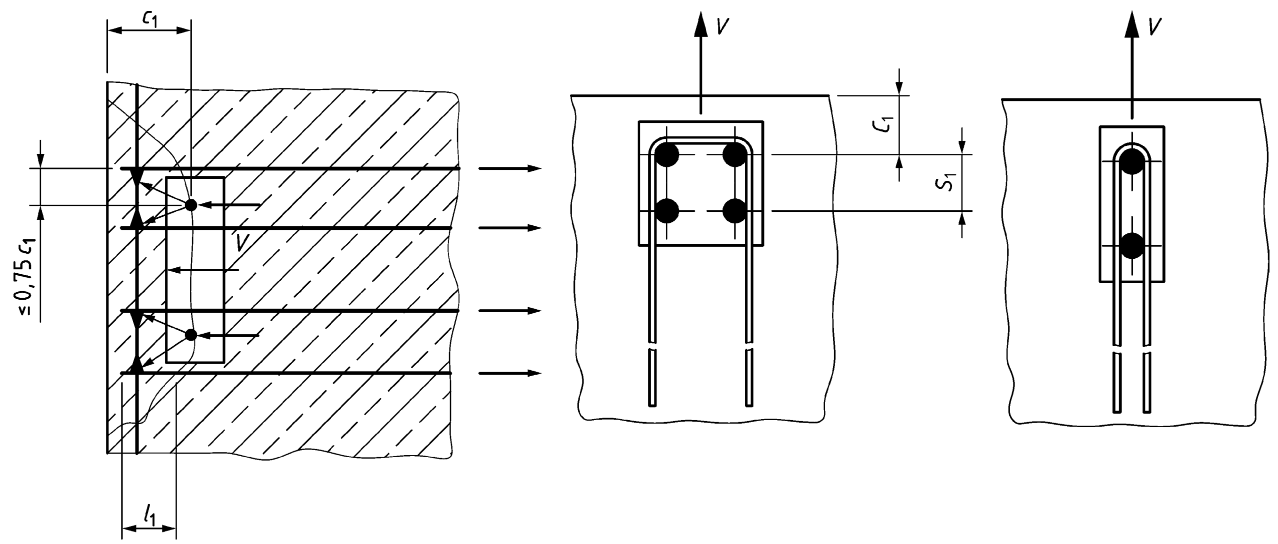
b) The supplementary reinforcement consists of ribbed bars with $f_{yk} \leq 600 \text{ N/mm}^2$ and the diameter ϕ is not larger than 16 mm. The mandrel diameter, ϕ_m, complies with EN 1992-1-1.

c) Bars are within a distance of $0{,}75 c_1$ from the fastener.

d) The anchorage length l_1 in the concrete breakout body is at least min $l_1 = 10\phi$ for straight bars with or without welded transverse bars and min $l_1 = 4\phi$ for bars with a hook, bend or loop. Exception see 7.2.2.2 (4).

e) The breakout body assumed should be the same as that for calculating the resistance for concrete edge failure (see 6.2.2.2 and 7.2.2.5).

f) Reinforcement along the edge of the member is provided and designed for the forces according to an appropriate strut and tie model. As a simplification an angle of the compression struts of 45° may be assumed.



Key

a) surface reinforcement to take up shear forces with simplified strut and tie model to design edge reinforcement

b) supplementary reinforcement in the shape of stirrups

c) supplementary reinforcement in the shape of loops

Figure 7.10 — Reinforcement to take up shear forces acting on a fastening

(4) If the shear forces are taken up by a supplementary reinforcement detailed in the shape of stirrups or loops (see Figure 7.10 b) and c)), the reinforcement shall enclose and be in contact with the shaft of the fastener and be positioned as closely as possible to the fixture, because direct force transfer from the fastener to the supplementary reinforcement is assumed and therefore no verification of the anchorage length in the breakout body is required.

7.2.2.3 Steel failure of fastener

7.2.2.3.1 Shear load without lever arm

(1) The characteristic resistance of a single fastener in case of steel failure $V^0_{Rk,s}$ is given in the relevant European Technical Product Specification.

NOTE For a single fastener made out of carbon steel without sleeve in the sheared section (threaded rod) and without significant reduction in cross-section along its total length $V^0_{Rk,s}$ can be calculated as follows:

$$V^0_{\mathrm{Rk,s}} = k_6 \cdot A_s \cdot f_{\mathrm{uk}} \tag{7.34}$$

where

k_6 = 0,6 for $f_{\mathrm{uk}} \le 500\ \mathrm{N/mm^2}$

= 0,5 for $500\ \mathrm{N/mm^2} < f_{\mathrm{uk}} \le 1\ 000\ \mathrm{N/mm^2}$

For fasteners with a ratio $h_{\mathrm{ef}} / d < 5$ and a concrete compressive strength class < C20/25 the characteristic resistance $V^0_{\mathrm{Rk,s}}$ should be multiplied by a factor of 0,8.

(2) The characteristic resistance of a fastener $V_{\mathrm{Rk,s}}$ accounting for ductility of the fastener in a group and including a possible grout layer with a thickness $t_{\mathrm{grout}} \le d/2$ is:

$$V_{\mathrm{Rk,s}} = k_7 \cdot V^0_{\mathrm{Rk,s}} \tag{7.35}$$

where

for single fasteners k_7 = 1;

for fasteners in a group k_7 is given in the relevant European Technical Product Specification.

NOTE For fasteners in a group the factor k_7 for ductile steel can be assumed as k_7 = 1, for steel with a rupture elongation $A_5 \le 8\%$ a value k_7 = 0,8 can be used.

(3) If the conditions given in 6.2.2.3 (2) are fulfilled, the characteristic resistance of one fastener $V_{\mathrm{Rk,s}}$ in uncracked concrete is:

$$V_{\mathrm{Rk,s}} = \left(1 - 0,01 \cdot t_{\mathrm{grout}}\right) \cdot k_7 \cdot V^0_{\mathrm{Rk,s}} \tag{7.36}$$

7.2.2.3.2 Shear load with lever arm

The characteristic resistance in case of steel failure $V_{\mathrm{Rk,s,M}}$ shall be obtained from Formula (7.37):

$$V_{\mathrm{Rk,s,M}} = \frac{\alpha_{\mathrm{M}} \cdot M_{\mathrm{Rk,s}}}{l_{\mathrm{a}}} \tag{7.37}$$

with

α_{M}, l_{a} see 6.2.2.3 (3)

$$M_{\mathrm{Rk,s}} = M^0_{\mathrm{Rk,s}} \cdot \left(1 - N_{\mathrm{Ed}} / N_{\mathrm{Rd,s}}\right) \tag{7.38}$$

$$N_{\mathrm{Rd,s}} = N_{\mathrm{Rk,s}} / \gamma_{\mathrm{Ms}}$$

The characteristic resistance under tension load in case of steel failure $N_{Rk,s}$, the partial factor γ_{Ms} and the characteristic bending resistance of a single fastener $M^0_{Rk,s}$ are given in the relevant European Technical Product Specification where applicable.

Formula (7.38) can only be used for tension load N_{Ed}; where N_{Ed} is a compression load the fastener should be designed as a steel element according to EN 1993-1-8.

7.2.2.4 Concrete pry-out failure

(1) Fastenings may fail due to a concrete pry-out failure at the side opposite to load direction. Pull-out failure may also occur due to a tension force introduced in the fasteners by the shear load. For reason of simplicity this effect is not verified explicitly, but implicitly accounted for in the verification for pry-out failure, where relevant.

NOTE The tension force is caused by the eccentricity between the applied shear force and the resultant of the resistance in the concrete.

(2) The corresponding characteristic resistance $V_{Rk,cp}$ shall be calculated for fastenings with headed or mechanical post-installed fasteners as follows:

— for fastenings without supplementary reinforcement

$$V_{Rk,cp} = k_8 \cdot N_{Rk,c} \quad (7.39a)$$

— for fastenings with supplementary reinforcement

$$V_{Rk,cp} = 0{,}75 \cdot k_8 \cdot N_{Rk,c} \quad (7.39b)$$

where

k_8 is a factor to be taken from the relevant European Technical Product Specification

$N_{Rk,c}$ is determined according to 7.2.1.4 for a single fastener or all fasteners in a group loaded in shear.

(3) The characteristic resistance $V_{Rk,cp}$ shall be calculated for fastenings with bonded fasteners as follows:

— for fastenings without supplementary reinforcement

$$V_{Rk,cp} = k_8 \cdot \min\left\{N_{Rk,c}; N_{Rk,p}\right\} \quad (7.39c)$$

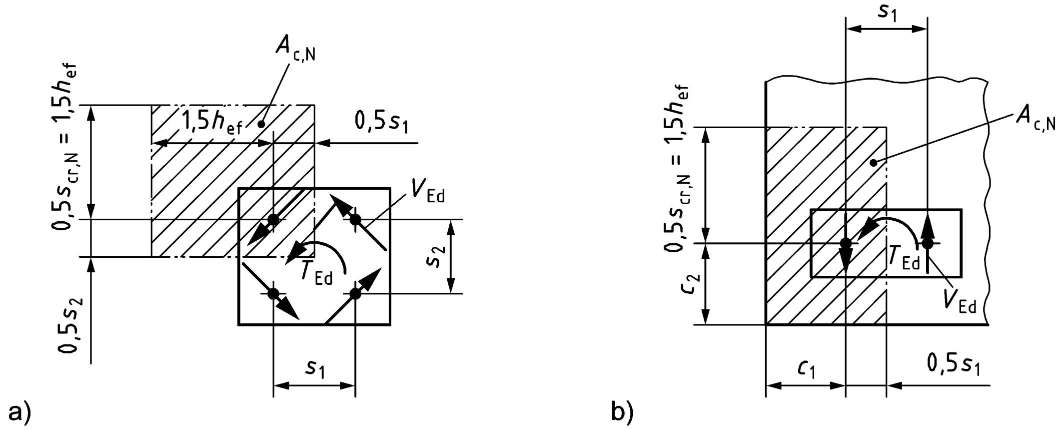
— for fastenings with supplementary reinforcement

$$V_{Rk,cp} = 0{,}75 \cdot k_8 \cdot \min\left\{N_{Rk,c}; N_{Rk,p}\right\} \quad (7.39d)$$

where

$N_{Rk,p}$ is determined according to 7.2.1.6 for a single fastener or all fasteners in a group loaded in shear.

(4) For anchor groups of fasteners with shear forces (or components thereof) on the individual fasteners in opposing directions (e.g. fastenings loaded predominantly by a torsion moment), the most unfavourable fastener shall be verified. When calculating the areas $A_{c,N}$ and $A_{p,N}$ it shall be assumed that there is a virtual edge (c = 0,5s) in the direction of the neighbouring fastener(s) (see Figure 7.11).



Key

a) group of four fasteners without edge influence

b) group of two fasteners located in a corner

Figure 7.11 — Calculation of area $A_{c,N}$ for pryout failure for a group of fasteners with shear load (or components thereof) on fasteners acting in opposing directions – Examples, assuming $s_{cr,N} = 3h_{ef}$

7.2.2.5 Concrete edge failure

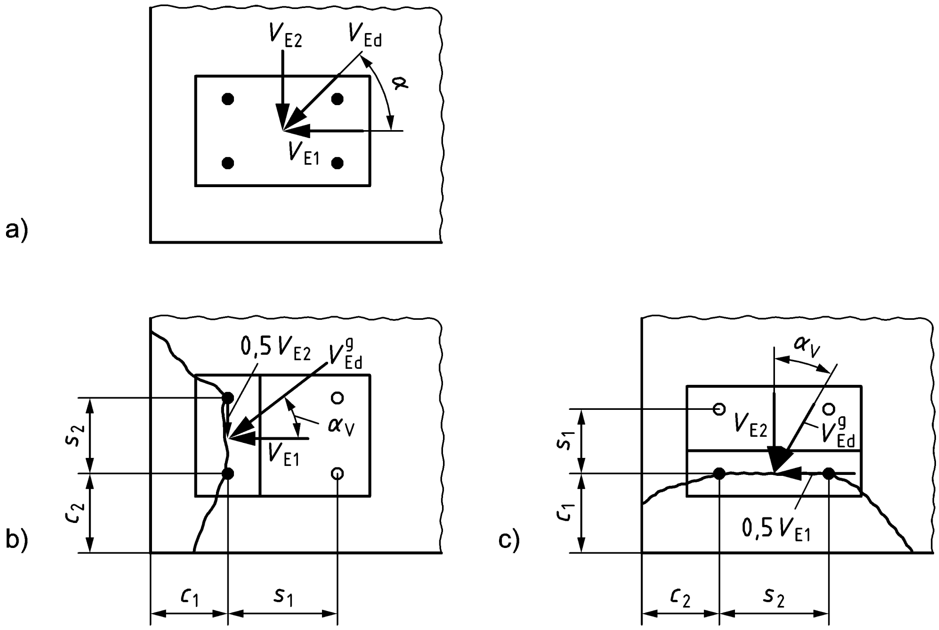
(1) For embedded base plates with an edge distance in direction of the shear load $c \leq \max\left\{10\ h_{ef}\ ;\ 60\ d\right\}$ the provisions are valid only if the thickness t of the base plate in contact with the concrete is smaller than 0,25 h_{ef}. For fastenings where the shear load acts with lever arm, the provisions are valid if $c > \max\left\{10\ h_{ef}\ ;\ 60\ d\right\}$ $c > \max\left\{10\ h_{ef}\ ;\ 60\ d\right\}$.

NOTE In case of fastenings located close to an edge and loaded by a shear load with lever arm the effect of an overturning moment on the concrete edge resistance is not considered in the following provisions.

(2) Only the fasteners located closest to the edge are used for the verification of concrete edge failure (see Figure 7.12). For load distribution see 6.2.2.2.

(3) For fastenings with more than one edge (see Figure 7.12), the verification shall be carried out for all edges.

(4) The minimum spacing of fasteners in a group should be $s_{min} \geq 4d_{nom}$.



Key

$V_{E1} = V_{Ed}\ \cos\alpha$

$V_{E2} = V_{Ed}\ \sin\alpha$

a) applied action

b) verification for the left edge

c) verification for the bottom edge

● fastener in a); loaded fastener in b) and c)

○ unloaded fastener in b) and c)

Figure 7.12 — Verification for a quadruple fastening with hole clearance at a corner – Example

(5) The characteristic resistance $V_{Rk,c}$ of a fastener or a group of fasteners loaded towards the edge is:

$$V_{Rk,c} = V_{Rk,c}^{0} \cdot \frac{A_{c,V}}{A_{c,V}^{0}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{ec,V} \cdot \psi_{\alpha,V} \cdot \psi_{re,V} \qquad (7.40)$$

The different factors of Formula (7.40) are given below.

(6) The initial value of the characteristic resistance of a fastener loaded perpendicular to the edge is calculated as:

$$V_{Rk,c}^{0} = k_9 \cdot d_{nom}^{\alpha} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1,5} \qquad (7.41)$$

with

k_9 = 1,7 for cracked concrete

= 2,4 for uncracked concrete

$$\alpha = 0{,}1 \cdot \left(\frac{l_f}{c_1}\right)^{0,5} \qquad (7.42)$$

$$\beta = 0{,}1 \cdot \left(\frac{d_{\text{nom}}}{c_1} \right)^{0,2} \tag{7.43}$$

l_f = h_{ef} in case of a uniform diameter of the shank of the headed fastener and a uniform diameter of the post-installed fastener

$\leq 12\, d_{\text{nom}}$ in case of $d_{\text{nom}} \leq 24$ mm

$\leq \max\left\{8\, d_{\text{nom}}; 300 \text{ mm}\right\}$ in case of $d_{\text{nom}} > 24$ mm

The values d_{nom} and l_f are given in the relevant European Technical Product Specification.

(7) The ratio $A_{c,V} / A^0_{c,V}$ takes into account the geometrical effect of spacing as well as of further edge distances and the effect of thickness of the concrete member on the characteristic resistance.

$A^0_{c,V}$ is the reference projected area, see Figure 7.13

$$= 4{,}5\, c_1^2 \tag{7.44}$$

$A_{c,V}$ is the area of the idealized concrete break-out body, limited by the overlapping concrete cones of adjacent fasteners $(s \leq 3\, c_1)$ as well as by edges parallel to the assumed loading direction $(c_2 \leq 1{,}5\, c_1)$ and by member thickness $(h < 1{,}5\, c_1)$. Examples for the calculation of $A_{c,V}$ are given in Figure 7.14.

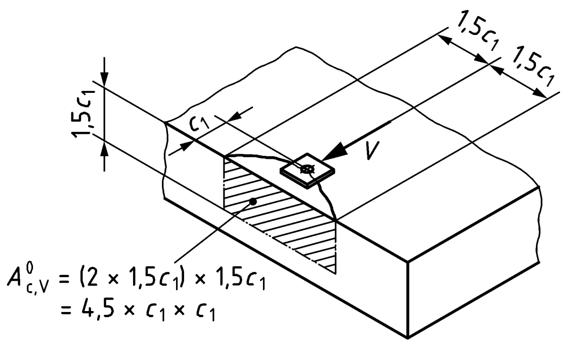
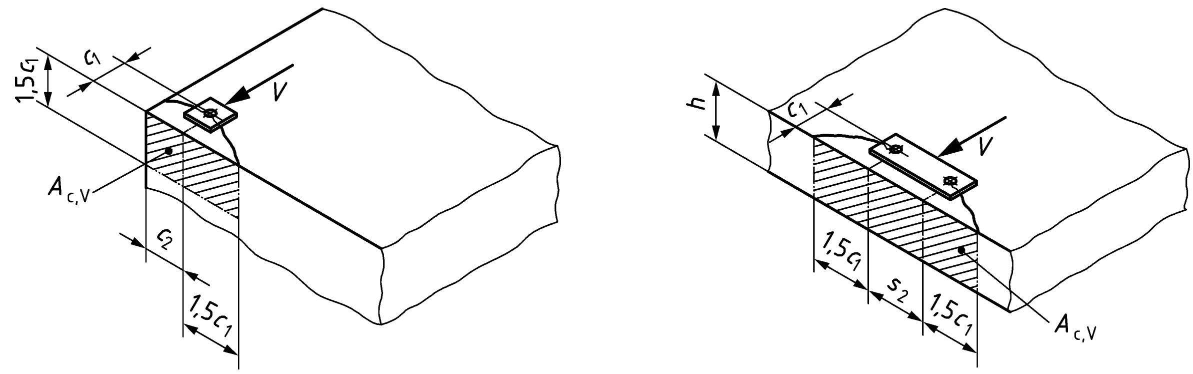


Figure 7.13 — Idealized concrete break-out body and area $A^0_{c,V}$ for a single fastener



$A_{c,V} = 1{,}5\, c_1 (1{,}5\, c_1 + c_2)$

$h \geq 1{,}5\, c_1$

$c_2 \leq 1{,}5\, c_1$

a) Single fastener at a corner

$A_{c,V} = (2 \cdot 1{,}5\, c_1 + s_2) \cdot h$

$h < 1{,}5\, c_1$

$s_2 \leq 3\, c_1$

b) Group of fasteners at an edge in a thin concrete member

Figure 7.14 — Examples of actual projected areas $A_{c,V}$ of the idealized concrete break-out bodies for different fastener arrangements under shear loading

(8) Resistance calculated in accordance with Formula (7.40) may be unconservative for concrete edge failure in cases where the fastenings comprising two fasteners are subject to torsion resulting in shear in opposite directions in the fasteners due to overlapping of the concrete breakout bodies. If the ratio between the concrete edge breakout resistance (verified edge) to the concrete breakout resistance of the second fastener (pry-out or edge failure) is larger than 0,7 and $s_2 \leq s_{crit}$, $V_{Rk,c}$ according to Formula (7.40) should be multiplied by a factor of 0,8 which is assumed to be conservative. Herein, s_{crit} is defined as follows:

— $s_{crit} = 1{,}5 h_{ef} + 1{,}5 c_1$, if the second fastener is governed by pry-out failure;

— $s_{crit} = 1{,}5 c_1$, if the second fastener is governed by concrete edge failure with respect to a second edge (perpendicular to the verified edge).

(9) The factor $\psi_{s,V}$ takes account of the disturbance of the distribution of stresses in the concrete due to further edges of the concrete member on the shear resistance. For fastenings with two edges parallel to the direction of loading (e.g. in a narrow concrete member) the smaller value of these edge distances shall be used for c_2 in Formula (7.45).

$$\psi_{s,V} = 0{,}7 + 0{,}3 \cdot \frac{c_2}{1{,}5\, c_1} \leq 1 \tag{7.45}$$

(10) The factor $\psi_{h,V}$ takes account of the fact that the concrete edge resistance does not decrease proportionally to the member thickness as assumed by the ratio $A_{c,V} / A^0_{c,V}$ (Figure 7.14 b)).

$$\psi_{h,V} = \left(\frac{1{,}5 c_1}{h} \right)^{0{,}5} \geq 1 \tag{7.46}$$

(11) The factor $\psi_{ec,V}$ takes into account a group effect when different shear loads are acting on the individual fasteners of a group (see Figure 7.15).

$$\psi_{ec,V} = \frac{1}{1 + 2 \cdot e_V / (3c_1)} \leq 1 \quad (7.47)$$

where

e_V is the eccentricity of the resulting shear load acting on the fasteners relative to the centre of gravity of the fasteners loaded in shear

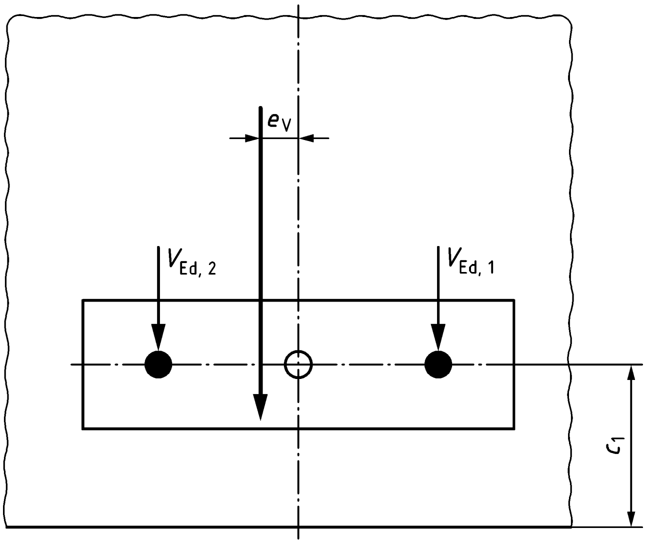


Figure 7.15 — Resolving unequal shear components into an eccentric shear load resultant – Example

(12) The factor $\psi_{\alpha,V}$ takes account of the influence of a shear load inclined to the edge under consideration on the concrete edge resistance.

$$\psi_{\alpha,V} = \sqrt{\frac{1}{(\cos \alpha_V)^2 + (0,5 \cdot \sin \alpha_V)^2}} \geq 1 \quad (7.48)$$

where

α_V is the angle between design shear load V_{Ed} (single fastener) or V_{Ed}^{g} (group of fasteners) and a line perpendicular to the verified edge, $0° \leq \alpha_V \leq 90°$, see Figure 7.12.

(13) The factor $\psi_{re,V}$ takes account of the effect of the reinforcement located on the edge.

$\psi_{re,V} = 1,0$ fastening in uncracked concrete and fastening in cracked concrete without edge reinforcement or stirrups

$\psi_{re,V} = 1,4$ fastening in cracked concrete with edge reinforcement (see Figure 7.10) and closely spaced stirrups or wire mesh with a spacing $a \leq 100$ mm and $a \leq 2c_1$.

A factor $\psi_{re,V} > 1$ for applications in cracked concrete shall only be applied, if the embedment depth h_{ef} of the fastener is at least 2,5 times the concrete cover of the edge reinforcement.

(14) For fastenings in a narrow, thin member with $c_{2,max} \leq 1,5\, c_1$ and $h \leq 1,5\, c_1$ (see Figure 7.16) the calculation according to Formula (7.40) leads to conservative results. More precise results are achieved if c_1 is replaced by:

$$c'_1 = \max\left\{\frac{c_{2,max}}{1,5}; \frac{h}{1,5}\right\} \text{ in case of single fasteners} \tag{7.49}$$

or

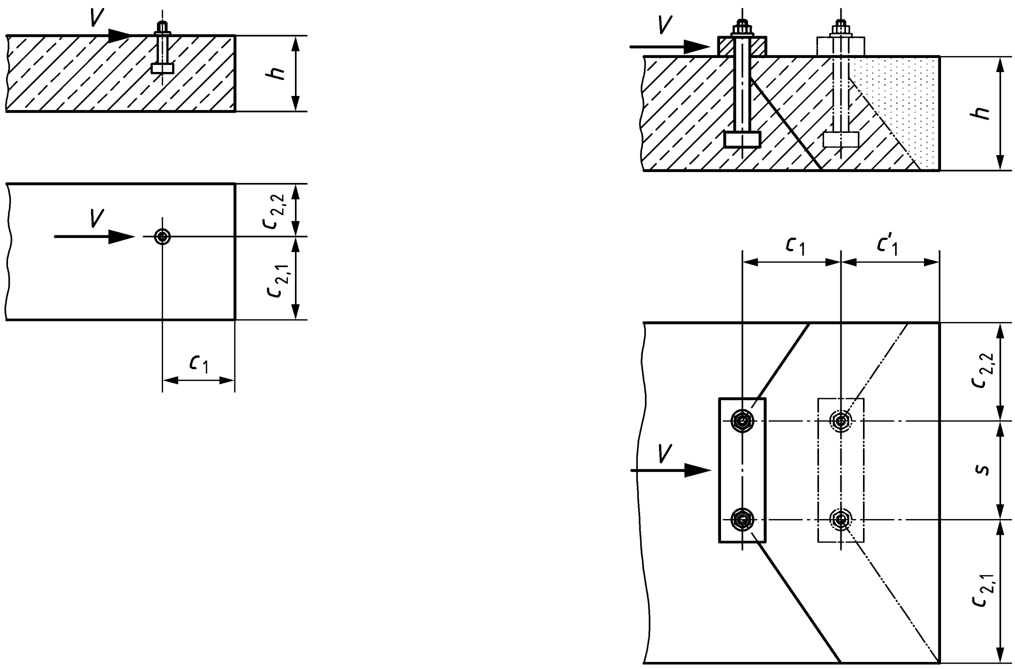
$$c'_1 = \max\left\{\frac{c_{2,max}}{1,5}; \frac{h}{1,5}; \frac{s_{2,max}}{3}\right\} \text{ in case of groups} \tag{7.50}$$

where

$c_{2,max}$ is the larger of the two distances to the edges parallel to the direction of loading; and

$s_{2,max}$ is the maximum spacing in direction 2 between fasteners within a group.

The value of c'_1 instead of c_1 is used in Formulae (7.41) to (7.47) as well as in the determination of the areas $A^0_{c,V}$ and $A_{c,V}$ according to Figures 7.13 and 7.14.



$\max\{c_{2,1}; c_{2,2}\} < 1{,}5\, c_1$ and $h < 1{,}5\, c_1$

s = 100 mm, c_1 = 200 mm, h = 120 mm < 1,5 · 200 mm ,

$c_{2,1}$ = 150 mm ≤ 1,5 · 200 mm , $c_{2,2}$ = 100 mm < 1,5 · 200 mm ,

c'_1 = max {150/1,5; 120/1,5; 100/3} = 100 mm

Figure 7.16 — Fasteners in thin, narrow members where the value c'_1 may be used

7.2.2.6 Failure of supplementary reinforcement

7.2.2.6.1 General

When supplementary reinforcement comprises a mixture of surface reinforcement (see Figure 7.10 a)) and loops in contact with the fastener (see Figures 7.10 b) and c)) their resistances shall not be added unless the strain compatibility of the various failure modes (steel and anchorage failure) of the two types of reinforcements is taken into account.

7.2.2.6.2 Steel failure

The characteristic resistance of one fastener in case of steel failure of the supplementary reinforcement may be calculated according to Formula (7.51).

$$N_{\text{Rk,re}} = k_{10} \sum_{i=1}^{n_{\text{re}}} A_{\text{s,re,i}} \cdot f_{\text{yk,re}} \tag{7.51}$$

where

n_{re} is the number of bars of supplementary reinforcement effective for one fastener

k_{10} is the efficiency factor

= 1,0 surface reinforcement according to Figure 7.10 a)

= 0,5 supplementary reinforcement in the shape of stirrups or loops enclosing the fastener (see Figure 7.10 b) and c))

$f_{yk,re} \leq 600\ \text{N/mm}^2$

NOTE Where the contact between the supplementary reinforcement in the shape of stirrups or loops and the shaft of the fastener as well as the position of this reinforcement with respect to the concrete surface cannot be ensured (see 7.2.2.2 (4)) due to tolerances in workmanship the factor k_{10} = 0,5 accounts for the consequences on the resistance.

7.2.2.6.3 Anchorage failure

(1) For applications with supplementary reinforcement in the shape of stirrups or loops in contact with the fastener (see Figure 7.10 b) and c)) no proof of the anchorage capacity of the supplementary reinforcement in the assumed concrete break-out body is necessary.

(2) For applications according to Figure 7.10 a) the design resistance $N_{Rd,a}$ of the supplementary reinforcement of one fastener in case of an anchorage failure in the concrete edge break-out body is given by Formula (7.52):

$$N_{Rd,a} = \sum_{i=1}^{n_{re}} N_{Rd,a}^{0} \quad (7.52)$$

where

$$N_{Rd,a}^{0} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2} \leq A_{s,re} \cdot f_{yk,re} \cdot \frac{1}{\gamma_{Ms,re}} \quad (7.53)$$

l_1 is the anchorage length in the break-out body (see Figure 7.10 a)); l_1 shall be larger than the minimum anchorage length in 7.2.2.2 (3) d);

f_{bd} is the design bond strength according to EN 1992-1-1:2004, 8.4.2;

α_1, α_2 are the influencing factors according to EN 1992-1-1:2004, 8.4.4.

7.2.3 Combined tension and shear loads

7.2.3.1 Fastenings without supplementary reinforcement

The required verifications are given in Table 7.3. Verifications for steel and concrete failure modes are carried out separately. Both verifications shall be fulfilled.

Table 7.3 — Required verifications for headed and post-installed fasteners without supplementary reinforcement subjected to a combined tension and shear load

	Failure mode	Verification
1	**Steel failure of fastener** [a]	$$\left(\frac{N_{\text{Ed}}}{N_{\text{Rd,s}}}\right)^2 + \left(\frac{V_{\text{Ed}}}{V_{\text{Rd,s}}}\right)^2 \le 1 \quad (7.54)$$ If N_{Ed} and V_{Ed} are different for the individual fasteners of the group, the interaction shall be verified for all fasteners.
2	**Failure modes other than steel failure**	$$\left(\frac{N_{\text{Ed}}}{N_{\text{Rd,i}}}\right)^{1,5} + \left(\frac{V_{\text{Ed}}}{V_{\text{Rd,i}}}\right)^{1,5} \le 1 \quad (7.55)$$ or $$\left(\frac{N_{\text{Ed}}}{N_{\text{Rd,i}}}\right) + \left(\frac{V_{\text{Ed}}}{V_{\text{Rd,i}}}\right) \le 1,2 \quad (7.56)$$ with $N_{\text{Ed}} / N_{\text{Rd,i}} \le 1$ and $V_{\text{Ed}} / V_{\text{Rd,i}} \le 1$ The largest value of $N_{\text{Ed}} / N_{\text{Rd,i}}$ and $V_{\text{Ed}} / V_{\text{Rd,i}}$ for the different failure modes shall be taken.

[a] This verification is not required in case of shear load with lever arm as Formula (7.37) accounts for the interaction.

7.2.3.2 Fastenings with supplementary reinforcement

(1) For fastenings with supplementary reinforcement for both tension and shear loads 7.2.3.1 applies. However, for the verifications according to Table 7.3, line 2 $N_{\text{Ed}} / N_{\text{Rd,i}}$ for concrete cone failure mode (tension) and $V_{\text{Ed}}/V_{\text{Rd,i}}$ for concrete edge failure mode (shear) are both replaced by the corresponding values for failure of supplementary reinforcement.

(2) For fastenings with supplementary reinforcement to take up either tension or shear loads only, Formula (7.57) shall be used with the largest value of $N_{\text{Ed}} / N_{\text{Rd,i}}$ and $V_{\text{Ed}} / V_{\text{Rd,i}}$ for the different failure modes other than steel failure of the fastener.

$$\left(\frac{N_{\text{Ed}}}{N_{\text{Rd,i}}}\right)^{k_{11}} + \left(\frac{V_{\text{Ed}}}{V_{\text{Rd,i}}}\right)^{k_{11}} \le 1 \quad (7.57)$$

where

k_{11} is given in the relevant European Technical Product Specification

$N_{\text{Ed}} / N_{\text{Rd,i}} \le 1$ and

$V_{\text{Ed}} / V_{\text{Rd,i}} \le 1$

In case of fastenings with supplementary reinforcement to take up tension loads only, $N_{\text{Rd,i}}$ and $V_{\text{Rd,i}}$ represent the design resistances $N_{\text{Rd,p}}$, $N_{\text{Rd,sp}}$, $N_{\text{Rd,cb}}$, $N_{\text{Rd,re}}$, $N_{\text{Rd,a}}$, and $V_{\text{Rd,c}}$, $V_{\text{Rd,cp}}$, respectively. If supplementary reinforcement is used to take up shear loads only, $N_{\text{Rd,i}}$ and $V_{\text{Rd,i}}$ represent the design resistances $N_{\text{Rd,p}}$, $N_{\text{Rd,c}}$, $N_{\text{Rd,sp}}$, $N_{\text{Rd,cb}}$ and $V_{\text{Rd,cp}}$, $N_{\text{Rd,re}}$, $N_{\text{Rd,a}}$, respectively. For N_{Ed} and V_{Ed} the actions corresponding to the specific failure modes shall be used.

If no value for k_{11} is given in the relevant European Technical Product Specification, k_{11} = 2/3 may be assumed. This value is based on engineering considerations and is considered as conservative.

7.3 Fasteners in redundant non-structural systems

(1) In redundant non-structural systems when excessive slip or failure of one fastener occurs, it is assumed that the load can be transmitted to adjacent fasteners without violating the requirements on the fixture in the serviceability and ultimate limit state.

(2) The definition of redundant non-structural systems is given in the National Regulations.

NOTE Details on the design of fasteners in redundant non-structural systems can be found in CEN/TR 17079, *Design of fastenings for use in concrete — Redundant non-structural systems*.

(3) Verification for fastenings in redundant non-structural systems shall be verified according to 7.1 and 7.2, and Annex G may be used.

7.4 Anchor channels

7.4.1 Tension load

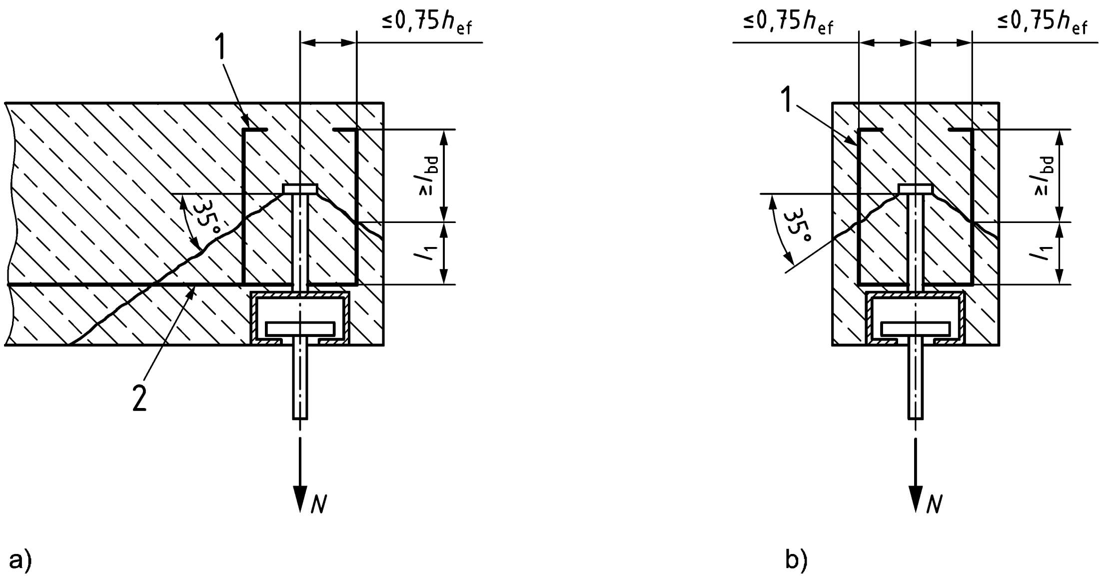
7.4.1.1 Required verifications

The verifications of Table 7.4 apply. The failure modes addressed are shown in Table 7.4.

7.4.1.2 Detailing of supplementary reinforcement

(1) When the design relies on supplementary reinforcement, concrete cone failure according to Formula (7.60) need not to be verified but the supplementary reinforcement shall be designed to resist the total load. The reinforcement shall be anchored adequately on both sides of the potential failure planes. 7.2.1.2 applies.

(2) For anchor channels located parallel to the edge of a concrete member or in a narrow concrete member, the plane of the supplementary reinforcement shall be located perpendicular to the longitudinal axis of the channel (see Figure 7.17).



Key

1 supplementary reinforcement

2 surface reinforcement

Figure 7.17 — Arrangement of supplementary reinforcement

7.4.1.3 Steel failure

(1) The characteristic resistances $N_{Rk,s,a}$ (failure of anchor), $N_{Rk,s,c}$ (failure of the connection between anchor and channel), $N^0_{Rk,s,l}$ (basic value for local failure by flexure of channel lips), $N_{Rk,s}$ (failure of the channel bolt) and $M_{Rk,s,flex}$ (failure by flexure of the channel) are given in the relevant European Technical Product Specification.

(2) The characteristic resistance $N_{Rk,s,l}$ for lip failure is:

$$N_{Rk,s,l} = N^0_{Rk,s,l} \cdot \psi_{l,N} \tag{7.58}$$

with

$$\psi_{l,N} = 0,5\left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \leq 1 \tag{7.59}$$

where

s_{cbo} is the spacing of channel bolts

$s_{l,N}$ is the characteristic spacing for channel lip failure under tension, taken from the European Technical Product Specification.

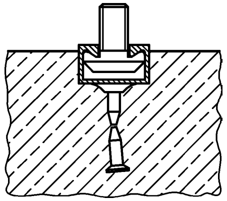
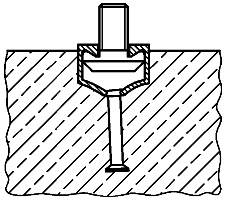
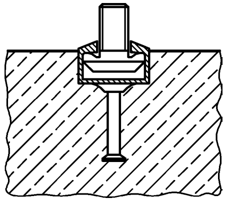
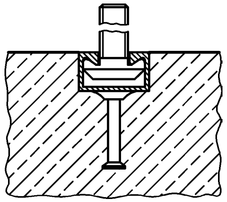
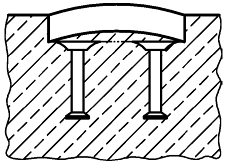
As indicative value $s_{l,N} = 2\, b_{ch}$ may be used.

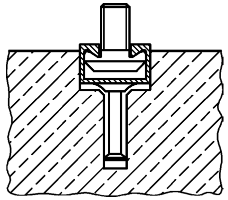
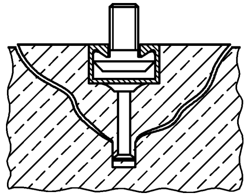
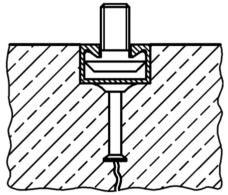
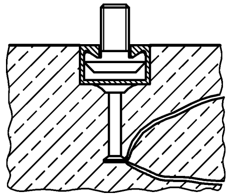
7.4.1.4 Pull-out failure

The characteristic resistance $N_{Rk,p}$ for pull-out failure of the anchor is given in the relevant European Technical Product Specification.

The characteristic resistance $N_{Rk,p}$ should be limited by the concrete pressure under the head of the anchor according to 7.2.1.5.

Table 7.4 — Required verifications for anchor channels in tension

	Failure mode		Channel	Most unfavourable anchor or channel bolt	
1	**Steel failure**	anchor		$N_{Ed}^{a} \leq N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$	
2		connection between anchor and channel		$N_{Ed}^{a} \leq N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$	
3		local flexure of channel lip[a]	$N_{Ed}^{cb} \leq N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$		
4		channel bolt		$N_{Ed}^{cb} \leq N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	
5		flexure of channel	$M_{Ed}^{ch} \leq M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$		

	Failure mode	Channel	Most unfavourable anchor or channel bolt	
6	**Pull out failure**		$N_{\mathrm{Ed}}^{\mathrm{a}} \leq N_{\mathrm{Rd,p}} = \dfrac{N_{\mathrm{Rk,p}}}{\gamma_{\mathrm{Mp}}}$	
7	**Concrete cone failure[b]**		$N_{\mathrm{Ed}}^{\mathrm{a}} \leq N_{\mathrm{Rd,c}} = \dfrac{N_{\mathrm{Rk,c}}}{\gamma_{\mathrm{Mc}}}$	
8	**Concrete splitting failure[b]**		$N_{\mathrm{Ed}}^{\mathrm{a}} \leq N_{\mathrm{Rd,sp}} = \dfrac{N_{\mathrm{Rk,sp}}}{\gamma_{\mathrm{Msp}}}$	
9	**Concrete blow-out failure[b, c]**		$N_{\mathrm{Ed}}^{\mathrm{a}} \leq N_{\mathrm{Rd,cb}} = \dfrac{N_{\mathrm{Rk,cb}}}{\gamma_{\mathrm{Mc}}}$	
10	**Steel failure of supplementary reinforcement**		$N_{\mathrm{Ed,re}}^{\mathrm{a}} \leq N_{\mathrm{Rd,re}} = \dfrac{N_{\mathrm{Rk,re}}}{\gamma_{\mathrm{Ms,re}}}$	
11	**Anchorage failure of supplementary reinforcement**		$N_{\mathrm{Ed,re}}^{\mathrm{a}} \leq N_{\mathrm{Rd,a}}$	

[a] Most loaded anchor or channel bolt.

[b] The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

[c] Not required for anchors with $c > 0,5\ h_{\mathrm{ef}}$.

7.4.1.5 Concrete cone failure

(1) For anchor channels where $h_{ch} / h_{ef} \le 0,4$ and $b_{ch} / h_{ef} \le 0,7$ the effective embedment depth is determined according to Figure 3.2 a). In case that $h_{ch} / h_{ef} > 0,4$ and/or $b_{ch} / h_{ef} > 0,7$ the concrete cone resistance may be calculated using one of the following options.

a) The effective embedment depth is determined according to Figure 3.2 b), $h_{ef} = h_{ef}^{*}$; or

b) the effective embedment depth h_{ef} is determined according to Figure 3.2 a) with the value for $s_{cr,N}$ taken from the relevant European Technical Product Specification. The value for $s_{cr,N}$ used in design shall not be smaller than that for anchor channels with $h_{ch} / h_{ef} \le 0,4$ and $b_{ch} / h_{ef} \le 0,7$ according to Formula (7.62).

(2) The characteristic resistance of one anchor of an anchor channel in case of concrete cone failure shall be calculated according to Formula (7.60).

$$N_{Rk,c} = N_{Rk,c}^{0} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N} \quad (7.60)$$

The different factors in Formula (7.60) are given in the following.

(3) For the determination of the basic characteristic resistance $N_{Rk,c}^{0}$ of one anchor not influenced by adjacent anchors, edges or corners of the concrete member located in cracked or uncracked concrete Formula (7.2) applies.

NOTE The anchor channel may have an adverse effect on the concrete cone resistance. This is recognized in the values $k_{cr,N}$ and $k_{ucr,N}$ given in the European Technical Product Specification. Usually these values are smaller than for headed fasteners.

(4) The influence of neighbouring anchors on the concrete cone resistance is taken into account by the factor $\psi_{ch,s,N}$ according to Formula (7.61).

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}} \right)^{1,5} \cdot \frac{N_i}{N_0} \right]} \quad (7.61)$$

where (see Figure 7.18):

s_i is the distance between the anchor under consideration and the neighbouring anchors

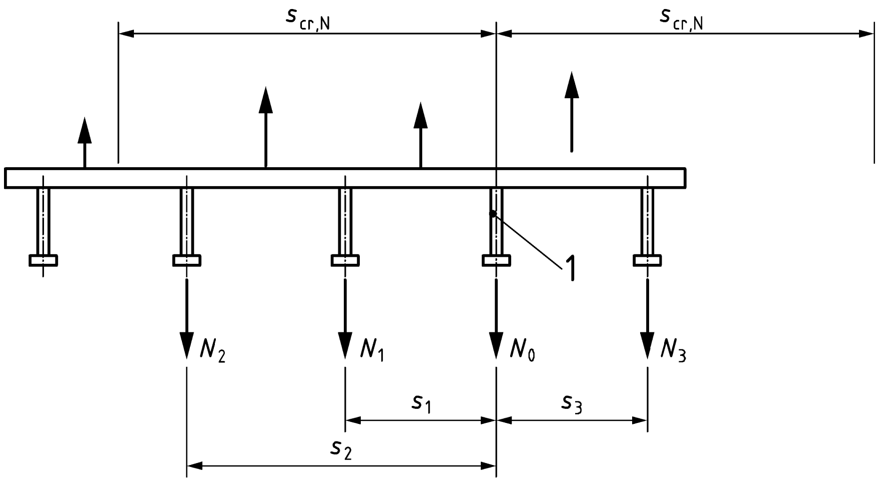
$\le s_{cr,N}$

$$s_{cr,N} = 2 \cdot \left(2,8 - 1,3 \cdot h_{ef} / 180 \right) \cdot h_{ef} \ge 3 \cdot h_{ef} \quad (7.62)$$

N_i is the tension force of an influencing anchor;

N_0 is the tension force of the anchor under consideration;

$n_{ch,N}$ is the number of anchors within a distance $s_{cr,N}$ to both sides of the anchor under consideration.



Key

1 anchor under consideration

Figure 7.18 — Anchor channel with different anchor tension forces – Example

(5) The influence of an edge of the concrete member on the characteristic resistance is taken into account by the factor $\psi_{ch,e,N}$ according to Formula (7.63).

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0,5} \leq 1 \tag{7.63}$$

where

c_1 is the edge distance of the anchor channel (see Figure 7.19 a))

$$c_{cr,N} = 0,5 s_{cr,N} \tag{7.63a}$$

With anchor channels located in a narrow concrete member with different edge distances $c_{1,1}$ and $c_{1,2}$ (see Figures 7.19 b) and 7.20 d)) the minimum value of $c_{1,1}$ and $c_{1,2}$ shall be inserted for c_1 in Formula (7.63).

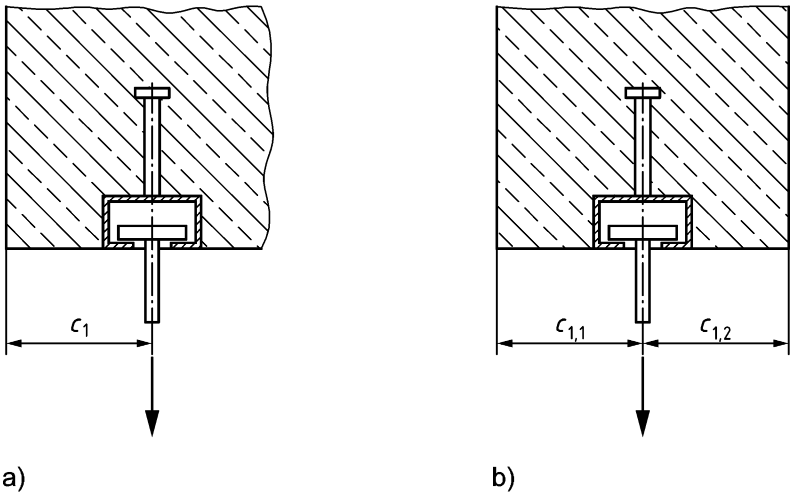


Figure 7.19 — Anchor channel at an edge or in a narrow member

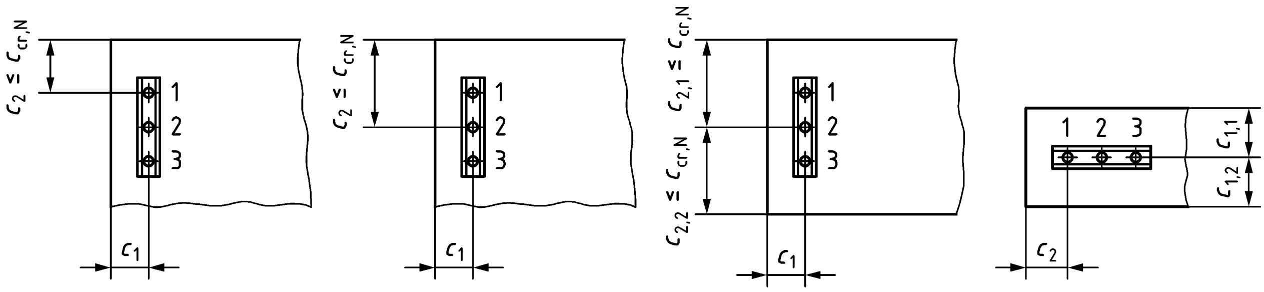
(6) The influence of a corner of the concrete member (see Figure 7.20) on the characteristic resistance is taken into account by the factor $\psi_{ch,c,N}$ according to Formula (7.64).

$$\psi_{ch,c,N} = \left(\frac{c_2}{c_{cr,N}}\right)^{0,5} \leq 1 \qquad (7.64)$$

where

c_2 is the corner distance of the anchor under consideration (see Figure 7.20).

If an anchor is influenced by two corners (see Figure 7.20 c)), the factor $\psi_{ch,c,N}$ shall be calculated for $c_{2,1}$ and $c_{2,2}$ and the product of the factors $\psi_{ch,c,N}$ shall be inserted in Formula (7.60).



a) b) c) d)

Key

a) Resistance of anchor 1 is calculated
b) Resistance of anchor 2 is calculated
c) Resistance of anchor 2 is calculated
d) Resistance of anchor 1 is calculated

Figure 7.20 — Definition of the corner distance of an anchor channel in the corner of a concrete member

(7) The shell spalling factor $\psi_{re,N}$ takes account of the effect of a dense reinforcement for embedment depths $h_{ef} \leq 100\ \text{mm}$. 7.2.1.4 (5) applies.

(8) For the case of anchor channels with $h_{ef} > 180\ \text{mm}$ in a narrow member with influence of neighbouring anchors and influence of an edge and 2 corners (see Figure 7.20 c) and d)) with edge distances less than $c_{cr,N}$ from the anchor under consideration the calculation according to Formula (7.60) leads to conservative results. More precise results are obtained if the value h_{ef} is substituted by the larger value of:

$$h'_{ef} = \frac{c_{max}}{c_{cr,N}} \cdot h_{ef} \geq 180\ \text{mm} \quad \text{and} \quad h'_{ef} = \frac{s_{max}}{s_{cr,N}} \cdot h_{ef} \geq 180\ \text{mm} \qquad (7.65)$$

where

c_{max} is the maximum distance from the centre of an anchor to the edge of the concrete member $\leq c_{cr,N}$. In the example given in Figure 7.20 c) c_{max} is the maximum value of c_1, $c_{2,1}$ and $c_{2,2}$

s_{max} is the maximum centre to centre spacing of anchors $\leq s_{cr,N}$

The value h'_{ef} is inserted in Formula (7.2) as well as in Formula (7.62). The resulting value for $s_{cr,N}$ is then inserted in Formula (7.63a).

7.4.1.6 Concrete splitting failure

(1) Concrete splitting failure during installation (e.g. when applying the installation torque on a channel bolt) is avoided by complying with minimum values for edge distances c_{min}, spacing s_{min}, member thickness h_{min} and requirements for reinforcement as given in the relevant European Technical Product Specification.

(2) Concrete splitting failure due to loading shall be taken into account according to the following rules.

a) The characteristic edge distance in the case of splitting under load, $c_{cr,sp}$, is given in the relevant European Technical Product Specification. The characteristic spacing is defined as $s_{cr,sp} = 2\ c_{cr,sp}$.

b) No verification is required if at least one of the following conditions is fulfilled.

1) The edge distance in all directions is $c \geq 1,2\ c_{cr,sp}$, and the member depth is $h \geq h_{min}$ with h_{min} corresponding to $c_{cr,sp}$.

2) The characteristic resistances for concrete cone failure and pull-out failure are calculated for cracked concrete and reinforcement resists the splitting forces and limits the crack width to $w_k \leq 0,3$ mm.

In absence of better information the cross-section of the reinforcement, $\sum A_{s,re}$, to resist the splitting forces can be determined as follows:

$$\sum A_{s,re} = 0,5 \cdot \frac{N_{Ed}^{a}}{f_{yk,re} / \gamma_{Ms,re}} \tag{7.66}$$

where

N_{Ed}^{a} is the design tensile force on the most loaded anchor under the design value of actions

$f_{yk,re}$ is the nominal yield strength of the reinforcing steel $\leq 600\ \text{N}/\text{mm}^2$

It is recommended that this reinforcement is placed symmetrically and close to each anchor of the channel.

c) If the conditions b) 1) and b) 2) are not fulfilled, the characteristic resistance of an anchor channel in case of concrete splitting failure shall be calculated according to Formula (7.67).

$$N_{Rk,sp} = N_{Rk}^{0} \cdot \psi_{ch,s,N} \cdot \psi_{ch,c,N} \cdot \psi_{ch,e,N} \cdot \psi_{re,N} \cdot \psi_{h,sp} \tag{7.67}$$

with

$$N_{\rm Rk}^{0} = \min\left\{N_{\rm Rk,p}\,;\,N_{\rm Rk,c}^{0}\right\}$$

$N_{\rm Rk,p}$ according to 7.4.1.4

$N_{\rm Rk,c}^{0}$, $\psi_{\rm ch,s,N}$, $\psi_{\rm ch,c,N}$, $\psi_{\rm ch,e,N}$, $\psi_{\rm re,N}$ according to 7.4.1.5, however, the values $c_{\rm cr,N}$ and $s_{\rm cr,N}$ shall be replaced by $c_{\rm cr,sp}$ and $s_{\rm cr,sp}$, respectively, which correspond to the minimum member thickness $h_{\rm min}$.

$$\psi_{\rm h,sp} = \left(\frac{h}{h_{\rm min}}\right)^{2/3} \le \max\left\{1;\left(\frac{h_{\rm ef} + c_{\rm cr,N}}{h_{\rm min}}\right)^{2/3}\right\} \le 2 \tag{7.68}$$

d) If in the relevant European Technical Product Specification $c_{\rm cr,sp}$ is given for more than one minimum member thickness $h_{\rm min}$, the minimum member thickness corresponding to $c_{\rm cr,sp}$ used in Formula (7.67) shall be inserted in Formula (7.68).

7.4.1.7 Concrete blow-out failure

(1) Verification of concrete blow-out failure is not required with anchors if the edge distance is $c \ge 0{,}5\,h_{\rm ef}$. If verification is required, the characteristic resistance of one anchor in case of blow-out is:

$$N_{\rm Rk,cb} = N_{\rm Rk,cb}^{0} \cdot \psi_{\rm ch,s,Nb} \cdot \psi_{\rm ch,c,Nb} \cdot \psi_{\rm ch,h,Nb} \tag{7.69}$$

The different factors in Formula (7.69) are given in the following.

For anchor channels located perpendicular to the edge, verification is required only for the anchor closest to the edge.

(2) The characteristic resistance of a single anchor $N_{\rm Rk,cb}^{0}$ is calculated according to 7.2.1.8 (2).

(3) The influence of neighbouring anchors on the blow-out resistance is taken into account by the factor $\psi_{\rm ch,s,Nb}$, which may be calculated analogous to Formula (7.61), however, with $s_{\rm cr,Nb} = 4\,c_1$ instead of $s_{\rm cr,N}$.

(4) The influence of a corner of the concrete member on the characteristic resistance is taken into account by the factor $\psi_{\rm ch,c,Nb}$ according to Formula (7.70):

$$\psi_{\rm ch,c,Nb} = \left(\frac{c_2}{c_{\rm cr,Nb}}\right)^{0,5} \le 1 \tag{7.70}$$

where

c_2 is the corner distance of the anchor, for which the resistance is calculated (see Figure 7.20)

$c_{\rm cr,Nb} = s_{\rm cr,Nb}\,/2$

If an anchor is influenced by two corners - example see Figure 7.20 c) — then the factor $\psi_{\rm ch,c,Nb}$ shall be calculated for the values of $c_{2,1}$ and $c_{2,2}$ and the product of the factors shall be inserted in Formula (7.69).

(5) The effect of the thickness of the concrete member in case of a distance $f \le 2\,c_1$, where f is defined in Figure 7.21, is taken into account by the factor $\psi_{\rm ch,h,Nb}$ according to Formula (7.71).

$$\psi_{ch,h,Nb} = \frac{h_{ef} + f}{4c_1} \leq \frac{2c_1 + f}{4c_1} \leq 1 \quad (7.71)$$

where

f is the distance between the anchor head and the lower surface of the concrete member (see Figure 7.21).

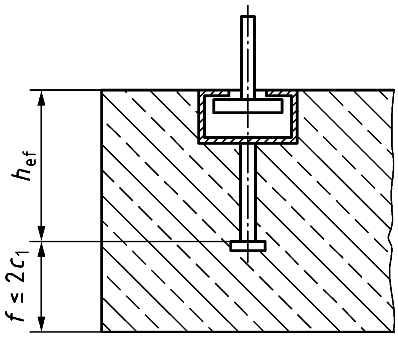


Figure 7.21 — Anchor channel at the edge of a thin concrete member

7.4.1.8 Failure of supplementary reinforcement

7.4.1.8.1 Steel failure

In case of steel failure of the supplementary reinforcement the relevant provision of 7.2.1.9.1 applies.

7.4.1.8.2 Anchorage failure

In case of anchorage failure of the supplementary reinforcement in the concrete cone the relevant provision of 7.2.1.9.2 applies.

7.4.2 Shear load

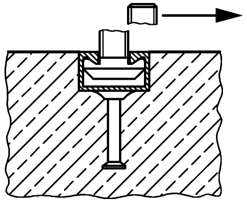
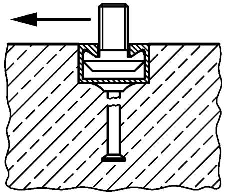
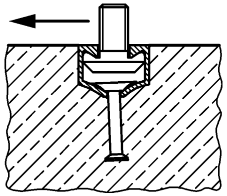
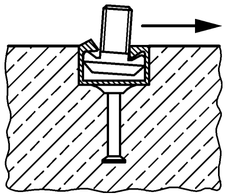
7.4.2.1 Required verifications

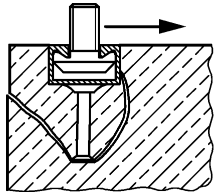
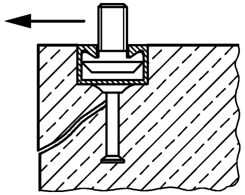
The verifications of Table 7.5 apply. The failure modes addressed are shown in this table.

7.4.2.2 Detailing of supplementary reinforcement

Supplementary reinforcement to take up shear loads shall only comprise surface reinforcement (see Figure 7.10 a)) and the corresponding provisions of 7.2.2.2 apply.

Table 7.5 — Verifications for anchor channels loaded in shear

	Failure mode			Channel	Most unfavourable anchor or channel bolt	
1	**Steel failure**	**Shear force without lever arm**	channel bolt[a]		$V_{Ed}^{cb} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	
2			anchor		$V_{Ed}^{a} \leq V_{Rd,s,a} = \frac{V_{Rk,s,a}}{\gamma_{Ms}}$	
3			connection between anchor and channel		$V_{Ed}^{a} \leq V_{Rd,s,c} = \frac{V_{Rk,s,c}}{\gamma_{Ms,ca}}$	
4			local flexure of channel lip[a]	$V_{Ed}^{cb} \leq V_{Rd,s,l} = \frac{V_{Rk,s,l}}{\gamma_{Ms,l}}$		
5		**Shear force with lever arm**	channel bolt		$V_{Ed}^{cb} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	

	Failure mode	Channel	Most unfavourable anchor or channel bolt	
6	**Concrete pry-out failure[b]**		$V_{Ed}^{a} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$	
7	**Concrete edge failure[b]**		$V_{Ed}^{a} \leq V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$	
8	**Steel failure of supplementary reinforcement[c]**		$N_{Ed,re}^{a} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
9	**Anchorage failure of supplementary reinforcement[c]**		$N_{Ed,re}^{a} \leq N_{Rd,a}$	

[a] Verification for most loaded channel bolt.

[b] The load on the anchor in conjunction with the edge distance and spacing shall be considered in determining the most unfavourable anchor.

[c] The tension force acting on the reinforcement shall be calculated from V_{Ed} according to Formula (6.6) for the most loaded anchor.

7.4.2.3 Steel failure

7.4.2.3.1 Shear force without lever arm

(1) The characteristic resistances $V_{Rk,s}$ (failure of channel bolt), $V_{Rk,s,a}$ (failure of anchor), $V_{Rk,s,c}$ (failure of connection anchor/channel) and $V^0_{Rk,s,l}$ (basic value for failure due to local flexure of channel lips) are given in the relevant European Technical Product Specification.

(2) The characteristic resistance $V_{Rk,s,l}$ for lip failure is:

$$V_{Rk,s,l} = V^0_{Rk,s,l} \cdot \psi_{l,V} \tag{7.72}$$

with

$$\psi_{l,V} = 0,5\left(1 + \frac{s_{cbo}}{s_{l,V}}\right) \le 1 \tag{7.73}$$

where

s_{cbo} is the spacing of channel bolts

$s_{l,V}$ is the characteristic spacing for channel lip failure under shear, taken from the European Technical Product Specification.

As indicative value $s_{l,V} = 2\ b_{ch}$ may be used.

7.4.2.3.2 Shear force with lever arm

The characteristic resistance of a channel bolt in case of steel failure, $V_{Rk,s,M}$, shall be obtained from Formula (7.74).

$$V_{Rk,s,M} = \frac{\alpha_M \cdot M_{Rk,s}}{l_a} \tag{7.74}$$

where

α_M is determined according to 6.2.2.3

$$M_{Rk,s} = M^0_{Rk,s} \cdot \left(1 - N_{Ed} / N_{Rd,s}\right) \tag{7.75}$$

$$N_{Rd,s} = N_{Rk,s} / \gamma_{Ms}$$

$M^0_{Rk,s}$ is the characteristic bending resistance of the channel bolt, given in the relevant European Technical Product Specification

NOTE The influence of the shear load with lever arm on lip failure is covered by the prequalification of the anchor channel.

7.4.2.4 Concrete pry-out failure

The characteristic resistance of the most unfavourable anchor for concrete pry-out failure shall be calculated according to Formula (7.76):

— for fastenings without supplementary reinforcement

$$V_{\mathrm{Rk,cp}} = k_8 \cdot N_{\mathrm{Rk,c}} \tag{7.76a}$$

where

k_8 is a factor to be taken from the relevant European Technical Product Specification;

$N_{\mathrm{Rk,c}}$ is determined according to 7.4.1.5 for the anchors loaded in shear.

— for fastenings with supplementary reinforcement

$$V_{\mathrm{Rk,cp}} = 0{,}75 \cdot k_8 \cdot N_{\mathrm{Rk,c}} \tag{7.76b}$$

7.4.2.5 Concrete edge failure

(1) The characteristic resistance of one anchor loaded perpendicular to the edge is calculated according to Formula (7.77):

$$V_{\mathrm{Rk,c}} = V^0_{\mathrm{Rk,c}} \cdot \psi_{\mathrm{ch,s,V}} \cdot \psi_{\mathrm{ch,c,V}} \cdot \psi_{\mathrm{ch,h,V}} \cdot \psi_{\mathrm{ch,90°,V}} \cdot \psi_{\mathrm{re,V}} \tag{7.77}$$

The different factors of Formula (7.77) are given below.

(2) The basic characteristic resistance of an anchor channel with one anchor loaded perpendicular to the edge not influenced by neighbouring anchors, member thickness or corner effects is:

$$V^0_{\mathrm{Rk,c}} = k_{12} \cdot \sqrt{f_{\mathrm{ck}}} \cdot c_1^{4/3} \tag{7.78}$$

with

k_{12} = $k_{\mathrm{cr,V}}$ for cracked concrete

= $k_{\mathrm{ucr,V}}$ for uncracked concrete,

$k_{\mathrm{cr,V}}$ and $k_{\mathrm{ucr,V}}$ are given in the relevant European Technical Product Specification.

NOTE An indicative value $k_{\mathrm{cr,V}}$ = 4,5 or $k_{\mathrm{ucr,V}}$ = 6,3 can be used where $h_{\mathrm{ch}} / h_{\mathrm{ef}} \le 0{,}4$ and $b_{\mathrm{ch}} / h_{\mathrm{ef}} \le 0{,}7$.

(3) The influence of neighbouring anchors on the concrete edge resistance is taken into account by the factor $\psi_{\mathrm{ch,s,V}}$ according to Formula (7.79):

$$\psi_{\mathrm{ch,s,V}} = \frac{1}{1 + \sum_{i=1}^{n_{\mathrm{ch,V}}} \left[\left(1 - \frac{s_i}{s_{\mathrm{cr,V}}}\right)^{1{,}5} \cdot \frac{V_i}{V_0} \right]} \le 1 \tag{7.79}$$

where (see Figure 7.22):

s_i is the distance between the anchor under consideration and the neighbouring anchors $\le s_{\mathrm{cr,V}}$

$$s_{cr,V} = 4 \cdot c_1 + 2b_{ch}\text{, where the conditions } h_{ch} / h_{ef} \leq 0{,}4 \text{ and } b_{ch} / h_{ef} \leq 0{,}7 \text{ are fulfilled} \quad (7.80)$$

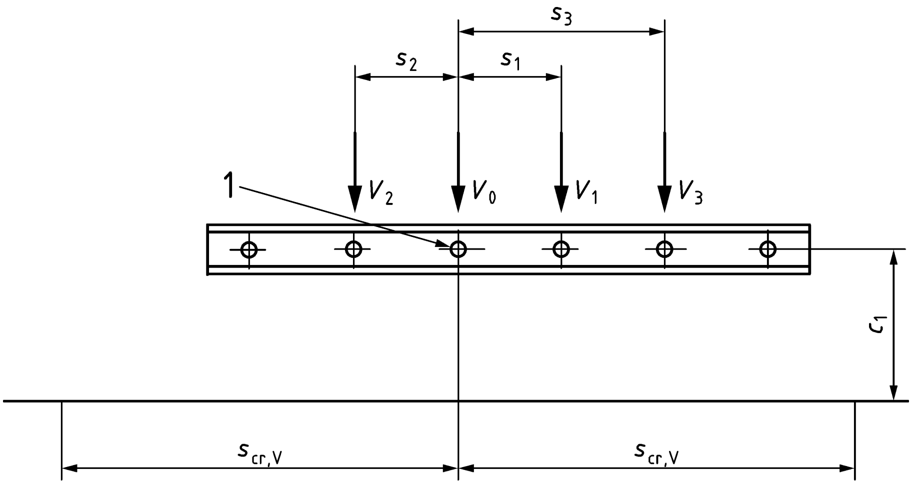
$s_{cr,V}$ to be taken from the relevant European Technical Product Specification if $h_{ch} / h_{ef} > 0{,}4$ and/or $b_{ch} / h_{ef} > 0{,}7$. $s_{cr,V}$ used in design shall not be smaller than the value according to Formula (7.80)

V_i is the shear force on an influencing anchor;

V_0 is the shear force on the anchor under consideration;

$n_{ch,V}$ is the number of anchors within a distance $s_{cr,V}$ to both sides of the anchor under consideration.

In Formula (7.79) it is assumed that all shear forces acting on the anchors are directed towards the edge. Shear forces on anchors acting away from the edge may be neglected.



Key

1 anchor under consideration

Figure 7.22 — Anchor channel with different anchor shear forces — Example

(4) The influence of a corner on the characteristic edge resistance is taken into account by the factor $\psi_{ch,c,V}$

$$\psi_{ch,c,V} = \left(\frac{c_2}{c_{cr,V}} \right)^{0,5} \leq 1 \quad (7.81)$$

where

$$c_{cr,V} = 0{,}5 s_{cr,V} \quad (7.82)$$

If an anchor is influenced by two corners (see Figure 7.23 b)), the factor $\psi_{ch,c,V}$ according to Formula (7.81) shall be calculated for each corner and the product shall be inserted in Formula (7.77).

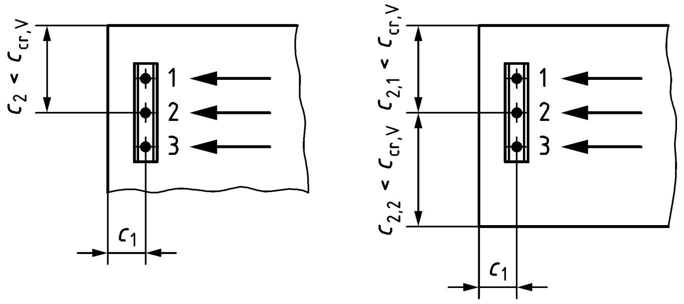


Figure 7.23 — Anchor channel with anchors influenced by one (a) or two (b) corners, anchor 2 is under consideration – Example

(5) The influence of a member thickness $h < h_{cr,V}$ is taken into account by the factor $\psi_{ch,h,V}$.

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0,5} \leq 1 \tag{7.83}$$

with

$h_{cr,V} = 2\,c_1 + 2\,h_{ch}$ (see Figure 7.24) for $h_{ch} / h_{ef} \leq 0,4$ and $b_{ch} / h_{ef} \leq 0,7$ are fulfilled (7.84)

$h_{cr,V}$ to be taken from the relevant European Technical Product Specification if $h_{ch} / h_{ef} > 0,4$ and/or $b_{ch} / h_{ef} > 0,7$. The value $h_{cr,V}$ used in design shall not be smaller than the value according to Formula (7.84).

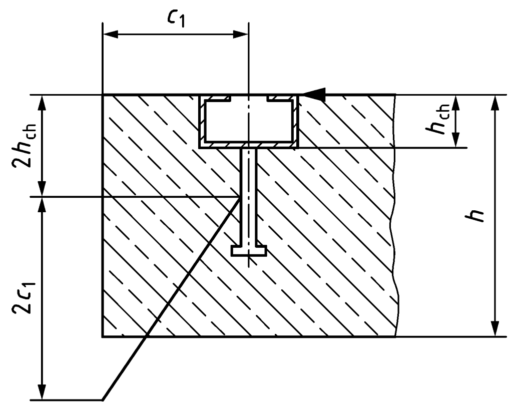


Figure 7.24 — Anchor channel influenced by the member thickness – Example

(6) The factor $\psi_{ch,90°,V}$ takes into account the influence of shear loads acting parallel to the edge (see Figure 7.25).

$$\psi_{ch,90°,V} = 2,5 \tag{7.85}$$

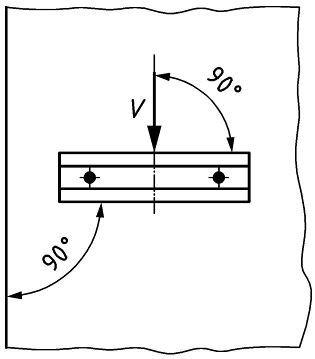


Figure 7.25 — Anchor channel loaded parallel to the edge

(7) The factor $\psi_{re,V}$ accounting for the type of reinforcement on the edge is calculated according to 7.2.2.5. In case of presence of edge reinforcement for applications in cracked concrete a factor $\psi_{re,V} > 1$ shall only be used, if the height of the channel is $h_{ch} \leq 40$ mm (see Figure 6.8 b)).

(8) For an anchor channel in a narrow, thin member (see Figure 7.26) with $c_{2,max} \leq c_{cr,V}$ ($c_{cr,V}$ according to Formula (7.82)) and $h < h_{cr,V}$ ($h_{cr,V}$ according to Formula (7.84)), the calculation according to Formula (7.77) leads to conservative results. More precise results are achieved if the edge distance c_1 is replaced by c_1':

$$c_1' = \max\left\{\left(c_{2,max} - b_{ch}\right) / 2; \left(h - 2h_{ch}\right) / 2\right\} \tag{7.86}$$

with

$c_{2,max} = \max\left\{c_{2,1}; c_{2,2}\right\}$, i.e. the largest of the two edge distances parallel to the direction of load

The value c_1' is inserted in Formulae (7.78), (7.80), and (7.84).

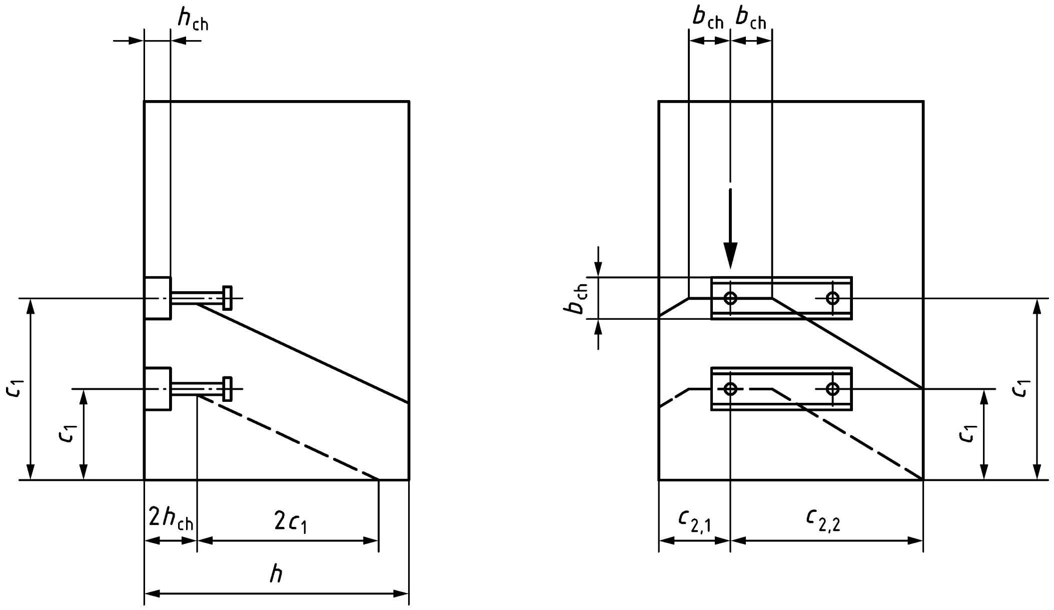


Figure 7.26 — Illustration of an anchor channel influenced by two corners and member thickness

($c_{2,2}$ is decisive for the determination of c'_1)

7.4.2.6 Supplementary reinforcement

7.4.2.6.1 Steel failure

In case of steel failure of the supplementary reinforcement the relevant provision of 7.2.2.6.2 applies.

7.4.2.6.2 Anchorage failure

In case of anchorage failure of the supplementary reinforcement in the concrete cone the relevant provision of 7.2.2.6.3 (2) applies.

7.4.3 Combined tension and shear loads

7.4.3.1 Anchor channels without supplementary reinforcement

The required verifications are given in Table 7.6. Verifications for steel failure of channel bolt, other steel failure modes and failure modes other than steel failure are carried out separately. All verifications shall be fulfilled.

Table 7.6 — Required verifications for anchor channels without supplementary reinforcement subjected to a combined tension and shear load

	Failure mode		Verification
1	**Steel failure**	channel bolt [a]	$\left(\frac{N_{Ed}^{cb}}{N_{Rd,s}}\right)^{2} + \left(\frac{V_{Ed}^{cb}}{V_{Rd,s}}\right)^{2} \le 1$ (7.87) $N_{Rd,s}$, $V_{Rd,s}$ of the channel bolt shall be calculated from the characteristic values given in the relevant European Technical Product Specification.
2		channel lips and flexural failure of channel	$\max\left(\frac{N_{Ed}^{cb}}{N_{Rd,s,l}};\frac{M_{Ed}^{ch}}{M_{Rd,s,flex}}\right)^{k_{13}} + \left(\frac{V_{Ed}^{cb}}{V_{Rd,s,l}}\right)^{k_{13}} \le 1$ (7.88) with k_{13} = 2,0 if $V_{Rd,s,l} \le N_{Rd,s,l}$ = to be taken from the European Technical Product Specification if $V_{Rd,s,l} > N_{Rd,s,l}$ = 1,0 as a simplification $N_{Rd,s,l}$, $M_{Rd,s,flex}$ and $V_{Rd,s,l}$ shall be calculated from the characteristic values given in the relevant European Technical Product Specification.
3		anchor and connection between anchor and channel	$\max\left(\frac{N_{Ed}^{a}}{N_{Rd,s,a}};\frac{N_{Ed}^{a}}{N_{Rd,s,c}}\right)^{k_{14}} + \left(\frac{V_{Ed}^{a}}{V_{Rd,s,a}}\right)^{k_{14}} \le 1$ (7.89) with k_{14} = 2,0 if $V_{Rd,s,a} \le \min\left(N_{Rd,s,a}, N_{Rd,s,c}\right)$ = to be taken from the European Technical Product Specification if $V_{Rd,s,a} > \min\left(N_{Rd,s,a}, N_{Rd,s,c}\right)$ = 1,0 as a simplification $N_{Rd,s,a}$, $N_{Rd,s,c}$ and $V_{Rd,s,a}$ shall be calculated from the characteristic values given in the relevant European Technical Product Specification.
4	**Failure modes other than steel failure**		$\left(\frac{N_{Ed}^{a}}{N_{Rd}}\right)^{1,5} + \left(\frac{V_{Ed}^{a}}{V_{Rd}}\right)^{1,5} \le 1$ (7.90) or $\left(\frac{N_{Ed}^{a}}{N_{Rd}}\right) + \left(\frac{V_{Ed}^{a}}{V_{Rd}}\right) \le 1,2$ (7.91) $N_{Ed}^{a} / N_{Rd} \le 1$ and $V_{Ed}^{a} / V_{Rd} \le 1$ The largest value of $N_{Ed}^{a} / N_{Rd,i}$ and $V_{Ed}^{a} / V_{Rd,i}$ for the different failure modes shall be inserted for N_{Ed}^{a} / N_{Rd} and V_{Ed}^{a} / V_{Rd}, respectively.

[a] This verification is not required in case of shear load with lever arm as Formula (7.75) accounts for the interaction.

7.4.3.2 Anchor channels with supplementary reinforcement

(1) For anchor channels with supplementary reinforcement to take up both tension and shear loads 7.4.3.1 applies. However, for the verification according to Table 7.6, line 4 $N_{Ed}/N_{Rd,i}$ for concrete cone failure mode (tension) and $V_{Ed}/V_{Rd,i}$ for concrete edge failure mode (shear) are both replaced by the corresponding values for failure of supplementary reinforcement.

(2) In the case of anchor channels at the edge with supplementary reinforcement to take up tension or shear loads, 7.4.3.1 applies. However, Formula (7.92) shall be used instead of Formula (7.90) or Formula (7.91).

$$\left(\frac{N_{Ed}^{a}}{N_{Rd,i}}\right)+\left(\frac{V_{Ed}^{a}}{V_{Rd,i}}\right)\leq 1 \qquad (7.92)$$

In case of fastenings with supplementary reinforcement to take up tension loads only, $N_{Rd,i}$ and $V_{Rd,i}$ represent the design resistances $N_{Rd,p}$, $N_{Rd,sp}$, $N_{Rd,cb}$, $N_{Rd,re}$, $N_{Rd,a}$, and $V_{Rd,c}$, $V_{Rd,cp}$, respectively. If supplementary reinforcement is used to take up shear loads only, $N_{Rd,i}$ and $V_{Rd,i}$ represent the design resistances $N_{Rd,p}$, $N_{Rd,c}$, $N_{Rd,sp}$, $N_{Rd,cb}$ and $V_{Rd,cp}$, $N_{Rd,re}$, $N_{Rd,a}$, respectively.

8 Verification of ultimate limit state for fatigue loading

8.1 General

(1) This EN covers applications with post-installed fasteners and headed fasteners under pulsating tension or shear load and alternating shear load and combinations thereof.

(2) Only fastenings with shear load without lever arm as defined in 6.2.2.3 (1) are covered.

(3) Fasteners only qualified for use in redundant non-structural systems (see 7.3) are not covered.

(4) Fatigue verification shall be carried out when fasteners are subjected to frequently repeated load cycles (e.g. fastening of cranes, reciprocating machinery, guide rails of elevators).

(5) Fasteners used to resist fatigue loading shall be prequalified by a European Technical Product Specification for this application.

(6) Annular gaps are not allowed and loosening of the nut or screw shall be avoided. A permanent prestressing force on the fastener shall be present during the service life of the fastener.

(7) The verification of the resistance under fatigue loading consists of both, the verification under static and fatigue loading. Under static loading the fasteners shall be designed using the design methods given in Clause 7. The verifications under fatigue loading are given in 8.3.

8.2 Derivation of forces acting on fasteners – analysis

6.1 and 6.2 apply. However, the restrictions given in 8.1 shall be observed.

8.3 Resistance

8.3.1 Tension load

The required verifications for tension load are summarized in Table 8.1.

Table 8.1 — Required verifications – Tension loading

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	Steel failure	$\gamma_{F,fat} \cdot \Delta N_{Ek} \le \frac{\Delta N_{Rk,s}}{\gamma_{Ms,N,fat}}$	$\gamma_{F,fat} \cdot \Delta N_{Ek}^{h} \le \frac{\psi_{F,N} \cdot \Delta N_{Rk,s}}{\gamma_{Ms,N,fat}}$	
2	Concrete cone failure	$\gamma_{F,fat} \cdot \Delta N_{Ek} \le \frac{\Delta N_{Rk,c}}{\gamma_{Mc,fat}}$		$\gamma_{F,fat} \cdot \Delta N_{Ek}^{g} \le \frac{\Delta N_{Rk,c}}{\gamma_{Mc,fat}}$
3	Pull-out failure [a]	$\gamma_{F,fat} \cdot \Delta N_{Ek} \le \frac{\Delta N_{Rk,p}}{\gamma_{Mp,fat}}$	$\gamma_{F,fat} \cdot \Delta N_{Ek}^{h} \le \frac{\psi_{F,N} \cdot \Delta N_{Rk,p}}{\gamma_{Mp,fat}}$	
4	Concrete splitting failure	$\gamma_{F,fat} \cdot \Delta N_{Ek} \le \frac{\Delta N_{Rk,sp}}{\gamma_{Mc,fat}}$		$\gamma_{F,fat} \cdot \Delta N_{Ek}^{g} \le \frac{\Delta N_{Rk,sp}}{\gamma_{Mc,fat}}$
5	Concrete blow-out failure	$\gamma_{F,fat} \cdot \Delta N_{Ek} \le \frac{\Delta N_{Rk,cb}}{\gamma_{Mc,fat}}$		$\gamma_{F,fat} \cdot \Delta N_{Ek}^{g} \le \frac{\Delta N_{Rk,cb}}{\gamma_{Mc,fat}}$

$\gamma_{F,fat}$, $\gamma_{Mc,fat}$, $\gamma_{Mp,fat}$ according to 4.4

$\gamma_{Ms,N,fat} = \gamma_{Ms,fat}$ according to 4.4.2.3

$\psi_{F,N}$ is the reduction factor applied to the tension resistance to account for the unequal distribution of the tension load acting on the fixture to the individual fasteners of a group
≤ 1, given in the European Technical Product Specification

$\Delta N_{Ek} = N_{Ek,max} - N_{Ek,min}$, peak to peak amplitude of the fatigue tensile action blow-out for $2 \cdot 10^{6}$ load cycles

$N_{Rk,c}$, $N_{Rk,sp}$, $N_{Rk,cb}$ are calculated according to 7.2.1

$\Delta N_{Rk,s}$ is the fatigue resistance, tension, steel, given in the European Technical Product Specification

$\Delta N_{Rk,c} = 0{,}5 \cdot N_{Rk,c}$, fatigue resistance, tension, concrete cone for $2 \cdot 10^{6}$ load cycles

$\Delta N_{Rk,p}$ is the fatigue resistance, tension, pull-out, given in the European Technical Product Specification

$\Delta N_{Rk,sp} = 0{,}5 \cdot N_{Rk,sp}$, fatigue resistance, tension, concrete splitting for $2 \cdot 10^{6}$ load cycles

$\Delta N_{Rk,cb} = 0{,}5 \cdot N_{Rk,cb}$, fatigue resistance, tension, concrete

[a] Pull-out failure addresses post-installed mechanical fasteners, headed fasteners and post-installed bonded expansion fasteners.

8.3.2 Shear load

The required verifications for shear load are summarized in Table 8.2.

Table 8.2 — Required verifications – Shear loading

	Failure mode	Single fastener	Group of fasteners	
			most loaded fastener	group
1	**Steel failure without lever arm**	$\gamma_{F,fat} \cdot \Delta V_{Ek} \le \frac{\Delta V_{Rk,s}}{\gamma_{Ms,V,fat}}$	$\gamma_{F,fat} \cdot \Delta V_{Ek}^{h} \le \frac{\psi_{F,V} \cdot \Delta V_{Rk,s}}{\gamma_{Ms,V,fat}}$	
2	**Concrete pry-out failure**	$\gamma_{F,fat} \cdot \Delta V_{Ek} \le \frac{\Delta V_{Rk,cp}}{\gamma_{Mc,fat}}$		$\gamma_{F,fat} \cdot \Delta V_{Ek}^{g} \le \frac{\Delta V_{Rk,cp}}{\gamma_{Mc,fat}}$
3	**Concrete edge failure**	$\gamma_{F,fat} \cdot \Delta V_{Ek} \le \frac{\Delta V_{Rk,c}}{\gamma_{Mc,fat}}$		$\gamma_{F,fat} \cdot \Delta V_{Ek}^{g} \le \frac{\Delta V_{Rk,c}}{\gamma_{Mc,fat}}$

$\gamma_{F,fat}$, $\gamma_{Mc,fat}$ according to 4.4

$\psi_{F,V}$ is the reduction factor applied to the shear resistance to account for the unequal distribution of the shear load acting on the fixture to the individual fasteners of a group

≤ 1, given in the European Technical Product Specification. For groups with 2 fasteners under shear load perpendicular to the axis of the fasteners when the fixture is not restrained against in-plane rotation $\psi_{F,V} = 1$.

$\gamma_{Ms,V,fat} = \gamma_{Ms,fat}$ according to 4.4.2.3

$\Delta V_{Ek} = V_{Ek,max} - V_{Ek,min}$, peak to peak amplitude of the fatigue shear action

$\Delta V_{Rk,s}$ is the fatigue resistance, shear, steel, given in the European Technical Product Specification

$\Delta V_{Rk,cp} = 0,5 \cdot V_{Rk,cp}$ fatigue resistance, shear, concrete pry-out failure for $2 \cdot 10^6$ load cycles

$\Delta V_{Rk,c} = 0,5 \cdot V_{Rk,c}$, fatigue resistance, shear, concrete edge failure for $2 \cdot 10^6$ load cycles

$V_{Rk,cp}$, $V_{Rk,c}$ are calculated according to 7.2.2

8.3.3 Combined tension and shear load

For combined tension and shear loading the following formulae shall be satisfied for steel failure and failure modes other than steel failure separately:

$$\left(\beta_{N,fat}\right)^{\alpha} + \left(\beta_{V,fat}\right)^{\alpha} \le 1 \tag{8.1}$$

with

$$\beta_{N,fat} = \frac{\gamma_{F,fat} \cdot \Delta N_{Ek}}{\psi_{F,N} \cdot \Delta N_{Rk} / \gamma_{M,fat}} \le 1 \tag{8.2}$$

$$\beta_{V,fat} = \frac{\gamma_{F,fat} \cdot \Delta V_{Ek}}{\psi_{F,V} \cdot \Delta V_{Rk} / \gamma_{M,fat}} \le 1 \tag{8.3}$$

where

$\psi_{F,N}$, $\psi_{F,V}$ are defined in Tables 8.1 and 8.2

α $= \alpha_s$ for verification of steel failure

$= \alpha_c$ for verification of failure modes other than steel failure

α_s and α_c are given in the European Technical Product Specification

ΔN_{Ek}, ΔV_{Ek}, ΔN_{Rk}, ΔV_{Rk} are defined in Tables 8.1 and 8.2.

In Formula (8.1) the largest value of $\beta_{N,fat}$ and $\beta_{V,fat}$ for the different failure modes under consideration shall be taken.

9 Verification for seismic loading

9.1 General

(1) This Clause provides requirements for the design of post-installed fasteners and cast-in headed fasteners used to transmit seismic actions by means of tension, shear, or a combination of tension and shear loads between connected structural elements or between non-structural attachments and structural elements.

(2) In cases of very low seismicity according to EN 1998-1:2004, 3.2.1 (5), fasteners may be designed as for permanent and transient situations (see Clauses 4 to 7, 11).

(3) For the seismic design situation at the ultimate limit state where the seismic design tension load applied to a single fastener or a group of fasteners is equal to or less than 20 % of the total design tensile load for the same load combination, the tension component acting on a single fastener or a group of fasteners may be verified omitting the requirements given in 9.2 (3).

(4) For the seismic design situation at the ultimate limit state where the seismic design shear component of the design load applied to a single fastener or a group of fasteners is equal to or less than 20 % of the total design shear load for the same load combination, the shear component acting on a single fastener or a group of fasteners may be verified omitting the requirements given in 9.2 (3).

(5) Fastenings in stand-off installation or with a grout layer $\geq 0{,}5\,d$ as well as fasteners qualified for multiple use only (see 7.3) are not covered.

(6) Detailed information on the design of fasteners under seismic actions is given in normative Annex C.

9.2 Requirements

(1) Fasteners used to resist seismic actions shall meet all applicable requirements for non-seismic applications.

(2) Only fasteners qualified for cracked concrete and seismic applications shall be used (see relevant European Technical Product Specification).

(3) In the design of fastenings one of the following options a1), a2) or b) shall be satisfied.

a) Design without requirements on the ductility of the fasteners. It shall be assumed that fasteners are non-dissipative elements and they are not able to dissipate energy by means of ductile hysteretic behaviour and that they do not contribute to the overall ductile behaviour of the structure.

a1) Capacity design: The fastener or group of fasteners is designed for the maximum tension and/or shear load that can be transmitted to the fastening based on either the development of a ductile yield mechanism in the fixture or the attached element taking into account strain hardening and material over-strength or the capacity of a non-yielding attached element.

a2) Elastic design: The fastening is designed for the maximum load obtained from the design load combinations that include seismic actions E_{Ed} corresponding to the ultimate limit state (see EN 1998-1) assuming elastic behaviour of the fastening and the structure. Furthermore, uncertainties in the model to derive seismic actions on the fastening shall be taken into account.

b) Design with requirements on the ductility of the fasteners:

This option is applicable only for the tension component of the load acting on the fastener.

The fastener or group of fasteners is designed for the design actions including the seismic actions E_{Ed} corresponding to the ultimate limit state (see EN 1998-1). The tension steel capacity of the fastening shall be smaller than the tension capacity governed by concrete related failure modes. Sufficient elongation capacity of the fasteners is required.

The fasteners should not be accounted for energy dissipation in the global structural analysis or in the analysis of a non-structural element. The contribution of the fastening to the energy dissipation capacity of the structure (see EN 1998-1:2004, 4.2.2) is not addressed within this standard.

Option b) should not be used for the fastening of primary seismic members (see EN 1998-1) due to the possible large non-recoverable displacements of the fastener that may be expected. Unless shear loads acting on the fastening are resisted by additional means, additional fasteners should be provided and designed in accordance with option a1) or a2).

In option b) the fastening may be accounted for energy dissipation if proper justification is provided e.g. by a nonlinear time history (dynamic) analysis (according to EN 1998-1) and the hysteretic behaviour of the fastener is taken from a European Technical Product Specification.

(4) The concrete in the region of the fastening shall be assumed to be cracked when determining design resistances unless it is demonstrated according to Formula (4.4) that the concrete remains uncracked during the seismic event.

(5) The provisions in this section do not apply to the design of fastenings in critical regions of concrete elements where concrete spalling or yielding of the reinforcement might occur during seismic events as e.g. in plastic hinge zones.

(6) Displacement of the fastening shall be accounted for in the design. This requirement needs not to be applied to anchoring of non-structural elements of minor importance. The displacement shall be limited when a rigid connection in the analysis is assumed or when the operability of the attached element during and after an earthquake shall be ensured.

NOTE Fastener displacements for seismic applications at both damage limitation state and ultimate limit state are provided in the relevant European Technical Product Specification for fasteners with seismic performance category C2 as defined in Annex C.

(7) In general, an annular gap between a fastener and its fixture should be avoided in seismic design situations. With fastenings of non-structural elements in minor non-critical applications an annular gap $\left(d_{f} \leq d_{f,1}\right)$ is allowed. The effect of the annular gap on the behaviour of fastenings shall be taken into account (see Annex C).

(8) Loosening of the nut or screw shall be prevented by appropriate measures.

9.3 Derivation of forces acting on fasteners

(1) The design value of the effect of seismic actions E_{Ed} acting on the fixture shall be determined according to EN 1998-1 and its additional parts. Additional provisions are given in Annex C.

NOTE National rules for the determination of seismic action effects for use in a Country or parts of a Country may be found in its National Annex of EN 1998-1:2004.

(2) Distribution of forces to the individual fasteners of a group shall be in accordance with Clause 6 if the base plate remains elastic in the seismic design situation.

9.4 Resistance

(1) The seismic characteristic resistance $R_{k,eq}$ of a fastening shall be determined in accordance with Annex C taking into account the seismic reduction factors α_{gap} and α_{eq}. The basic characteristic seismic resistances for steel, pull-out and combined pull-out and concrete failure under tension load and steel failure under shear load are given in the relevant European Technical Product Specification. For all other failure modes $R_{k,eq}$ shall be determined based on the characteristic resistance obtained for the persistent and transient design situation according to Clause 7 as described in Annex C.

(2) The partial factors for resistance $\gamma_{M,eq}$ shall be determined according to 4.4.2.

10 Verification for fire resistance

(1) The verification of fasteners under fire exposure shall include all failure modes of the cold state (see Clause 7).

(2) The relevant requirements of EN 1992-1-2, e.g. partial factors and load combinations, shall be observed.

(3) Informative Annex D provides a design method for cast-in-place headed fasteners, anchor channels and post-installed fasteners exposed to fire.

11 Verification of serviceability limit state

(1) For the required verifications see 4.2 and 4.3.

(2) The admissible displacement C_d shall be evaluated by the designer taking into account the type of application in question (e.g. the structural element to be fastened). It may be assumed that the displacements C_d are a linear function of the applied load. In case of combined tension and shear loads, the displacements for the shear and tension components of the resultant load shall be added vectorially.

(3) The characteristic displacement of the fastener located in cracked or uncracked concrete under given tension and shear loads shall be taken from the relevant European Technical Product Specification.

(4) Loading on fastenings with supplementary reinforcement may induce cracks locally at serviceability limit state. However, the crack widths are generally acceptable as they are implicitly accounted for in the detailing requirements of the supplementary reinforcement.

Annex A
(normative)

Additional rules for verification of concrete elements due to loads applied by fastenings

A.1 General

(1) Compliance with the design methods given in this document will result in satisfactory transmission of the loads on the fixture to the concrete member.

(2) Safe transmission of the fastener loads by the concrete member to its supports shall be demonstrated for the ultimate limit state and the serviceability limit state according to EN 1992-1-1. The provisions in A.2 clarify the methods of complying with EN 1992-1-1:2004, 6.2.1 (9).

(3) Loads applied to the underside of a precast element with added structural topping may be assumed to be transferred to the whole of the composite construction only if

a) adequate shear reinforcement is provided at the interface between the precast element and the *in situ* topping, in cases where the fasteners are attached only to the precast element; or

b) h_{ef} is assumed to be the depth of the fasteners embedded in the topping.

In other cases only light ceilings or similar construction (with unit loading not exceeding 1 kN/m²) may be fastened to the precast elements.

A.2 Verification of the shear resistance of the concrete member

A.2.1 In the following it is assumed that the fastener loads are applied to the tension face of a concrete element.

A.2.2 No additional verification for local transmission of loads is required, if one of the following conditions is met.

a) The design shear force V_{Ed} at the support caused by the design actions including the design fastener loads is

$$V_{Ed} \leq 0{,}8\, V_{Rd,c} \quad \text{for a member without shear reinforcement} \quad (A.1)$$

$$\leq 0{,}8 \min\left(V_{Rd,s}\,;\, V_{Rd,max}\right) \quad \text{for a member with shear reinforcement} \quad (A.2)$$

where

$V_{Rd,c}$, $V_{Rd,s}$, $V_{Rd,max}$ are the shear resistances according to EN 1992-1-1

b) Under the characteristic combination of actions on the fixture, the resultant characteristic tension force N_{Ek} of the tensioned fasteners is $N_{Ek} \leq 30$ kN and the spacing a between the outermost fasteners of adjacent groups or between the outer fasteners of a group and individual fasteners satisfies Formula (A.3):

$$a \geq 200\sqrt{N_{Ek}} \quad (A.3)$$

with

N_{Ek} [kN]

c) The fastener design loads are taken up by additional hanger reinforcement, which encloses the tension reinforcement and is anchored at the opposite side of the concrete member. Its distance from an individual fastener or the outermost fasteners of a group shall be smaller than h_{ef}. Hanger reinforcement already present in the structure and underutilized may be used for this purpose.

d) The embedment depth of the fastener is $h_{ef} \geq 0{,}8 \cdot h$.

A.2.3 If no condition of A.2.2 is fulfilled, the design shear forces $V_{Ed,a}$ at the support caused by fastener loads shall fulfill the following condition.

$$V_{Ed,a} \leq 0{,}4\, V_{Rd,c} \quad \text{for a member without shear reinforcement} \tag{A.4}$$

$$\leq 0{,}4 \cdot \min\left(V_{Rd,s}; V_{Rd,max}\right) \quad \text{for a member with shear reinforcement} \tag{A.5}$$

When calculating $V_{Ed,a}$ the fastener loads shall be assumed as point loads with a width of load application $t_1 = s_{t1} + 2h_{ef}$ and $t_2 = s_{t2} + 2h_{ef}$ with s_{t1} (s_{t2}) equal to the spacing between the outer fasteners of a group in direction 1 (2). The active width over which the shear force is transmitted shall be calculated according to the theory of elasticity.

A.2.4 If under the characteristic combination of actions on the fixture the resultant characteristic tension force N_{Ek} of the tensioned fasteners in a group is $N_{Ek} \geq 60$ kN, the conditions in A.2.2 c) or A.2.2 d) shall be complied with.

Annex B
(informative)

Durability

B.1 General

(1) In the absence of better information in National Regulations or in the relevant European Technical Product Specification the provisions of this Annex may be used. These provisions are based on an assumed intended working life of the fastener of 50 years.

(2) Electrolytic corrosion shall be prevented between dissimilar metals by suitable separation or by the choice of compatible materials.

B.2 Fasteners in dry, internal conditions

(1) These conditions are similar to exposure classes X0 and XC1 according to EN 1992-1-1 for dry environment.

(2) In general, no special corrosion protection is necessary for steel parts as coatings provided for preventing corrosion during storage prior to use and to ensure proper functioning are considered sufficient. Malleable cast iron parts in general do not require any protection.

B.3 Fasteners in external atmospheric or in permanently damp internal exposure condition

(1) These conditions are similar to exposure classes XC2, XC3 and XC4 according to EN 1992-1-1.

(2) Stainless steel fasteners of appropriate grade should be used. The grade of stainless steel suitable for the various service environments (marine, industrial, etc.) should be in accordance with existing national rules. In general, austenitic steels with at least 17 % chromium and 12 % nickel and addition of molybdenum e.g. material 1.4401, 1.4404, 1.4571, 1.4578 and 1.4439 according to EN 10088-2, EN 10088-3 or equivalent may be used.

B.4 Fasteners in high corrosion exposure by chloride and sulphur dioxide

(1) The conditions for chlorides are similar to exposure classes XD and XS according to EN 1992-1-1. Examples include permanent, alternating immersion in seawater or the splash zone of seawater, chloride atmosphere of indoor swimming pools, road tunnels or car park decks, where de-icing materials are used.

(2) Examples for exposure to sulphur dioxide are atmosphere with extreme chemical pollution (e.g. in desulphurization plants), where special considerations to corrosion resistance should be given.

(3) The metal parts of the fastener (bolt, screw, nut and washer) should be made of a stainless steel suitable for the high corrosion exposure and shall be in accordance with national rules. In general stainless steel with about 20 % chromium, 20 % nickel and 6 % molybdenum e.g. materials 1.4565, 1.4529 and 1.4547 according to EN 10088-2, EN 10088-3 or equivalent should be used under high corrosion exposure.

Annex C
(normative)

Design of fastenings under seismic actions

C.1 General

(1) This Annex provides detailed requirements for fastenings used to transmit seismic actions in addition to Clause 9.

(2) The following types of connections are distinguished:

— Type 'A' – Connection between structural elements of primary and/or secondary seismic members according to EN 1998-1.

— Type 'B' – Attachment of non-structural elements.

C.2 Performance categories

(1) The seismic performance of fasteners subjected to seismic loading is categorized by performance categories C1 and C2. Performance category C1 provides fastener capacities only in terms of resistances at ultimate limit state, while performance category C2 provides fastener capacities in terms of both resistances at ultimate limit state and displacements at damage limitation state and ultimate limit state. The requirements for category C2 are more stringent compared to those for category C1. The performance category valid for a fastener is given in the corresponding European Technical Product Specification.

(2) Table C.1 relates the seismic performance categories C1 and C2 to the seismicity level and building importance class. The level of seismicity is defined as a function of the product $a_g \cdot S$, where a_g is the design ground acceleration on Type A ground and S the soil factor both in accordance with EN 1998-1.

NOTE The recommended seismic performance categories are given in Table C.1. The value of a_g or that of the product $a_g \cdot S$ used in a Country to define threshold values for the seismicity classes may be found in its National Annex of EN 1998–1. Furthermore the assignment of the seismic performance categories C1 and C2 to the seismicity level and building importance classes in a Country may be found in its National Annex to this EN.

Table C.1 — Recommended seismic performance categories for fasteners

	Seismicity level[a]		Importance Class acc. to EN 1998–1:2004, 4.2.5			
1	Class	$a_g \cdot S^c$	**I**	**II**	**III**	**IV**
2	Very Low[b]	$a_g \cdot S \le 0{,}05\ g$	No seismic performance category required			
3	Low[b]	$0{,}05\ g < a_g \cdot S \le 0{,}1\ g$	C1	C1[d] or C2[e]		C2
4	> low	$a_g \cdot S > 0{,}1\ g$	C1	C2		

[a] The values defining the seismicity levels are subject to a National Annex. The recommended values are given here.

[b] Definition according to EN 1998–1:2004, 3.2.1.

[c] a_g = design ground acceleration on type A ground (see EN 1998–1:2004, 3.2.1),

S = soil factor (see EN 1998–1:2004, 3.2.2).

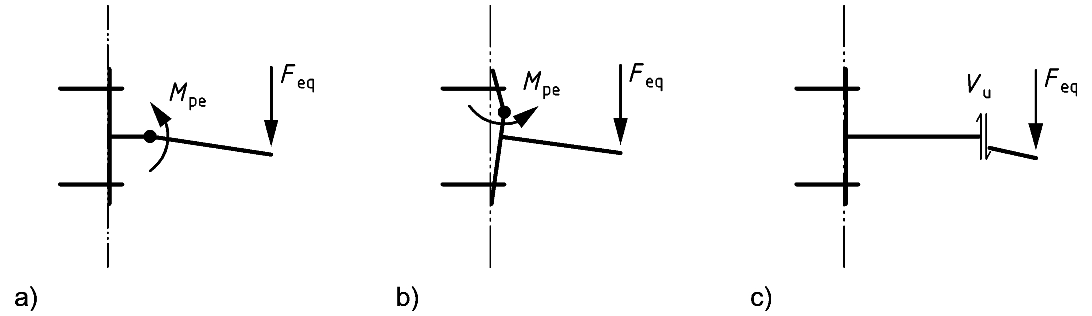
[d] C1 for fixing non-structural elements to structures (Type 'B' connections)

[e] C2 for fixing structural elements to structures (Type 'A' connections)

C.3 Design criteria

(1) For the design of fasteners according to 9.2 (3), option a1) 'capacity design', for both Type ‘A’ and Type ‘B’ connections, the fastening is designed for the maximum load that can be transmitted to the fastening based either on the development of a ductile yield mechanism in the attached steel component (see Figure C.1 a)) or in the steel base plate (see Figure C.1 b)) taking into account strain hardening and material overstrength effects, or on the capacity of a non-yielding attached component or structural element (see Figure C.1 c)).

The assumption of a plastic hinge in the fixture (see Figure C.1 b)) requires to take into account specific aspects including e.g. the redistribution of loads to the individual fasteners of a group, the redistribution of the loads in the structure and the low cycle fatigue behaviour of the fixture.



Key

a) yielding in attached element;

b) yielding in baseplate;

c) capacity of attached element

Figure C.1 — Seismic design by protection of the fastening

(2) For the design of fasteners according to 9.2 (3), option a2) 'elastic design' the action effects for Type 'A' connections shall be derived according to EN 1998-1 with a behaviour factor q = 1,0. For Type 'B' connections the action effects shall be derived with $q_a = 1,0$ for the attached element. q_a is defined as the behaviour factor for non-structural elements. If action effects are derived in accordance with the simplified approach given in C.4.4 with $q_a = 1,0$, they shall be multiplied by an amplification factor equal to 1,5. If the action effects are derived from a more precise model, this additional amplification may be omitted.

(3) For the design of fasteners according to 9.2 (3), option b) 'design with requirements on the ductility of the fastener' the following additional conditions shall be observed.

a) The fastener shall have a European Technical Product Specification that includes a qualification for performance category C2.

b) To ensure steel failure of the fastening, condition (b1) shall be satisfied for fastenings with one fastener in tension and condition (b2) for groups with two and more tensioned fasteners. In addition for groups with two and more tensioned headed fasteners or post-installed mechanical fasteners condition (b3) applies.

NOTE In case of fastenings with supplementary reinforcement, in the verification the resistance for concrete cone failure is replaced by the resistance of the supplementary reinforcement (minimum of steel and anchorage failure).

b1) Fastenings with one fastener in tension:

$$R_{k,s,eq} \leq 0,7 \cdot \frac{R_{k,conc,eq}}{\gamma_{inst}} \tag{C.1}$$

where

$R_{k,s,eq}$ is the minimum characteristic seismic resistance for steel failure calculated according to Formula (C.8)

$R_{k,conc,eq}$ is the minimum characteristic seismic resistance for all concrete related failure modes (concrete cone, pull-out (headed and post-installed mechanical fasteners), combined pull-out and concrete (bonded fasteners), concrete blow-out and concrete splitting failure) calculated according to Formula (C.8)

γ_{inst} is the factor accounting for the sensitivity to installation according to the relevant European Technical Product Specification

b2) For groups of fasteners with two and more tensioned fasteners Formula (C.2) shall be satisfied for the fasteners loaded in tension:

$$\frac{R_{k,s,eq}}{E_d^h} \leq 0,7 \cdot \frac{R_{k,conc,eq}}{E_d^g \cdot \gamma_{inst}} \tag{C.2}$$

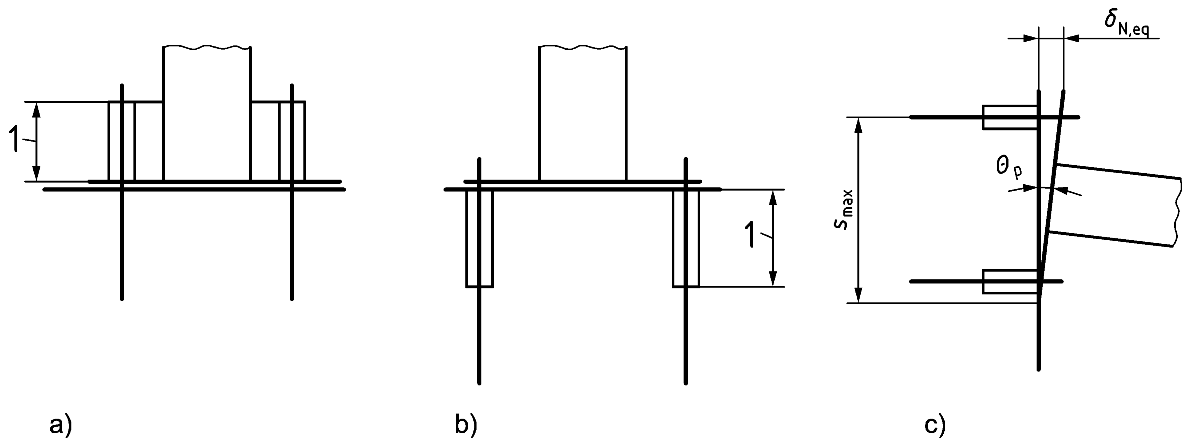
where

$R_{k,conc,eq}$ is the minimum characteristic seismic resistance for concrete cone, combined pull-out and concrete (only bonded fasteners), concrete blow-out and concrete splitting failure calculated according to Formula (C.8) b3) For a group of headed or post-installed mechanical fasteners with two and more tensioned fasteners the highest loaded fastener shall be verified for pull-out failure according to Formula (C.1), where $R_{k,conc,eq}$ is the seismic pull-out resistance of one fastener.

c) Fasteners that transmit tensile loads shall be ductile and shall have a stretch length of at least 8*d* unless otherwise determined by analysis. Illustrations of stretch lengths are shown in Figure C.2 a) and b).

1) A fastener is considered as ductile if the nominal steel ultimate strength of the load transferring section does not exceed $f_{uk} = 800\ \text{N/mm}^2$, the ratio of nominal yield strength to nominal ultimate strength does not exceed $f_{yk} / f_{uk} = 0{,}8$, and the rupture elongation (measured over a length equal to 5*d*) is at least 12 %.

2) The characteristic steel resistance N_{uk} of fasteners that incorporate a reduced section (e.g. thread) over a length smaller than 8 *d* (*d* = fastener diameter of reduced section) shall be greater than 1,3-times the characteristic yield resistance N_{yk} of the unreduced section.



Key

1 stretch length

a) illustration of stretch length – anchor chair;

b) illustration of stretch length – sleeve or debonded length;

c) fastening displacements and rotations

Figure C.2 — Seismic design by yielding of a ductile fastener

C.4 Derivation of forces acting on fasteners – analysis

C.4.1 General

(1) The design value of the effect of seismic actions E_{Ed} acting on the fixture shall be determined according to EN 1998-1 and 9.2 (3). Provisions in addition to EN 1998-1 including vertical seismic actions acting on non- structural elements are provided in this Clause.

(2) The maximum value of each action effect (tension and shear component of forces on a fastener) shall be considered to act simultaneously unless a more accurate model is used for the estimation of the probable simultaneous value of each action effect.

C.4.2 Addition to EN 1998-1:2004, 4.3.3.5

For the design of the fasteners in Type 'A' connections the vertical component of the seismic action shall be taken into account according to EN 1998-1:2004, 4.3.3.5.2 (2) to (4) if the vertical design ground acceleration a_{vg} is greater than 2,5 m/s^2.

C.4.3 Addition to EN 1998-1:2004, 4.3.5.1

In the design of fastenings for non-structural elements subjected to seismic actions, any beneficial effects of friction due to gravity loads should be ignored.

C.4.4 Additions and alterations to EN 1998-1:2004, 4.3.5.2

(1) In cases where EN 1998-1:2004, 4.3.5.1 (3) applies, the horizontal effects of the seismic action of non-structural elements may be determined according to EN 1998-1:2004, Formula (4)). However, the behaviour factor q_a may be taken from Table C.2.

NOTE Table C.2 includes information in addition to the values q_a given in EN 1998-1:2004, Table 4.4. The determination of the seismic action effects of non-structural elements for use in a Country may be found in its National Annex to this EN. The recommended rule is the application of Formula (4.24) of EN 1998-1:2004 in combination with Formula (C.3).

(2) Formula (4.25) of EN 1998-1:2004 may be rearranged as:

$$S_a = \alpha \cdot S \cdot \left[\left(1 + \frac{z}{H} \right) \cdot A_a - 0{,}5 \right] \geq \alpha \cdot S \quad \text{(C.3)}$$

with

$$A_a = \frac{3}{1 + \left(1 - \frac{T_a}{T_1} \right)^2} \quad \text{(C.4)}$$

The seismic amplification factor A_a may be calculated according to Formula (C.4) or taken from Table C.2 if one of the fundamental vibration periods is not known.

NOTE When calculating the forces acting on non-structural elements according to EN 1998-1:2004, Formula (4)), it can be difficult to establish with confidence the fundamental vibration period T_a of the non-structural element. Table C.2 provides a pragmatic approach.

Table C.2 — Values of q_a and A_a for non-structural elements

	Type of non-structural element	q_a	A_a
1	Cantilevering parapets or ornamentations	1,0	3,0
2	Signs and billboards		3,0
3	Chimneys, masts and tanks on legs acting as unbraced cantilevers along more than one half of their total height		3,0
4	Hazardous material storage, hazardous fluid piping		3,0
5	Exterior and interior walls	2,0	1,5
6	Partitions and facades		1,5
7	Chimneys, masts and tanks on legs acting as unbraced cantilevers along less than one half of their total height, or braced or guyed to the structure at or above their centre of mass		1,5
8	Elevators		1,5
9	Computer access floors, electrical and communication equipment		3,0
10	Conveyors		3,0
11	Anchorage elements for permanent cabinets and book stacks supported by the floor		1,5
12	Anchorage elements for false (suspended) ceilings and light fixtures		1,5
13	High pressure piping, fire suppression piping		3,0
14	Fluid piping for non-hazardous materials		3,0
15	Computer, communication and storage racks		3,0

(3) The vertical effects of the seismic action should be determined by applying a vertical force F_{va} to the non- structural element acting at the centre of mass of the non-structural element which is defined as follows:

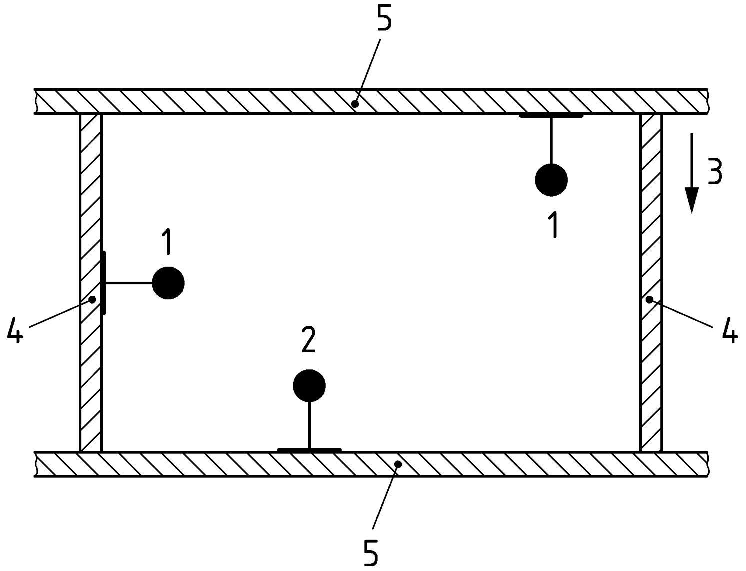
$$F_{va} = \left(S_{Va} \cdot W_a \cdot \gamma_a\right) / q_a \quad (C.5)$$

with

$$S_{Va} = \alpha_v \cdot A_a \quad (C.6)$$

q_a, A_a may be assumed to be equal to the values valid for horizontal forces.

NOTE The vertical effects of the seismic action F_{va} for non-structural elements may be neglected for the fastener when the vertical component of the design ground acceleration a_{vg} is less than 2,5 m/s^2 and the gravity loads are transferred through direct bearing of the fixture on the structure (see fastening 2 in Figure C.3). The determination of the vertical seismic action effects of non-structural elements for use in a Country may be found in its National Annex to this EN. The recommended rule is the application of Formula (C.5).



Key

1 include F_{Va}

2 neglect F_{Va} if $a_{Vg} \leq 2{,}5\ m/s^2$

3 gravity force

4 wall

5 ceiling or floor

Figure C.3 — Vertical effects of the seismic action – Example

C.4.5 Additions and alterations to EN 1998-1:2004, 4.3.5.4

Upper values for the behaviour factor q_a for non-structural elements may be selected from Table C.2.

C.5 Resistance

(1) The seismic design resistance of a fastening is given by:

$$R_{d,eq} = \frac{R_{k,eq}}{\gamma_{M,eq}} \quad (C.7)$$

with

$\gamma_{M,eq}$ in accordance with 4.4.2

(2) The characteristic seismic resistance $R_{k,eq}$ of a fastening shall be determined as follows:

$$R_{k,eq} = \alpha_{gap} \cdot \alpha_{eq} \cdot R^0_{k,eq} \quad (C.8)$$

where

α_{gap} is the reduction factor to take into account inertia effects due to an annular gap between fastener and fixture in case of shear loading, given in the relevant European Technical Product Specification

α_{eq} is the factor to take into account the influence of seismic actions and associated cracking on

a) concrete cone resistance and bond strength of supplementary reinforcement, and

b) resistance of groups due to uneven load transfer to the individual fasteners in a group, see Table C.3;

$R^0_{k,eq}$ is the basic characteristic seismic resistance for a given failure mode determined as follows:

For steel and pull-out failure under tension load and steel failure under shear load $R^0_{k,eq}$ shall be taken from the relevant European Technical Product Specification (i.e. $N_{Rk,s,eq}$, $N_{Rk,p,eq}$, $V_{Rk,s,eq}$).

For combined pull-out and concrete failure in case of post-installed bonded fasteners $R^0_{k,eq}$ shall be determined according to 7.2.1.6 (i.e. $N_{Rk,p}$), however, using the characteristic bond resistance $\left(\tau_{Rk,eq}\right)$ given in the relevant European Technical Product Specification.

For all other failure modes $R^0_{k,eq}$ shall be determined as for the persistent and transient design situation according to Clause 7 (i.e. for tension load: $N_{Rk,c}$, $N_{Rk,sp}$, $N_{Rk,cp}$, $N_{Rk,re}$, $N_{Rk,a} = \gamma_c \cdot N_{Rd,a}$, and for shear load: $V_{Rk,c}$, $V_{Rk,cp}$, $N_{Rk,re}$, $N_{Rk,a} = \gamma_c \cdot N_{Rd,a}$).

The forces on the fasteners are amplified in presence of an annular gap under shear loading due to a hammer effect on the fastener. For reasons of simplicity this effect is considered only in the resistance of the fastening. In absence of information in the European Technical Product Specification the following values α_{gap} may be used, which are based on a limited number of tests.

Shear loading:

α_{gap} = 1,0, no hole clearance between fastener and fixture (general case, see 9.2 (7))

= 0,5, connections with hole clearance according to Table 6.1

(3) The verification for interaction between tension and shear forces shall be carried out analogously to 7.2.3.1 and 7.2.3.2. It shall be determined separately for steel failure and failure modes other than steel failure according to Formula (C.9).

Table C.3 — Reduction factor α_{eq}

Loading	Failure mode	Single fastener[a]	Fastener group
tension	Steel failure	1,0	1,0
	Concrete cone failure — Headed fastener and undercut fasteners with k_1-factor same as headed fastener	1,0	0,85
	— all other fasteners	0,85	0,75
	Pull-out failure	1,0	0,85
	Combined pull-out and concrete failure (bonded fastener)	1,0	0,85
	Concrete splitting failure	1,0	0,85
	Concrete blow-out failure	1,0	0,85
	Steel failure of reinforcement	1,0	1,0
	Anchorage failure of reinforcement	0,85	0,75
shear	Steel failure	1,0	0,85
	Concrete pry-out failure — Headed fastener and undercut fasteners with k_1-factor same as headed fastener	1,0	0,85
	— all other fasteners	0,85	0,75
	Concrete edge failure	1,0	0,85
	Steel failure of reinforcement	1,0	1,0
	Anchorage failure of reinforcement	0,85	0,75

[a] This also applies where only one fastener in a group is subjected to tension load.

$$\left(\frac{N_{Ed}}{N_{Rd,i,eq}}\right)^{k_{15}} + \left(\frac{V_{Ed}}{V_{Rd,i,eq}}\right)^{k_{15}} \leq 1 \qquad \text{(C.9)}$$

where

N_{Ed}, V_{Ed} are the design actions on the fasteners including seismic effects for the corresponding failure modes.

k_{15} = 1 for steel failure

= 2/3 for fastenings with a supplementary reinforcement to take up tension or shear loads only

= 1 in all other cases

NOTE More precise values for k_{15} may be taken from the relevant European Technical Product Specification.

The following values shall be used in Formula (C.9):

— in case of steel failure: $N_{Rd,s,eq}$ and $V_{Rd,s,eq}$ for $N_{Rd,i,eq}$ and $V_{Rd,i,eq}$, respectively.

— in case of failure modes other than steel failure: Largest ratios for $N_{Ed}/N_{Rd,i,eq}$ and $V_{Ed}/V_{Rd,i,eq}$.

C.6 Displacements of fasteners

(1) The displacement of a fastener under tensile and shear loads at damage limitation state (DLS) shall be limited to a value $\delta_{N,req(DLS)}$ and $\delta_{V,req(DLS)}$ to meet requirements regarding e.g. functionality and assumed support conditions. These values shall be selected based on the requirements of the specific application. When assuming a rigid support in the analysis the designer shall establish the limiting displacement compatible to the requirement for the structural behaviour.

NOTE In a number of cases, the acceptable displacement associated with a rigid support condition is considered to be in the range of 3 mm.

(2) If deformations (displacements or rotations) are relevant for the design of the connection (such as, for example, on secondary seismic members or façade elements) it shall be demonstrated that these deformations can be accommodated by the fasteners.

The rotation of the connection θ_p (see Figure C.2 c)) is defined by Formula (C.10):

$$\theta_p = \delta_{N,eq} / s_{max} \tag{C.10}$$

where

$\delta_{N,eq}$ is the displacement of the fastener under seismic loading;

s_{max} is the distance between the outermost row of fasteners and the opposite edge of the baseplate.

(3) If the fastener displacements $\delta_{N,eq(DLS)}$ under tension loading and/or $\delta_{V,eq(DLS)}$ under shear loading provided in the relevant European Technical Product Specification are higher than the corresponding required values $\delta_{N,req(DLS)}$ and/or $\delta_{V,req(DLS)}$, the design resistance may be reduced according to Formula (C.11).

$$N_{Rd,eq,red} = N_{Rd,eq} \cdot \frac{\delta_{N,req(DLS)}}{\delta_{N,eq(DLS)}} \tag{C.11a}$$

$$V_{Rd,eq,red} = V_{Rd,eq} \cdot \frac{\delta_{V,req(DLS)}}{\delta_{V,eq(DLS)}} \tag{C.11b}$$

(4) If fastenings and attached elements shall be operational after an earthquake, the relevant displacements have to be taken into account.

Annex D
(informative)

Exposure to fire – design method

D.1 General

(1) The design method is valid for cast-in-place headed fasteners, anchor channels and post-installed fasteners and it complements EN 1992-1-2.

(2) Fasteners under fire exposure should have a European Technical Product Specification for use in cracked concrete.

(3) The characteristic resistances under fire exposure should be taken from the relevant European Technical Product Specification. In the absence of such data conservative values are given in D.4. However, for anchor channels only concrete and pull-out failure modes should be verified with the given approach, while the verification for steel failure should be based on the values given in the relevant European Technical Product Specification. In case of bonded fasteners under tension the verification for combined bond and concrete failure the value $\tau_{Rk,fi}$ should be taken from the relevant European Technical Product Specification.

(4) The fire resistance is classified according to EN 13501-2 using the Standard ISO time-temperature curve (STC).

(5) The design method covers fasteners with a fire exposure from one side only. For fire exposure from more than one side, the design method may be used only, if the edge distance of the fastener is both, $c \geq 300$ mm and $c \geq 2h_{ef}$.

(6) In general, the design under fire exposure is carried out according to the design method for ambient temperature given in this EN. However, partial factors and characteristic resistances under fire exposure are used instead of the corresponding values under ambient temperature.

(7) Spalling of concrete due to fire exposure shall be prevented by appropriate measures or taken into account in the design.

D.2 Partial factors

(1) The value of the factor accounting for the sensitivity to installation, γ_{inst} , of post-installed fasteners has its origin in the prequalification of the product and is product dependent. Therefore it should not be modified.

(2) Partial factors for materials $\gamma_{M,fi}$ may be found in a Country's National Annex to this EN.

NOTE The recommended value is $\gamma_{M,fi} = 1,0$ for steel failure and concrete related failure modes under shear loading. For concrete related failure modes under tension $\gamma_{M,fi} = 1,0 \cdot \gamma_{inst}$.

D.3 Actions

Actions on fastenings under fire exposure should be determined using the load combinations for accidental loads given in EN 1990.

D.4 Resistance

D.4.1 General

If characteristic resistances under fire exposure are not available in a European Technical Product Specification the conservative values given below may be used.

D.4.2 Tension load

D.4.2.1 Steel failure

The characteristic tension strength $\sigma_{Rk,s,fi}$ of a fastener in case of steel failure under fire exposure given in the following Tables D.1 and D.2 is valid for the unprotected steel part of the fastener outside the concrete and may be used in the design. The characteristic resistance $N_{Rk,s,fi}$ is obtained as:

$$N_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \tag{D.1}$$

Table D.1 — Characteristic tension strength of a carbon steel fastener under fire exposure

Fastener bolt/thread diameter	**Embedment depth h_{ef} [mm]**	**Characteristic tension strength $\sigma_{Rk,s,fi}$ [N/mm²]** of an unprotected fastener made of carbon steel according to the EN 10025 series in case of fire exposure			
		30 min (R15 to R30)	60 min (R45 to R60)	90 min (R90)	120 min (≤ R120)
Ø6	≥ 30	10	9	7	5
Ø8	≥ 30	10	9	7	5
Ø10	≥ 40	15	13	10	8
Ø12 and greater	≥ 50	20	15	13	10

Table D.2 — Characteristic tension strength of a stainless steel fastener under fire exposure

Fastener bolt/thread diameter	**Embedment depth h_{ef} [mm]**	**Characteristic tension strength $\sigma_{Rk,s,fi}$ [N/mm²]** of an unprotected fastener made of stainless steel of at least steel grade A4 according to the EN ISO 3506 series in case of fire exposure			
		30 min (R15 to R30)	60 min (R45 to R60)	90 min (R90)	120 min (≤ R120)
Ø6	≥ 30	10	9	7	5
Ø8	≥ 30	20	16	12	10
Ø10	≥ 40	25	20	16	14
Ø12 and greater	≥ 50	30	25	20	16

D.4.2.2 Concrete cone failure

(1) The characteristic resistance for concrete cone failure should be determined according to 7.2.1.4 (headed and post-installed fasteners) or 7.4.1.4 (anchor channels) with the following modifications.

(2) The characteristic resistance of a single fastener (anchor of anchor channels) not influenced by neighbouring fasteners (anchors) or concrete edges installed in concrete strength classes C20/25 to C50/60 may be obtained according to Formulae (D.2) and (D.3).

$$N^0_{\text{Rk,c,fi}(90)} = \frac{h_{\text{ef}}}{200} \cdot N^0_{\text{Rk,c}} \leq N^0_{\text{Rk,c}} \quad \text{for fire exposure up to 90 min} \qquad \text{(D.2)}$$

$$N^0_{\text{Rk,c,fi}(120)} = 0{,}8\frac{h_{\text{ef}}}{200} \cdot N^0_{\text{Rk,c}} \leq N^0_{\text{Rk,c}} \quad \text{for fire exposure between 90 min and 120 min} \qquad \text{(D.3)}$$

where

h_{ef} is the effective embedment depth;

$N^0_{\text{Rk,c}}$ is the characteristic resistance of a single fastener in cracked concrete C20/25 under ambient temperature according to 7.2.1.4.

(3) The characteristic spacing $s_{\text{cr,N}}$ and edge distance $c_{\text{cr,N}}$ should be taken as follows:

$s_{\text{cr,N}}$ = 2 $c_{\text{cr,N}}$ = 4 h_{ef} (headed and post-installed fasteners)

= 2 $c_{\text{cr,N}}$ according to Formula (7.62) but not smaller than 4 h_{ef} (anchor channels).

D.4.2.3 Pull-out failure

The characteristic resistance of headed and post-installed mechanical fasteners installed in concrete classes C20/25 to C50/60 may be obtained from Formulae (D.4) and (D.5):

$$N_{\text{Rk,p,fi}(90)} = 0{,}25 \cdot N_{\text{Rk,p}} \quad \text{for fire exposure up to 90 minutes} \qquad \text{(D.4)}$$

$$N_{\text{Rk,p,fi}(120)} = 0{,}20 \cdot N_{\text{Rk,p}} \quad \text{for fire exposure between 90 minutes and 120 minutes} \qquad \text{(D.5)}$$

where

$N_{\text{Rk,p}}$ is the characteristic resistance for pull-out failure given in the relevant European Technical Product Specification in cracked concrete C20/25 under ambient temperature

For bonded fastener and bonded expansion fastener the bond resistance under fire exposure depends on the specific product. Currently, no conservative lower bound is available. The characteristic resistance for pull-out failure shall be determined by fire tests.

D.4.2.4 Concrete splitting failure

The assessment of concrete splitting failure due to fire exposure is not required because the splitting forces are assumed to be taken up by the reinforcement.

D.4.2.5 Concrete blow-out failure

The assessment of concrete blow-out failure is not required because of the required edge distance.

D.4.3 Shear load

D.4.3.1 Steel failure

(1) For the characteristic shear strength $\tau_{Rk,s,fi}$ of a fastener in the case of shear load without lever arm and steel failure under fire exposure the values given in Tables D.1 and D.2 for the characteristic tension strength may be used $\left(\tau_{Rk,s,fi} = \sigma_{Rk,s,fi}\right)$. These values apply for the unprotected steel part of the fastener outside the concrete and may be used in the design. The characteristic resistance $V_{Rk,s,fi}$ is obtained as follows:

$$V_{Rk,s,fi} = \sigma_{Rk,s,fi} \cdot A_s \tag{D.6}$$

NOTE Limited numbers of tests have indicated, that the ratio of shear strength to tensile strength increases under fire conditions above that for normal ambient temperature design. Here it is assumed that this ratio is equal to 1,0. This is a discrepancy to the behaviour in the cold state where the ratio is smaller than 1.

(2) The characteristic shear resistance of a fastener in case of shear load with lever arm may be calculated according to 7.2.2.3.2. However, the characteristic tension strength is limited according to D.4.2.1 and the characteristic bending resistance of a single fastener under fire exposure, $M^0_{Rk,s,fi}$, should be obtained from Formula (D.7).

$$M^0_{Rk,s,fi} = 1{,}2 \cdot W_{el} \cdot \sigma_{Rk,s,fi} \tag{D.7}$$

with

$\sigma_{Rk,s,fi}$ according to D.4.2.1.

NOTE This approach is based on assumptions.

D.4.3.2 Concrete pry-out failure

The characteristic resistance in case of fasteners installed in concrete classes C20/25 to C50/60 should be obtained using Formulae (D.8) and (D.9).

$$V_{Rk,cp,fi(90)} = k_8 \cdot N_{Rk,c,fi(90)} \text{ for fire exposure up to 90 min} \tag{D.8}$$

$$V_{Rk,cp,fi(120)} = k_8 \cdot N_{Rk,c,fi(120)} \text{ for fire exposure between 90 min and 120 min} \tag{D.9}$$

where

k_8	is the factor to be taken from the relevant European Technical Product Specification (ambient temperature)
$N_{Rk,c,fi(90)}$, $N_{Rk,c,fi(120)}$	are calculated according to D.4.2.2.

D.4.3.3 Concrete edge failure

(1) The characteristic resistance of a fastening with headed and post-installed fasteners should be calculated according to 7.2.2.5 and of one anchor of an anchor channel according to 7.4.2.5 with the following modification.

(2) The characteristic resistance of a single fastener installed in concrete classes C20/25 to C50/60 should be obtained using Formula (D.10) and (D.11):

$$V^0_{\mathrm{Rk,c,fi}(90)} = 0{,}25 \cdot V^0_{\mathrm{Rk,c}} \quad \text{for fire exposure up to 90 min} \tag{D.10}$$

$$V^0_{\mathrm{Rk,c,fi}(120)} = 0{,}20 \cdot V^0_{\mathrm{Rk,c}} \quad \text{for fire exposure between 90 min and 120 min} \tag{D.11}$$

where

$V^0_{\mathrm{Rk,c}}$ is the initial value of the characteristic resistance of a single fastener in cracked concrete C20/25 under normal ambient temperature according to 7.2.2.5 (for headed and post-installed fasteners) and according to 7.4.2.5 (for anchor channels)

D.4.4 Combined tension and shear load

The verifications according to 7.2.3 for headed and post-installed fasteners and 7.4.3 for anchor channels may be used. However, the design actions and design resistances used in these verifications should correspond to fire exposure.

Annex E
(normative)

Characteristics for the design of fastenings to be provided by European Technical Products Specification

The characteristic values used for the design of fastenings shall be provided by corresponding European Technical Product Specifications. The characteristics of Table E.1 shall be given for fastenings under static loading. For the design of fastenings under fatigue loading the characteristics of Table E.2 and for fastenings under seismic actions the characteristics of Table E.3 are required in addition.

Table E.1 — Characteristics used for the design of fastenings under static loading to be taken from a European Technical Product Specification

Characteristic	Referenced in	Type of fastener			
		Post-installed		Cast-in	
		Mechanical	Bonded	Headed fastener	Anchor channel
h_{ef}	1.3 (2)	x	x	x	x
limitation re concrete strength class	1.5	x	x	x	x
γ_{inst}	4.4.2.1	x	x		
E_s (optional)	6.2.1	x	x	x	x
$N_{Rk,s}$	7.2.1.3	x	x	x	
$k_{cr,N}$; $k_{ucr,N}$	7.2.1.4 (2); 7.4.1.5 (3)	x	x	x	x
$c_{cr,N}$	7.2.1.4 (3)	x	x	x	
$N_{Rk,p}$	7.2.1.5; 7.4.1.4	x		x	x
ψ^0_{sus} ; $\tau_{Rk,cr}$; $\tau_{Rk,ucr}$	7.2.1.6 (2)		x		
c_{min}; s_{min}; h_{min}	7.2.1.7 (1); 7.4.1.6 (1)	x	x	x	x
$c_{cr,sp}$	7.2.1.7 (2); 7.4.1.6 (2)	x	x	x	x
$N^0_{Rk,sp}$	7.2.1.7 (2)	x	x	x	
A_h	7.2.1.8 (2)	(x)		x	
$V^0_{Rk,s}$	7.2.2.3.1 (1)	x	x	x	
k_7	7.2.2.3.1 (2)	x	x	x	

Characteristic	Referenced in	Type of fastener			
		Post-installed		Cast-in	
		Mechanical	Bonded	Headed fastener	Anchor channel
$M^0_{\mathrm{Rk,s}}$	7.2.2.3.2; 7.4.2.3.2	x	x	x	x
k_8	7.2.2.4 (2); 7.4.2.4	x	x	x	x
d_{nom}; l_{f}	7.2.2.5 (6)	x	x	x	
k_{11}	7.2.3.2 (2)	x	x	x	
$N_{\mathrm{Rk,s,a}}$; $N_{\mathrm{Rk,s,c}}$; $N^0_{\mathrm{Rk,s,l}}$; $N_{\mathrm{Rk,s}}$; $M_{\mathrm{Rk,s,flex}}$	7.4.1.3 (1)				x
$s_{\mathrm{l,N}}$	7.4.1.3 (2)				x
$s_{\mathrm{cr,N}}$	7.4.1.5 (1b)				x
$V_{\mathrm{Rk,s}}$; $V_{\mathrm{Rk,s,a}}$; $V_{\mathrm{Rk,s,c}}$; $V^0_{\mathrm{R\,k,s,l}}$	7.4.2.3.1 (1)				x
$s_{\mathrm{l,V}}$	7.4.2.3.1 (2)				x
$k_{\mathrm{cr,V}}$; $k_{\mathrm{ucr,V}}$	7.4.2.5 (2)				x
$s_{\mathrm{cr,V}}$	7.4.2.5 (3)				x
$h_{\mathrm{cr,V}}$	7.4.2.5 (5)				x
k_{13}; k_{14}	7.4.3.1				x
fastener displacement under given tension and shear load	Clause 11 (3)	x	x	x	x
$N_{\mathrm{Rk,s,fi}}$; $V_{\mathrm{Rk,s,fi}}$; $M^0_{\mathrm{Rk,s,fi}}$	D.1 (3)	x	x	x	x
$N_{\mathrm{Rk,p,fi}}$	D.1 (3)	x		x	x
$\tau_{\mathrm{Rk,fi}}$	D.1 (3)		x		
F^0_{Rk}; $M^0_{\mathrm{Rk,s}}$; γ_{M}; γ_{Ms}; s_{cr}; c_{cr}; h_{min}	G.2; G.3	x	x	x	
ψ_{c}; s_{min}; c_{min}	G.2	x	x	x	
γ_{c}; $\gamma_{\mathrm{Ms,l}}$ [a]		x	x	x	x

[a] See Table 4.1 for recommended values; reference to a National Standard should be added.

Table E.2 — Additional characteristics used for the design of fastenings under fatigue loading to be taken from a European Technical Product Specification

Characteristic	Referenced in	Type of fastener			
		Post-installed		Cast-in	
		Mechanical	Bonded	Headed fastener	Anchor channel
$\psi_{F,N}$; $\Delta N_{Rk,s}$; $\Delta N_{Rk,p}$	8.3.1	x	x	x	
$\psi_{F,V}$; $\Delta V_{Rk,s}$	8.3.2	x	x	x	
α_s; α_c	8.3.3	x	x	x	
maximum number of load cycles		x	x	x	

Table E.3 — Additional characteristics used for the design of fastenings under seismic loading to be taken from a European Technical Product Specification

Characteristic	Referenced in	Type of fastener			
		Post-installed		Cast-in	
		Mechanical	Bonded	Headed fastener	Anchor channel
performance category	C.2 (1)	x	x	x	
rupture elongation (A_5)	C.3 (3) c)	x	x	x	
α_{gap}	C.5 (2)	x	x	x	
$N_{Rk,s,eq}$; $V_{Rk,s,eq}$	9.4 (1); C.5 (2)	x	x	x	
$N_{Rk,p,eq}$	9.4 (1); C.5 (2)	x		x	
$\tau_{Rk,eq}$	9.4 (1); C.5 (2)		x		
k_{15}	C.5 (3)	x	x	x	
$\delta_{N,eq(ULS)}$; $\delta_{V,eq(ULS)}$	9.2 (6)	x	x	x	
$\delta_{N,eq(DLS)}$; $\delta_{V,eq(DLS)}$	9.2 (6); C.6 (3)	x	x	x	

Annex F
(normative)

Assumptions for design provisions regarding execution of fastenings

F.1 General

In this EN the following assumptions have been made in respect of installation and execution of the relevant type of fastener and regarding welding design of headed fasteners. The installation instructions should reflect the assumptions stated below for the corresponding type of fastener.

F.2 Post-installed fasteners

a) Concrete has been compacted adequately in the area of the fastening. This should be checked prior and during installation, e.g. by visual inspection.

   Requirements for drilling operation and bore hole are fulfilled when:

   1) Holes are drilled perpendicular to the surface of the concrete unless specifically required otherwise by the manufacturer's installation instructions.

   2) Drilling is carried out according to the manufacturer's installation instructions.

   3) Hammer-drill bits which comply with ISO (e.g. ISO 5468) or National Standards are used.

   4) The diameter of the segments for diamond core drilling complies with the prescribed diameter.

   5) Holes are cleaned according to the manufacturer's installation instructions which are typically given in the European Technical Product Specifications.

   6) Aborted or unused drill holes are filled with non-shrinkage mortar with a strength at least equal to the base material and ≥ 40 N/mm².

   Many drill bits exhibit a mark indicating that they are in accordance with ISO (e.g. ISO 5468) or National Standards. If the drill bits do not bear a conformity mark, evidence of suitability should be provided.

b) Inspection and approval of the correct installation of the fasteners is carried out by appropriately qualified personnel.

c) Reinforcement in close proximity to the hole position should not be damaged during drilling. In prestressed concrete elements the distance between the drilling hole and the prestressed reinforcement shall be at least 50 mm; for determination of the position of the prestressed reinforcement in the structure a suitable device e.g. a reinforcement detector may be used.

F.3 Headed fasteners

Fasteners are installed according to a quality system which shall at least include the following items:

— The welding procedure for studs is done in accordance with the provisions given in the relevant European Technical Product Specification.

— The fastener is fixed in a way that no movement of the fastener will occur during placing of reinforcement or during pouring and compacting of the concrete.

— Requirements for adequate compaction particularly under the head of the fastener and under the fixture as well as provisions for vent openings in fixtures are fulfilled. In general, fixtures $400\ \text{mm} \times 400\ \text{mm}$ or larger will require vent openings.

— Inspection and approval of the correct installation of the fasteners is carried out by appropriately qualified personnel.

The fasteners may be vibrated (not just punched) into the wet concrete immediately after pouring provided the following requirements are fulfilled:

— The size of the fixture and the number of fasteners are such that the fastening can be placed simultaneously during vibrating by the available personnel. In general fixtures $200\ \text{mm} \times 200\ \text{mm}$ and smaller with up to 4 fasteners will fulfil the requirement.

— The fastenings are not moved after vibrating has been finished.

— The concrete under the head of the headed fastener as well as under the base plate is properly compacted.

F.4 Anchor channels

a) The anchor channel is fixed in a way that no movement of the anchor channel will occur during placing of reinforcement or during pouring and compacting of the concrete.

b) The concrete in particular under the head of the anchor and under the channel is properly compacted.

c) Placing anchor channels by only pushing them into the wet concrete is not allowed.

d) Anchor channels might be vibrated into the wet concrete immediately after pouring according to a quality system which shall at least include the following items:

   1) The length of the anchor channel is limited to 1 m if placed by one person, so that it can be placed simultaneously during vibrating. Longer channels should be placed by at least two persons.

   2) The anchor channels are not moved after vibrating has been finished.

   3) The concrete in the region of the anchor and the anchor channel is properly compacted.

e) Inspection and approval of the correct installation of the anchor channels is performed by appropriately qualified personnel.

Annex G
(informative)

Design of post-installed fasteners – simplified methods

G.1 General

G.1.1 This Annex applies when

— forces on the fasteners have been calculated using elastic analysis,

— the requirements of 4.5 and Annex F are observed.

G.1.2 For the design of post-installed fasteners in the ultimate limit state, there are three different design methods available.

The methods differ in the degree of simplification at the expense of conservatism:

Increasing simplification and conservatism ↓

Method A: Resistance is established for all load directions and all modes of failure, using actual values of edge distance *c* to the fasteners and spacing *s* between fasteners in a group (see 7.2).

Method B: A single value of resistance is used for all load directions and modes of failure. This resistance is related to the characteristic values c_{cr} and s_{cr}. It is permitted to use smaller values for *c* and *s* than these but the resistance should then be modified as indicated (see G.2).

Method C: As method B but the values of *c* and *s* are not less than c_{cr} and s_{cr} (see G.3).

Each method has further options with regard to:

a) the use of fasteners in cracked and uncracked concrete or uncracked concrete only; and

b) the concrete strength class for which the resistance is valid.

The design method to be applied and the corresponding data are given in the relevant European Technical Product Specification. Each design method requires its own set of technical data. For design methods A, B and C the required data are given in Table E.1 and Subclauses G.2 and G.3, respectively.

G.2 Method B

Method B uses a single value of characteristic resistance F^0_{Rk} valid for all load directions and modes of failure and for a given concrete compressive strength under the following conditions:

a) The design resistance F_{Rd} is equal to the basic design resistance F^0_{Rd} according to Formula (G.1) if the spacing s_{cr} and the edge distance c_{cr} are observed.

$$F^0_{Rd} = F^0_{Rk} / \gamma_M \tag{G.1}$$

b) If the actual values for spacing and edge distance are smaller than the values s_{cr} and c_{cr}, the design resistance shall be calculated according to Formula (G.2).

$$F_{Rd} = \frac{1}{n} \cdot \frac{A_c}{A_c^0} \cdot \psi_s \cdot \psi_{re} \cdot \psi_c \cdot F_{Rd}^0 \tag{G.2}$$

where

n is the number of loaded fasteners.

The effect of spacing and edge distance is taken into account by the factors A_c / A_c^0 and ψ_s. The factors A_c / A_c^0 and ψ_s should be calculated according to 7.2.1.4 replacing $A_{c,N}$, $A_{c,N}^0$, $s_{cr,N}$ and $c_{cr,N}$ by A_c, A_c^0, s_{cr} and c_{cr}, respectively. The effect of a narrowly spaced reinforcement is taken into account by the factor ψ_{re}. The factor ψ_{re} is calculated according to 7.2.1.4 (5). The factor ψ_c takes into account the influence of the concrete compressive strength on the resistance. The factor ψ_c is given the European Technical Product Specification.

c) In case of fastener groups it shall be shown that the design load acting on the most loaded fastener does not exceed the value in Formula (G.2).

d) In case of shear load with lever arm the characteristic fastener resistance $V_{Rk,s,M}$ shall be calculated according to Formula (7.37), replacing $N_{Rd,s}$ in Formula (7.38) by the design resistance F_{Rd}^0 according to Formula (G.1).

e) The value $V_{Rk,s} / \gamma_{Ms}$ shall be limited to the value F_{Rd} according to Formula (G.2).

f) For bonded fasteners the value F_{Rk}^0 shall be multiplied by ψ_{sus} according to Formula (7.14).

The values for F_{Rk}^0, $M_{Rk,s}^0$, γ_M, γ_{Ms}, ψ_c, s_{cr}, c_{cr}, s_{min}, c_{min} and h_{min} are given in the relevant European Technical Product Specification.

G.3 Method C

Method C uses a single value of characteristic resistance F_{Rk} valid for all load directions and modes of failure. Method C is valid only for values of c and s not less than c_{cr} and s_{cr}, respectively. The design resistance F_{Rd} is calculated as:

$$F_{Rd} = F_{Rk} / \gamma_M \tag{G.3}$$

In case of shear load with lever arm the characteristic fastener resistance $V_{Rk,s,M}$ shall be calculated according to Formula (7.37), replacing $N_{Rd,s}$ in Formula (7.38) by the design resistance F_{Rd}. The value $V_{Rk,s} / \gamma_{Ms}$ shall be limited to F_{Rd}.

For bonded fasteners the value F_{Rk} shall be multiplied by ψ_{sus} according to Formula (7.14).

The values F_{Rk}, $M_{Rk,s}^0$, γ_M, γ_{Ms}, s_{cr}, c_{cr} and h_{min} are given in the relevant European Technical Product Specification.

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