EOTA®

TECHNICAL REPORT

Design of anchor channels

TR 047

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1 INTRODUCTION

This Technical Report contains a design method for anchor channels which have been awarded an ETA in accordance with EAD “Anchor channels” [2].

Note: *A design method that is consistent with the assessment according to EAD “Anchor channels” [2] has been developed during the revision of the CEN/TS 1992-4 series [1] and is incorporated in EN 1992-4 [8]. Since EN 1992-4 has not yet been published the need for a publicly available document arises. The design method for anchor channels in this Technical Report (TR) is intended to bridge the time span until the publication of EN 1992-4. The design method given in this TR complies with the final draft of EN 1992-4 prepared by CEN/TC 250/SC 2/WG 2 for CEN Formal Vote.*

This document should be withdrawn within a reasonable time frame when EN 1992-4 is published. Once EN 1992-4 has been published no ETA should be issued with reference to this Technical Report.

This document has been written to represent current best practice. However, users should verify that applying its provisions allows local regulatory requirements to be satisfied.

2 SCOPE

2.1 General

This TR provides a design method for anchor channels in concrete members (connection between structural elements and attachment of non-structural elements to structural components).

This TR is intended for safety related applications in which the failure of anchor channels 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.

The design rules in this TR are only valid for anchor channels with a European Technical Assessment (ETA).

The transfer of the loads applied to the anchor channel to the supports of the concrete member shall be shown for both, ultimate limit state and serviceability limit state according to EN 1992-1-1 [6].

This TR does not cover the design of the fixture. The design of the fixture shall be carried out to comply with the appropriate Standards and fulfil the requirements on the fixture as given in this TR.

This document relies on characteristic resistances and distances which are stated in an ETA and referred to in this TR.

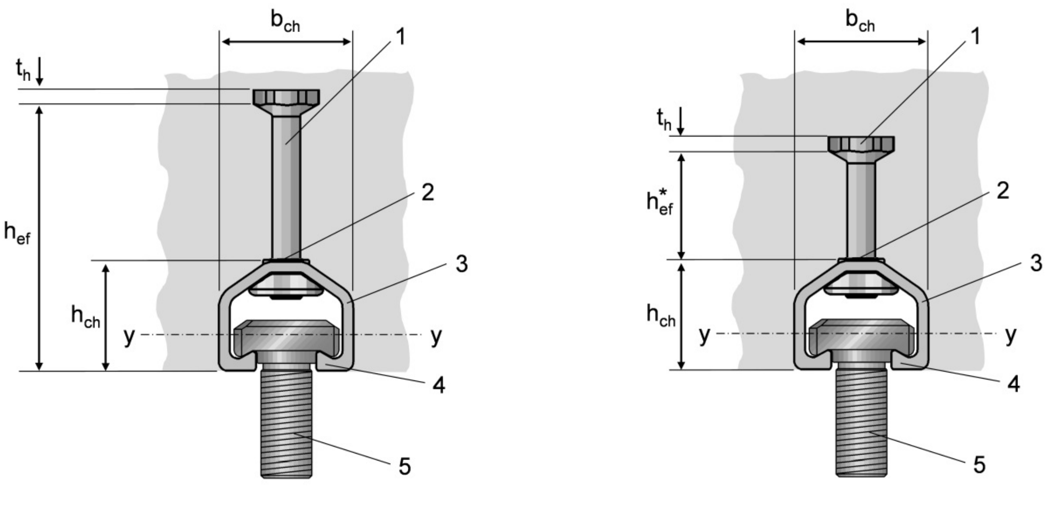
Note: The numerical values for certain parameters given in Notes may be used for pre-dimensioning. The corresponding values for verification are given in the ETAs and may be different.

2.2 Type, dimensions and materials of anchor channels

This TR applies to anchor channels with rigid connection (e.g. welded, forged, bolted) between anchor and channel. The anchor channels shall have an established suitability for the specified application in concrete, which is stated in the relevant ETA.

The effective embedment depth shall be $h_{ef} \geq 40$ mm.

This TR covers anchor channels made of either carbon steel or stainless steel. The surface of the steel may be coated or uncoated. This TR is valid for anchor channels with a nominal steel tensile strength $f_{uk} \leq 1000$ N/mm^2. An example for anchor channels is given in Figure 2.1.



a) b)

Key

1 anchor
2 connection between anchor and channel
3 channel
4 channel lip
5 channel bolt
a) h_{ef} for anchor channels (see 7.2.5 and 7.2.5 b))
b) h_{ef}^* for anchor channels (see 7.2.5 a))

Figure 2.1 Definitions for anchor channels

2.3 Anchor channel loading

Loading on the anchor channel covered by this document may be static and quasi-static. The loading on the anchor channel resulting from the actions on the fixture will generally be axial tension and/or shear. A shear force applied with a lever arm will result in a bending moment on the channel bolt and the channel. Any axial compression on the fixture should be transmitted to the concrete either directly to the concrete surface or via contact between the fixture and the anchor channel.

Shear in the direction of the longitudinal axis of the channel is covered by Annex B of this TR.

Design of fastenings under fire exposure is covered by this TR (see section 8).

Loading scenarios such as fatigue, impact and seismic loads are not covered.

2.4 Concrete member

This TR is valid for anchor channels 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 [3]. It should be noted that in the design of anchor channels the values of f_{ck} used for calculation shall not exceed 60 N/mm^2 even if the structure uses a higher strength class. The range of concrete strength classes in which particular anchor channels may be used is given in the relevant ETA and may be more restrictive than stated above.

In the context of this TR the concrete members shall be subjected to static loading only.

3 NOTATIONS AND DEFINITIONS

3.1 Indices

E	action effects
L	load
M	material
N	normal force
R	resistance, restraint
V	shear force
adm	admissible
b	bond
	blow-out
c	concrete
	connection between anchor and channel
ca	connection
cb	blow-out
cbo	channel bolt
ch	channel
cp	concrete pry-out
cr	cracked concrete
	characteristic value
d	design value
ef	effective
fi	fire
fix	fixture
flex	bending
h	head of anchor of anchor channel
ind	indirect
k	characteristic value
l	local
max	maximum
min	minimum
nom	nominal
p	pull-out
re	reinforcement
s	steel
sp	splitting
u	ultimate
ucr	uncracked concrete
y	yield

3.2 Superscripts

0	basic value
a	anchor
cb	channel bolt
ch	anchor channel

3.3 Actions and resistances

γ	partial factor
z	height of the non-structural element above the level of application of the seismic action
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
C_d	nominal value, e.g. limiting displacement
E	effect of action
R	resistance
F	force in general
N	axial force (positive = tension force, negative = compression force)

N_{Ed}	resultant design tension force
V	shear force
M	moment
$F_{Rk}(N_{Rk}; V_{Rk})$	characteristic value of resistance (axial force, shear force)
$F_{Rd}(N_{Rd}; V_{Rd})$	design value of resistance (axial force, shear force)
F_{Ek} (N_{Ek}; V_{Ek}; M_{Ek})	characteristic value of actions acting on the fixture (axial load, shear load, bending moment, torsion moment)
F_{Ed} (N_{Ed}; V_{Ed}; M_{Ed})	design value of actions acting on the channel bolt (axial load, shear load, bending moment)
F_{Ed}^{a} (N_{Ed}^{a}; V_{Ed}^{a})	design value of action on one anchor of the anchor channel
$F_{Ed,i}^{a}$ ($N_{Ed,i}^{a}$; $V_{Ed,i}^{a}$)	design value of action on anchor i of the anchor channel
F_{Ed}^{cb} (N_{Ed}^{cb}; V_{Ed}^{cb})	design value of action on one channel bolt of the anchor channel
M_{Ed}^{ch}	design value of bending moment acting on the anchor channel due to tension loads N_{Ed}^{cb} (see section 6.2)
$N_{Ed,re}^{a}$	design value of tension load acting on the supplementary reinforcement of one anchor of the anchor channel

3.4 Concrete and steel

f_{bd}	design bond strength of supplementary reinforcement
f_{ck}	nominal characteristic compressive cylinder strength (150 mm diameter by 300 mm cylinder)
f_{yk}	nominal characteristic steel yield strength
f_{uk}	nominal characteristic steel ultimate tensile strength
$A_{s,re}$	cross section of a reinforcing bar
I_y	moment of inertia of the channel relative to the y-axis of the channel (Figure 2.1)

3.5 Anchor channels, reinforcement

ϕ	diameter of reinforcing bar
ϕ_m	mandrel diameter of reinforcing bar
ψ	influence factor
$\psi_{ch,c}$	influence factor taking into account corner of concrete member
$\psi_{ch,e,N}$	influence factor taking into account edge of concrete member
$\psi_{ch,h}$	influence factor taking into account the thickness of the concrete member
$\psi_{ch,s}$	influence factor taking into account neighbouring anchors
$\psi_{ch,90°,V}$	influence factor taking into account shear loads acting parallel to the edge
$\psi_{h,sp}$	influence factor taking into account the thickness of the concrete member
$\psi_{l,N}$	influence factor for closely spaced channel bolts
$\psi_{re,N}$	influence factor taking into account dense reinforcement
b_{ch}	width of the channel, (Figure 2.1)
c	edge distance from the axis of an anchor channel
c_1	edge distance in direction 1 (Figure 7.4)
c_2	edge distance in direction 2 (Figure 7.5), where direction 2 is perpendicular to direction 1
c_{cr}	characteristic edge distance for ensuring the transmission of the characteristic resistance
c_{min}	minimum allowable edge distance
d	diameter of channel bolt, effective depth to axis of supplementary reinforcement (Figure 6.4)
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 anchor head (see section 7.2.4)
e_1	distance between shear load and concrete surface (Figure 6.3)
e_s	distance between the line of the shear load and the axis of the supplementary reinforcement for shear (Figure 6.4)
h	thickness of concrete member in which the anchor channel is installed (Figure 7.10)
h_{ch}	height of the channel (Figure 2.1)
h_{ef}	effective embedment depth (Figure 2.1)

h_{min}	minimum allowed thickness of concrete member
l_a	lever arm of the shear force acting on an anchor channel (Figure 6.3)
l_{bd}	anchorage length of supplementary reinforcement
l_i	influence length of an external load N_{Ed} or V_{Ed} along an anchor channel (Figure 6.2 and Equation (6.3))
l_1	anchorage length of the reinforcing bar in the assumed concrete break-out body (Figure 7.1 and Figure 7.7)
n	number of anchors within the influence length l_i
n_{re}	number of legs of the supplementary reinforcement effective for one anchor
s	centre to centre spacing of anchors of an anchor channel (Figure 6.2) or spacing of reinforcing bars
s_{cbo}	centre to centre spacing of channels bolts
s_{cr}	characteristic spacing for ensuring the transmission of the characteristic resistance
s_{min}	minimum allowable spacing of anchor
t_{fix}	thickness of the fixture
t_h	thickness of anchor head
z	internal lever arm of concrete member (Figure 6.4 and Equation (6.6))

3.6 Definitions

anchor
element made of steel attached to the back of anchor channels.

anchor channel
steel profile with two or more steel anchors rigidly connected to the back of the anchor channel (see Figure 2.1) installed prior to concreting

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

attachment
fixture
assembly that transmits loads to the anchor channel

base material
concrete member in which the anchor channel is installed

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

channel bolt
screw or bolt which connects the element to be fixed to the anchor channel (Figure 2.1)

characteristic edge distance
edge distance required to ensure that the edge does not influence the characteristic resistance of an anchor

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

characteristic spacing
spacing required to ensure the characteristic resistance of a single anchor

combined tension and shear loads
tension and shear load applied simultaneously

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. This is usually associated with anchor channels with small side cover and deep embedment of the anchor.

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

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

concrete related failure modes
failure modes under tension loading: Pull-out failure, concrete cone failure, concrete blow-out failure, concrete splitting failure, anchorage failure of supplementary reinforcement; failure modes under shear loading: Concrete pry-out failure, concrete edge failure

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

displacement
movement of a channel bolt or the anchor channel relative to the concrete element in the direction of the axis of the bolt/anchor in case of tension and perpendicular to this axis in case of shear.

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

effective embedment depth
overall depth through which the anchor of an anchor channel transfers force to the surrounding concrete; see Figure 2.1.

European Technical Assessment (ETA)
document containing performance characteristics for anchor channels based on a European Assessment Document (EAD)

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

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

mechanical interlock
load transfer to a concrete member via interlocking surfaces

minimum edge distance
smallest allowable distance to allow adequate placing and compaction of concrete and to avoid damage to the concrete during prestressing of the channel bolt, given in the ETA

minimum member thickness
smallest value for member thickness, in which an anchor channel is allowed to be installed, given in the ETA

minimum spacing
smallest value for distance between anchors to allow adequate placing and compaction of concrete

pull-out failure
failure mode in which the anchor pulls out of the concrete without development of the full concrete resistance

shear load
load acting parallel to the concrete surface and transversely with respect to the longitudinal axis of the channel

spacing
distance between centre lines of channel bolts as well as anchors of anchor channels

steel failure
failure mode characterised by fracture of the steel elements of anchor channels (anchor, channel bolt and connection) or flexure of the channel lip or channel itself

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

tension load
load applied perpendicular to the surface of the base material

3.7 Units

In this TR SI-units are used. Unless stated otherwise in the equations, the following units are used: Dimensions are given in mm, cross sections in mm^2, section modulus in mm^3, moment of inertia in mm^4, forces and loads in N and stresses, strengths and moduli of elasticity in N/mm^2.

4 DESIGN AND SAFETY CONCEPT

4.1 General

Anchor channels shall resist all actions and influences likely to occur during execution and use with the level of required reliability (ultimate limit state). Deformation to an inadmissible degree (serviceability limit state) shall be avoided and the anchor channels shall 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.

The design of anchor channels shall be in accordance with the same principles and requirements valid for structures given in EN 1990 [4] (including load combinations) and EN 1992-1-1 [6].

The design working life of the anchor channels shall meet that of the fixture. The partial factors for resistance and durability in this TR are based on a design working life of 50 years for the anchor channel. Actions shall be determined based on the relevant parts of EN 1991 [5].

The design of the concrete member in which the anchor channels are installed shall comply with EN 1992-1 and a safe transfer of loads to the supports of the member shall be ensured (see also section 10). For the design and execution of anchor channels the same quality requirements are valid as for the design and execution of structures and the attachment:

- The design of the anchor channels shall be performed by qualified personnel;
- the execution shall comply with the requirements stated in section 4.5.

In the ultimate limit state (ULS), verifications are required for all appropriate load directions and all relevant failure modes. In the serviceability limit state (SLS), the displacements caused by the applied actions shall not be larger than the admissible displacement.

The material of the anchor channels, including channel bolts, and the corrosion protection shall be selected and demonstrated taking into account the environmental conditions at the place of installation, and whether the anchor channels are inspectable and maintainable.

The fastening shall have an adequate fire resistance where required. In this document it is assumed that the fire resistance of the fixture is adequate. Section 8 provides guidance for the design of anchor channels exposed to fire.

4.2 Design format

At ULS the value of the design action E_d shall not exceed the value of the design resistance R_d.

$$E_d \leq R_d \tag{4.1}$$

where

E_d = value of design action;

R_d = value of design resistance.

The design resistance shall be calculated as follows:

$$R_d = R_k / \gamma_M \tag{4.2}$$

where

R_k = characteristic resistance of an anchor channel;

γ_M = partial safety factor for material.

The forces in the anchor channel 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 anchor channels. The design action shall be taken as $\gamma_{ind} \cdot Q_{ind}$. In general actions on the fixture may be calculated ignoring the displacement of the anchor channels. However, the effect of displacement of the anchor channels should be considered when a statically indeterminate stiff element is fastened.

At SLS the following criteria shall be met:

$$E_d \leq C_d \tag{4.3}$$

where the displacement of the anchor channel, E_d, shall be determined based on the information provided in the relevant ETA. Furthermore, cracking of the concrete for anchor channels with supplementary reinforcement close to an edge loaded in shear shall be considered. For C_d see section 9.

4.3 Verification by the partial factor method

4.3.1 Partial factors for actions

Partial factors shall be in accordance with EN 1990. The partial factor γ_{ind} shall be applied for the verification of indirect actions.

Note: The value of γ_{ind} for use in a Country may be found in its National Annex to EN 1990. The recommended values for ULS are γ_{ind} = 1,2 for concrete failure and γ_{ind} = 1,0 for other failure modes.

4.3.2 Partial factors for resistances – Ultimate limit states

Partial factors for fastenings under static and quasi-static loading shall be applied to characteristic resistances.

Note: In absence of national regulations the recommended values of partial factors are given in Table 4.1.

Table 4.1 Recommended values of partial factors

Failure modes		**Partial factor**	
		Permanent and transient design situations	**Accidential design situations**
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 in anchors and shear with and without lever arm in channel bolts	γ_{Ms}	$= 1,0 \cdot f_{uk}/f_{yk} \geq 1,25$ for $f_{uk} \leq 800$ N/mm² and $f_{yk}/f_{uk} \leq 0,8$ = 1,5 for $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0,8$	$= 1,0 \cdot f_{uk}/f_{yk} \geq 1,25$ for $f_{uk} \leq 800$ N/mm² and $f_{yk}/f_{uk} \leq 0,8$ = 1,3 for $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0,8$
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	= 1,00
Steel failure – supplementary reinforcement			
Tension	$\gamma_{Ms,re}$	= 1,15 [a]	= 1,00
Concrete failure			
Cone break-out failure, edge break-out failure, blow-out failure and pry-out failure	γ_{Mc}	$= \gamma_c \cdot \gamma_{inst}$	$= \gamma_c \cdot \gamma_{inst}$
	γ_c	= 1,5 [a]	= 1,2 [a]
	γ_{inst}	= 1,0 for anchor channels	
Splitting failure	γ_{Msp}	$= \gamma_{Mc}$	
Pull-out failure			
Pull-out	γ_{Mp}	$= \gamma_{Mc}$	
[a] The values are in accordance with EN 1992-1-1.			

4.3.3 Partial factors for resistances – Serviceability limit state

The partial factor for resistance γ_M 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 to EN 1990. The recommended value for the partial factor γ_M is γ_M = 1,0.

4.4 Project specification

The project specification shall typically include the following:

a) Strength class of the concrete used in the design and the condition of the concrete (cracked or uncracked). In case of uncracked concrete, verification of this condition is required (e.g. see section 4.6).

b) Environmental exposure used for the design (EN 206).

c) A note indicating that the number, 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

- location of the anchor channels in the structure, including tolerances;
- number and type of anchor channels and channel bolts;
- spacing and edge distance of the anchor channels including tolerances (typically specified with positive tolerances only);
- thickness of fixture and diameter of the clearance holes (if applicable);
- (special) installation instructions (if applicable). These shall not be in contradiction with the manufacturer's installation instructions.

e) Reference to the manufacturer's installation instructions.

4.5 Installation of anchor channels

The manner of installation of anchor channels affects the resistance and reliability of fastenings. The partial factors given in section 4.3 are valid only if the conditions and the assumptions given in the following are fulfilled:

a) The anchor channel is fixed such that movement of the anchor channel is avoided during placing of reinforcement or during pouring and compacting of the concrete.

b) The concrete is properly compacted especially under the head of the anchor and under the channel.

c) It is not allowed to place anchor channels by only pushing them into the wet concrete.

d) Anchor channels may be vibrated into the wet concrete right after pouring. This process is carried out in accordance with a quality system that includes at a minimum the following:

- The length of the anchor channel is ≤ 1 m for placement by one person (simultaneous to vibrating). At least two persons should install longer channels.
- The anchor channels are not moved after vibrating has been finished.
- 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.

These assumptions should be reflected in the installation instructions for the anchor channel.

4.6 Determination of concrete condition

The concrete may be cracked or uncracked in the region of the anchor channel. The designer shall determine the condition of the concrete for the service life.

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

Uncracked concrete may be assumed if it is shown that under the characteristic combination of loading at SLS the anchor channel with its entire embedment depth is located in uncracked concrete. This will be satisfied if Equation (4.4) is observed (compressive stresses are negative):

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

σ_L = stress in the concrete induced by external loads including anchor channel loads

σ_R = 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, $\sigma_R = 3$ N/mm^2 should be assumed.

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

Note: 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) Equation (4.4) should be fulfilled for both directions. The value of σ_{adm} may be found in a Country's corresponding National Regulation. The recommended value is $\sigma_{adm} = 0$ is based on the characteristic combination of loading at SLS.

5 DURABILITY

Anchor channels 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: Product specific information might be stated in the relevant ETA. Additional general information may be available on a national level.

6 FORCES ACTING ON ANCHOR CHANNELS - ANALYSIS

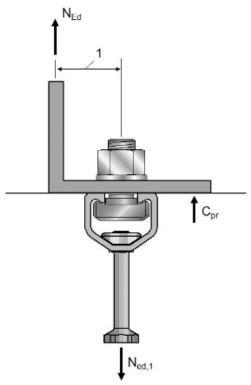
6.1 General

The actions acting on a fixture shall be transferred to the anchor channels as statically equivalent tension and shear forces. Any friction forces that may result from bending moment or compression forces acting on the fixture in contact with concrete are neglected in the design of the anchor channel.

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. The resulting anchor forces depend on the assumed anchor stiffness and degree of restraint.

When a bending moment and/or a compression force act on a fixture, which is in contact with concrete, a friction force will develop. This friction force will be superimposed to any shear force acting on the fixture resulting in a reduced shear force on the anchor channel. However, in this TR friction forces are neglected in the design of the anchor channels. Eccentricities and prying effects shall be taken into account within the design of the anchor channel (Figure 6.1). Prying forces C_{pr} are caused by deformation of the fixture and displacement of the channel bolt and on the anchor channel.

For reasons of simplicity, 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. For anchor channels with two or more anchors the alternative triangular-load-distribution-method may be used to determine the distribution of tension and shear loads to the anchor (see sections 6.2 and 6.3).



Key

1 eccentricity
C_{pr} prying force

Figure 6.1 Examples for amplification of tension forces acting on the anchor channel due to eccentricity

6.2 Tension loads

The tension in each anchor caused by a tension load acting on the channel is calculated according to Equation (6.1). The influence length l_i, determining the anchors affected by the load, shall be calculated according to Equation (6.3). An example for the calculation of the forces acting on the anchors is given in Figure 6.2.

$$N_{Ed,i}^{a} = k \cdot A_i^{'} \cdot N_{Ed}^{cb} \qquad (6.1)$$

with

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

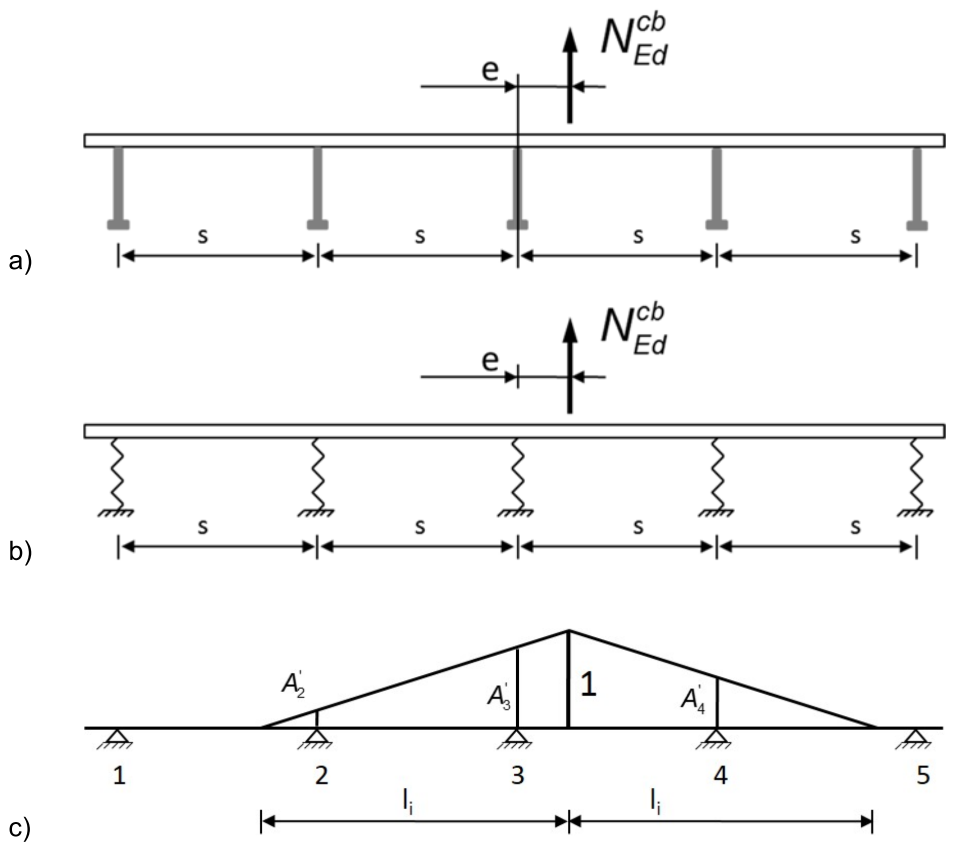
$$k = \frac{1}{\sum_{1}^{n} A_i^{'}} \qquad (6.2)$$

$$l_i = 13 \cdot I_y^{0,05} \cdot s^{0,5} \geq s \qquad (6.3)$$

n = number of anchors on the channel within the influence length l_i to either side of the applied load N_{Ed}^{cb} (Figure 6.2)

In case of several tension loads acting on the channel, a linear superposition of the anchor forces for all loads shall be carried out. The most unfavourable loading position shall be considered 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).

The design bending moment M_{Ed}^{ch} in the channel due to tension loads N_{Ed}^{cb} can be calculated based on the assumption of a simply supported single span beam with a span length equal to the anchor spacing. The characteristic values of the moments of the resistance are given in the relevant ETA.



$$A_2' = \frac{l_i - e - s}{l_i} \qquad A_3' = \frac{l_i - e}{l_i} \qquad A_4' = \frac{l_i - s + e}{l_i}$$

$$N_{Ed,2}^a = A_2' \cdot k \cdot N_{Ed}^{cb} \qquad N_{Ed,3}^a = A_3' \cdot k \cdot N_{Ed}^{cb} \qquad N_{Ed,4}^a = A_4' \cdot k \cdot N_{Ed}^{cb} \qquad N_{Ed,1}^a = N_{Ed,5}^a = 0$$

Figure 6.2 Anchor channels covered by this design method: a) example of anchor channel with 5 anchors; b) on elastic support; c) triangular load distribution method

6.3 Shear loads V_{Ed} acting transverse to the longitudinal axis of the channel

Shear loads acting on anchor channels may be assumed to act without a lever arm if the following two conditions are satisfied:

a) The fixture is made out of steel and is in contact with the channel bolt over a length of at least 0,5 t_{fix}.

b) The fixture is fixed directly to the concrete without an intermediate layer.

If the above conditions are not satisfied, shear force shall be considered acting with lever arm. For shear loads V_{Ed} with a lever arm, a bending moment acting on the channel bolt has to be taken into account. The corresponding design moment is calculated as follows:

$$M_{Ed} = V_{Ed} \cdot \frac{l_a}{\alpha_M} \tag{6.4}$$

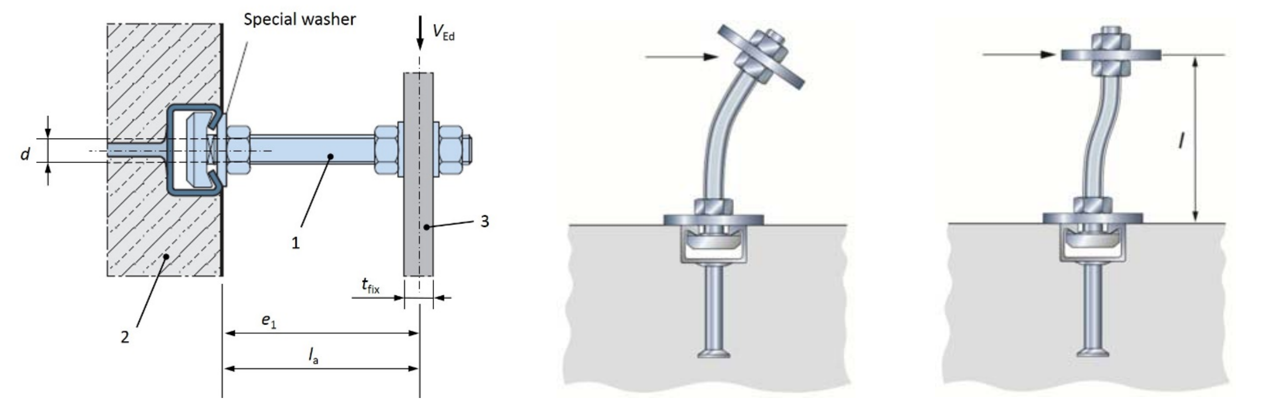
where

$$l_a = e_1 \tag{6.5}$$

with

e_1 = distance between shear load and concrete surface (Figure 6.3)

α_M = factor accounting for the degree of restraint of the anchor channel at the side of the fixture of the application in question. It should be determined according to good engineering practice.
= 1,0, if no restraint is assumed, meaning the fixture can rotate freely (see Figure 6.3 b))
= 2,0, if full restraint is assumed, valid only if the fixture cannot rotate (see Figure 6.3 c))



a) b) c)

Key

1 channel bolt
2 concrete element
3 attachment

Figure 6.3 Shear load with lever arm: a) Definition of lever arm; b) free rotation of the fixture; c) no rotation of fixture

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 section 6.2.

Note: Shear loads applied perpendicular to the longitudinal axis of 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.

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 calculated by use of an appropriate strut and tie model (for example see Figure 7.1 (tension load) and Figure 7.7 (shear load)).

6.4.2 Tension loads

For anchor channels the supplementary reinforcement shall be designed for the force N_{Ed}^{a} of the most loaded anchor. This reinforcement is then placed for each anchor.

6.4.3 Shear loads

For supplementary reinforcement placed in the direction of the design shear force V_{Ed} acting on a fixture perpendicular and towards to the edge, the corresponding design tension force $N_{Ed,re}$ in the supplementary reinforcement shall be determined as follows:

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

with (see Figure 6.4):

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

z ≈ 0,85 d, with $d \leq \min \{2\ h_{ef};\ 2\ c_1\}$

Note: For deep sections the internal lever arm will be much smaller than the section, and hence the effective depth is limited to min {2 h_{ef}; 2 c_1}.
In case the design shear force is inclined towards the edge, the supplementary reinforcement can be designed for the total design shear force acting perpendicular and towards to the edge. For design shear force acting parallel to the edge or inclined away from the edge, the following conservative assumption may be made: the component of the design shear force parallel to the edge is acting perpendicular and towards to the edge.

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

Supplementary reinforcement for anchor channels shall be designed using Equation (6.6) for a force V_{Ed} that is the maximum of the shear force on the most loaded anchor and on the most loaded channel bolt.

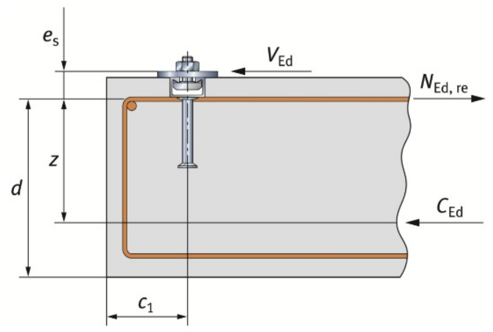


Figure 6.4 Surface reinforcement to take up shear forces — forces in the reinforcement

7 VERIFICATION OF ULTIMATE LIMIT STATE

7.1 General

Equation (4.1) shall be fulfilled for all load directions (tension, shear, combined tension and shear) as well as for all failure modes for each load combination. Both edge distance and spacing shall be specified only with positive tolerances.

Characteristic resistances for concrete failure modes given in this TR are valid for a spacing between adjacent anchor channels not smaller than $s_{cr,N}$.

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

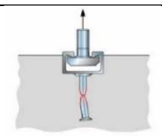
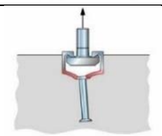
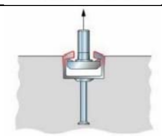
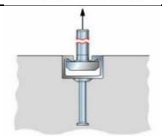
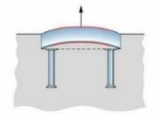
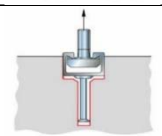
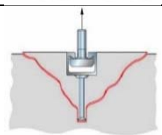
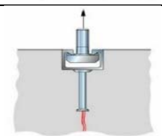
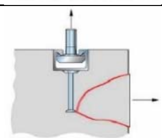
7.2 Tension load

7.2.1 Required verifications

The verifications of Table 7.1 apply.

For the design approach using supplementary reinforcement, the verification of concrete cone failure according to Table 7.1, line 7 is replaced by the verification of the supplementary reinforcement according to Table 7.1, line 10 and 11 to resist the total load.

Table 7.1 Required verifications for anchor channels in tension

	failure mode		channel	most unfavourable anchor / channel bolt	
1	**Steel failure**	anchor		$N_{Ed}^{a} \le N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$	
2		connection between anchor and channel		$N_{Ed}^{a} \le N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$	
3		local flexure of channel lip [a]	$N_{Ed}^{cb} \le N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$		
4		channel bolt		$N_{Ed}^{cb} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	
5		flexure of channel	$M_{Ed}^{ch} \le M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$		
6	**Pull-out failure**			$N_{Ed}^{a} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$	
7	**Concrete cone failure** [b]			$N_{Ed}^{a} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$	
8	**Concrete splitting failure** [b]			$N_{Ed}^{a} \le N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$	
9	**Concrete blow-out failure** [b, c]			$N_{Ed}^{a} \le N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$	
10	**Steel failure of supplementary reinforcement**			$N_{Ed,re}^{a} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
11	**Anchorage failure of supplementary reinforcement**			$N_{Ed,re}^{a} \le N_{Rd,a}$	

[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 $c > 0{,}5\ h_{ef}$

7.2.2 Detailing of supplementary reinforcement

The reinforcement shall be anchored adequately on both sides of the potential failure planes.

The supplementary reinforcement to take up tension loads shall comply with the following requirements (see also Figure 7.1):

a) The reinforcement shall consist of ribbed reinforcing bars ($f_{yk} \leq 600$ N/mm^2) 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.

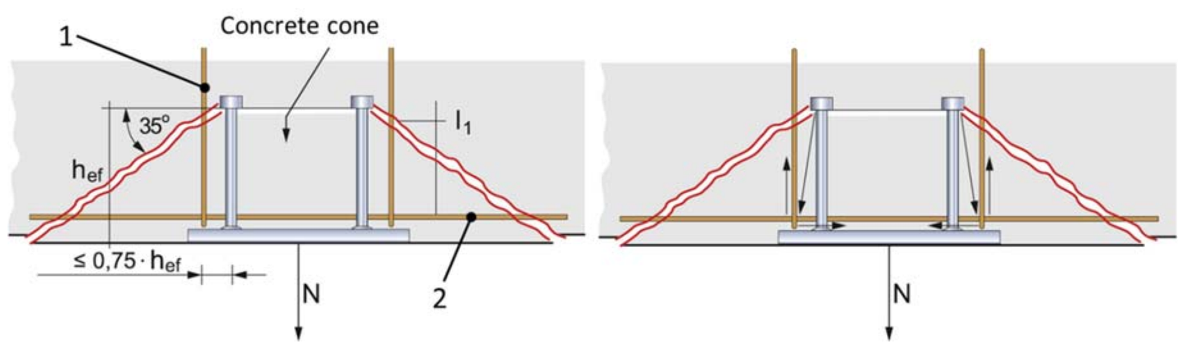
b) Where supplementary reinforcement has been sized for the most loaded anchor, the same reinforcement shall be provided around all anchors.

c) The supplementary reinforcement should be placed symmetrically as close to the anchors 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 these reinforcement bars with a distance ≤ 0,75 h_{ef} from the anchors 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. Concrete cone failure assuming an embedment length corresponding to the end of the supplementary reinforcement shall be verified using the appropriate model for headed studs for $N_{Rk,c}$ (see fib [10], section 10.1.4). 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.

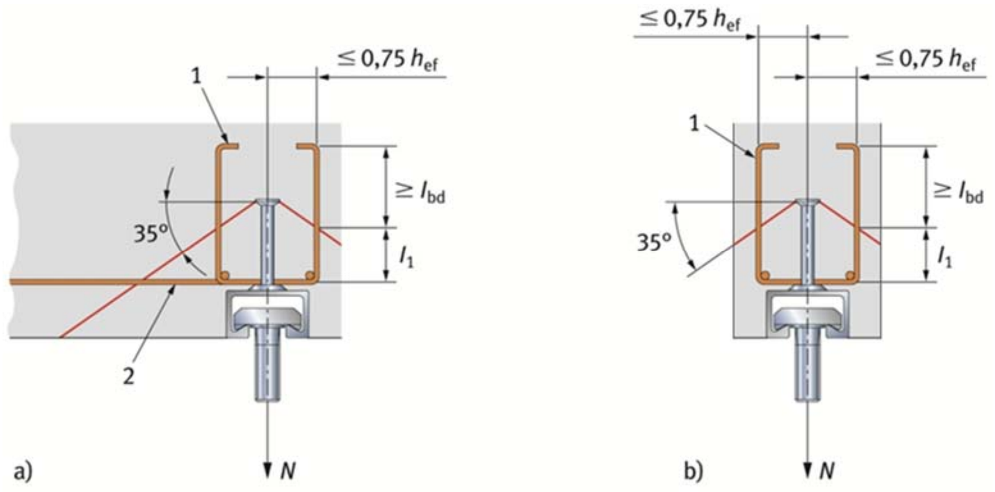
f) Surface reinforcement should be provided as shown in Figure 7.1 designed to resist the forces arising from the assumed strut and tie model and the splitting forces according to section 7.2.6 b).



Key
1 supplementary reinforcement
2 surface reinforcement

Figure 7.1 Arrangement of supplementary reinforcement to take up tension loads

Where anchor channels are placed parallel to the edge or in a narrow concrete member, the supplementary reinforcement shall be placed perpendicular to the longitudinal axis of the channel (see Figure 7.2).



Key
1 supplementary reinforcement
2 surface reinforcement

Figure 7.2 Arrangement of supplementary reinforcement
a) anchor channel parallel to the edge
b) anchor channel in narrow member

7.2.3 Steel failure

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 ETA.

The characteristic resistance $N_{Rk,s,l}$ for lip failure is given as

$$N_{Rk,s,l} = N^{0}_{Rk,s,l} \cdot \psi_{l,N} \tag{7.1}$$

with

$$\psi_{l,N} = 0{,}5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \leq 1 \tag{7.2}$$

where

s_{cbo} = spacing of channel bolts

$s_{l,N}$ = characteristic spacing for channel lip failure under tension, taken from the ETA.

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

7.2.4 Pull-out failure

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

Note: The concrete pressure under the head of the anchor limits the characteristic resistance $N_{Rk,p}$:

$$N_{Rk,p} = k_2 \cdot A_h \cdot f_{ck} \tag{7.3}$$

with

k_2 = *7,5 for anchors of anchor channels in cracked concrete*
= *10,5 for anchors of anchor channels in non-cracked concrete*
A_h = *load bearing area of the head of the fastener*

For circular shaped heads, the load bearing area shall be calculated as follows:

$$A_h = \frac{\pi}{4} \cdot \left(d_h^2 - d_a^2\right) \tag{7.4}$$

In Equation (7.4) d_h should not be taken larger than 6 t_h + d_a.

7.2.5 Concrete cone failure

For anchor channels where $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$, the effective embedment depth is determined according to Figure 2.1 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 2.1 b), with $h_{ef} = h_{ef}^{*}$, or

b) the effective embedment depth h_{ef} is determined according to Figure 2.1 a) but the value for $s_{cr,N}$ shall be taken from the relevant ETA. The value for $s_{cr,N}$ used in design shall not be smaller than that for anchor channels where $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$ is fulfilled (see Equation (7.8)).

The characteristic resistance of one anchor of an anchor channel in case of concrete cone failure may be calculated as follows:

$$N_{Rk,c} = N_{Rk,c}^{0} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N} \tag{7.5}$$

The various factors in Equation (7.5) are defined in the following. The basic characteristic resistance of one anchor not influenced by adjacent anchors, edges or corners of the concrete member located in cracked or uncracked concrete is calculated according to Equation (7.6).

$$N_{Rk,c}^{0} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1,5} \tag{7.6}$$

with

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

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

$k_{cr,N}$ and $k_{ucr,N}$ are given in the corresponding ETA.

The influence of neighbouring anchors on the concrete cone resistance is taken into account by the factor $\psi_{ch,s,N}$, which shall be calculated according to Equation (7.7).

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}} \right)^{1,5} \cdot \frac{N_i}{N_0} \right]} \leq 1,0 \tag{7.7}$$

with (see Figure 7.3):

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

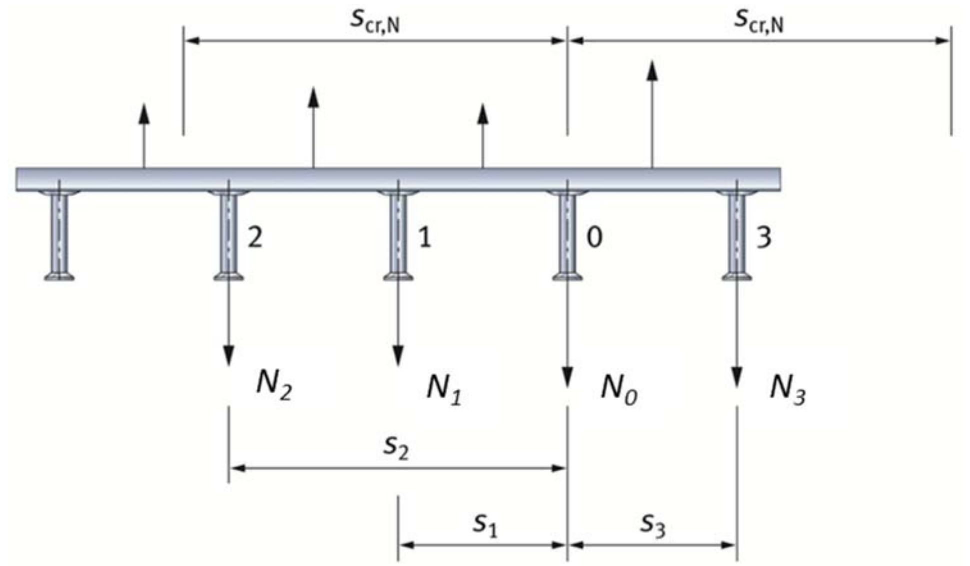
$\leq s_{cr,N}$

$$s_{cr,N} = 2 \cdot (2,8 - 1,3 \cdot h_{ef}/180) \cdot h_{ef} \geq 3 \cdot h_{ef} \tag{7.8}$$

N_i = tension force of an influencing anchor

N_0 = tension force of the anchor under consideration

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



Key

0 anchor under consideration

Figure 7.3 Anchor channel with different anchor tension forces - example

The factor $\psi_{ch,e,N}$ according to Equation (7.9) takes into account the influence of an edge of the concrete member on the characteristic resistance.

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0,5} \leq 1 \quad (7.9)$$

with

c_1 = edge distance of the anchor channel (see Figure 7.4 a))

$c_{cr,N}$ = 0,5 $s_{cr,N}$

With anchor channels located in a narrow concrete member with different edge distances $c_{1,1}$ and $c_{1,2}$ (see Figure 7.4 b) and Figure 7.5 d)) the minimum value of $c_{1,1}$ and $c_{1,2}$ shall be inserted for c_1 in Equation (7.9).

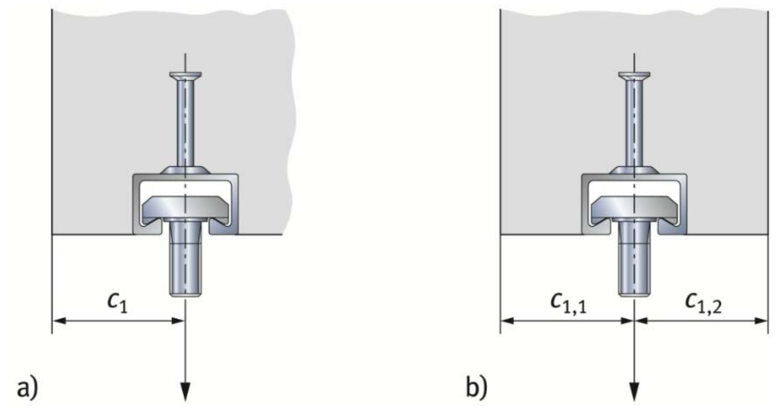


Figure 7.4 Anchor channel at an edge (a) or in a narrow member (b)

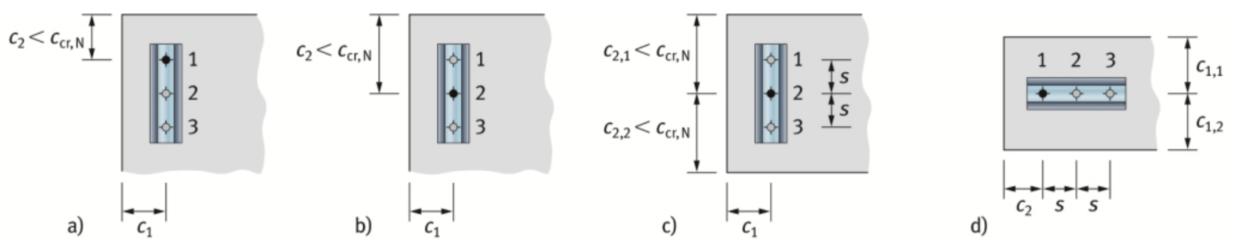
The influence of a corner of the concrete member (see Figure 7.5) on the characteristic resistance is taken into account by the factor $\psi_{ch,c,N}$, which shall be calculated as follows:

$$\psi_{ch,c,N} = \left(\frac{c_2}{c_{cr,N}}\right)^{0,5} \leq 1 \quad (7.10)$$

with

c_2 = corner distance of the anchor under consideration (see Figure 7.5).

For an anchor of an anchor channel being influenced by two corners (see Figure 7.5 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 Equation (7.5).



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 7.5 Definition of the corner distance of an anchor channel in the corner of a concrete member

The effect of a dense reinforcement for embedment depths $h_{ef} \leq 100$ mm is taken into account by the shell spalling factor $\psi_{re,N}$, which shall be calculated as follows:

$$\psi_{re,N} = 0{,}5 + \frac{h_{ef}}{200} \leq 1 \tag{7.11}$$

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.

For the case of anchor channels with h_{ef} > 180 mm in a narrow member with influence of neighbouring anchors and influence of an edge and 2 corners (Figure 7.5 c) and Figure 7.5 d)) located with edge distance less than $c_{cr,N}$ from the anchor under consideration, the calculation according to Equation (7.5) leads to conservative results. More precise results are obtained if the value h_{ef} is substituted by the larger value of

$$h'_{ef} = \frac{c_{\max}}{c_{cr,N}} \cdot h_{ef} \geq 180\ mm \quad and \quad h'_{ef} = \frac{s_{\max}}{s_{cr,N}} \cdot h_{ef} \geq 180\ mm \tag{7.12}$$

with

c_{max} = maximum distance from centre of an anchor to the edge of the concrete member ≤ $c_{cr,N}$. In the example given in Figure 7.5 c) c_{max} is the maximum value of c_1, $c_{2,1}$ and $c_{2,2}$

s_{max} = maximum centre to centre spacing of anchors ≤ $s_{cr,N}$

The value h'_{ef} is inserted in Equation (7.6) as well as in Equation (7.8). The resulting value for $s_{cr,N}$ is then used in the context of Equation (7.9).

7.2.6 Concrete splitting failure

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 ETA.

Splitting failure due to loading shall be accounted for as follows:

a) The characteristic edge distance in the case of splitting under load, $c_{cr,sp}$ is given in the relevant ETA. 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 resistance 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.

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

$$\sum A_{s,re} = 0{,}5 \cdot \frac{N_{Ed}^{a}}{f_{yk} / \gamma_{Ms,re}} \tag{7.13}$$

with

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

f_{yk} = *nominal yield strength of the reinforcing steel ≤ 600 N/mm²*

It is recommended to place the reinforcement 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 splitting failure shall be calculated according to Equation (7.14).

$$N_{Rk,sp} = N_{Rk}^{0} \cdot \psi_{ch,s,N} \cdot \psi_{ch,c,N} \cdot \psi_{ch,e,N} \cdot \psi_{re,N} \cdot \psi_{h,sp} \tag{7.14}$$

with

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

$N_{Rk,p}$ according to section 7.2.4, $N_{Rk,c}^{0}$, $\psi_{ch,s,N}$, $\psi_{ch,c,N}$, $\psi_{ch,e,N}$ and $\psi_{re,N}$ according to section 7.2.5.

The values $c_{cr,N}$ and $s_{cr,N}$ shall be replaced by $c_{cr,sp}$ and $s_{cr,sp}$, respectively, which correspond to the minimum member thickness h_{min}.

$$\psi_{h,sp} = \left(\frac{h}{h_{min}}\right)^{2/3} \leq max\left\{1; \left(\frac{h_{ef} + c_{cr,N}}{h_{min}}\right)^{2/3}\right\} \leq 2 \tag{7.15}$$

d) If in the relevant ETA $c_{cr,sp}$ is given for more than one minimum member thickness h_{min}, the minimum member thickness corresponding to $c_{cr,sp}$ used in Equation (7.14) shall be inserted in Equation (7.15).

7.2.7 Concrete blow-out failure

Verification of blow-out failure is not required for anchors where the edge distance exceeds $c = 0{,}5\ h_{ef}$. If verification is required, the characteristic resistance of one anchor in case of blow-out is:

$$N_{Rk,cb} = N_{Rk,cb}^{0} \cdot \psi_{ch,s,Nb} \cdot \psi_{ch,c,Nb} \cdot \psi_{ch,h,Nb} \tag{7.16}$$

The different factors in Equation (7.16) are given in the following.

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

The characteristic resistance of a single anchor $N_{Rk,cb}^{0}$ is calculated according to Equation (7.17).

$$N_{Rk,cb}^{0} = k_5 \cdot c_1 \cdot \sqrt{A_h} \cdot \sqrt{f_{ck}} \tag{7.17}$$

where

k_5 = 8,7 for cracked concrete;

= 12,2 for uncracked concrete.

A_h as defined in Equation (7.4) or given in the relevant ETA.

The influence of neighbouring anchors on the blow-out resistance is taken into account by the factor $\psi_{ch,s,Nb}$, which may be calculated analogous to Equation (7.7) using $s_{cr,Nb} = 4\ c_1$ instead of $s_{cr,N}$.

The influence of a corner of the concrete member on the characteristic resistance is taken into account by the factor $\psi_{ch,c,Nb}$, which is calculated according to Equation (7.18):

$$\psi_{ch,c,Nb} = \left(\frac{c_2}{c_{cr,Nb}}\right)^{0,5} \leq 1 \tag{7.18}$$

with

c_2 = corner distance of the anchor, for which the resistance is calculated (Figure 7.5)

$c_{cr,Nb} = 0,5\ s_{cr,Nb}$

If an anchor is influenced by two corners (example see Figure 7.5 c)), the factor $\psi_{ch,c,Nb}$ shall be calculated for the values of $c_{2,1}$ and $c_{2,2}$ and the product of the factors shall be inserted in Equation (7.16).

The influence of the thickness of the concrete member for $f \leq 2\ c_1$ (see Figure 7.6) is taken into account by the factor $\psi_{ch,h,Nb}$ according to Equation (7.19).

$$\psi_{ch,h,Nb} = \frac{h_{ef} + f}{4c_1} \leq \frac{2c_1 + f}{4c_1} \leq 1 \tag{7.19}$$

with

f = distance between the anchor head and the lower surface of the concrete member (Figure 7.6).

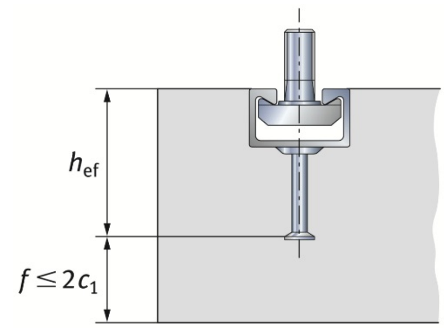


Figure 7.6 Anchor channel at the edge of a thin concrete member

7.2.8 Failure of supplementary reinforcement

7.2.8.1 Steel failure

The characteristic yield resistance of the supplementary reinforcement $N_{Rk,re}$ is given by:

$$N_{Rk,re} = \sum_{i=1}^{n_{re}} A_{s,re,i} \cdot f_{yk,re} \tag{7.20}$$

with

$f_{yk,re}$ $\leq$ 600 N/mm²

n_{re} = number of bars of supplementary reinforcement effective for one anchor

7.2.8.2 Anchorage failure

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

$$N_{Rd,a} = \sum_{i=1}^{n_{re}} N^0_{Rd,a,i} \tag{7.21}$$

with

$$N^0_{Rd,a} = \frac{l_1 \cdot \pi \cdot \phi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2} \leq A_{s,re} \cdot f_{yk,re} \cdot \frac{1}{\gamma_{Ms,re}} \tag{7.22}$$

l_1 = anchorage length in the break out body (see Figure 7.1); l_1 has to be larger than the minimum anchorage length in section 7.2.2 d);

f_{bd} = design bond strength according to EN 1992-1-1:2004/AC:2010, 8.4.2

α_1, α_2 = influencing factors according to EN 1992-1-1:2004/AC:2010, 8.4.4

7.3 Shear load V_{Ed} acting transverse to the longitudinal axis of the channel

7.3.1 Required verifications

The verifications of Table 7.2 apply.

For the design approach using supplementary reinforcement, the verification of concrete edge failure according to Table 7.2, line 7 is replaced by the verification of the supplementary reinforcement according to Table 7.2, line 8 and 9 to resist the total load.

7.3.2 Detailing of supplementary reinforcement

The supplementary reinforcement shall be in the form of a surface reinforcement (Figure 7.7).

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 rebar 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.

If the shear force is taken up by a surface reinforcement according to Figure 7.7, the bars shall only be assumed to be effective if the following requirements are fulfilled:

a) Supplementary reinforcement determined for the most loaded anchor, shall be placed around each anchor considered effective for concrete edge failure.

b) The supplementary reinforcement consists of ribbed bars with $f_{yk} \leq 600$ 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 $0{,}75 \cdot c_1$ from the anchor.

d) The anchorage length l_1 in the concrete breakout body is at least

   min $l_1 = 10\ \phi$, straight bars with or without welded transverse bars

   $= 4\ \phi$ bars with a hook, bend or loop

e) The breakout body assumed should be the same as that for calculating the resistance for concrete edge failure (see section 7.3.5).

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.

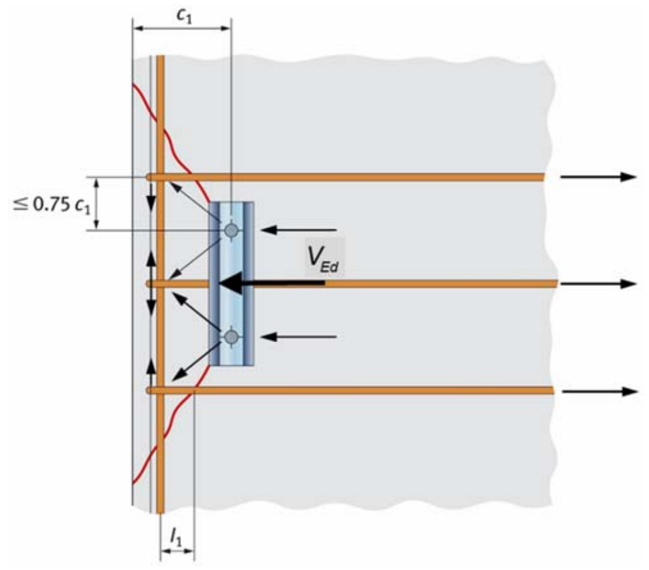
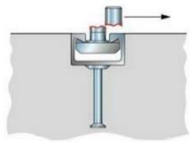
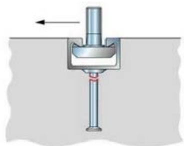
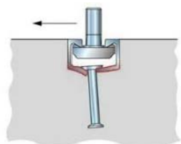
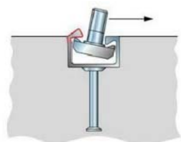
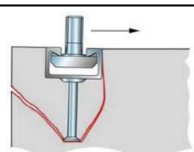
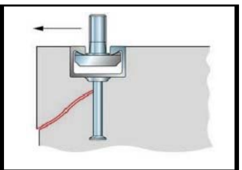
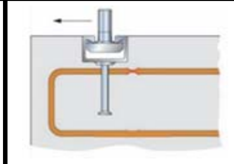
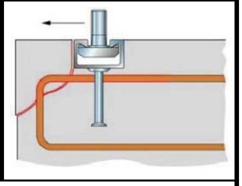


Figure 7.7 Surface reinforcement to take up shear forces with simplified strut and tie model to design edge reinforcement

Table 7.2 Verifications for anchor channels under shear load V_{Ed} acting transverse to the longitudinal channel axis

	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		$V_{Ed}^{cb} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	
6	**Pry-out failure** [b]				$V_{Ed}^{a} \leq V_{Rd,cp} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$	

7	**Concrete edge failure** [b]		$V_{Ed}^{a} \le V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$	
8	**Steel failure of supplementary reinforcement** [c]		$N_{Ed,re}^{a} \le N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	
9	**Anchorage failure of supplementary reinforcement** [c]		$N_{Ed,re}^{a} \le N_{Rd,a}$	

[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 Equation (6.6) for the most loaded anchor.

7.3.3 Steel failure

7.3.3.1 Shear force without lever arm

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 $V_{Rk,s,l}^{0}$ (basic value for failure due to local flexure of channel lips) are given in the relevant ETA. The characteristic resistance $V_{Rk,s,l}$ for lip failure is

$$V_{Rk,s,l} = V_{Rk,s,l}^{0} \cdot \psi_{l,V} \tag{7.23}$$

with

$$\psi_{l,V} = 0,5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,V}}\right) \le 1 \tag{7.24}$$

where

s_{cbo} = spacing of channel bolts.

$s_{l,V}$ = characteristic spacing for channel lip failure under shear, taken from the ETA.

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

7.3.3.2 Shear force with lever arm

The characteristic resistance of a channel bolt in case of steel failure, $V_{Rk,s,M}$, shall calculated according to Equation (7.25).

$$V_{Rk,s,M} = \frac{\alpha_M \cdot M_{Rk,s}}{l_a} \tag{7.25}$$

with

α_M as defined in section 6.3

$$M_{Rk,s} = M_{Rk,s}^{0} \cdot \left(1 - N_{Ed}^{cb} / N_{Rd,s}\right) \tag{7.26}$$

$$N_{Rd,s} = N_{Rk,s} / \gamma_{Ms} \tag{7.27}$$

$M_{Rk,s}^{0}$ = characteristic bending resistance of the channel bolt, given in the relevant ETA

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

7.3.4 Concrete pry-out failure

The characteristic resistance of the most unfavourable anchor for concrete pry-out failure shall be calculated as follows:

a) Anchor channels without supplementary reinforcement

$$V_{Rk,cp} = k_8 \cdot N_{Rk,c} \qquad (7.28)$$

with

k_8 = factor to be taken from the relevant ETA

$N_{Rk,c}$ according to section 7.2.5, determined for the anchors loaded in shear.

b) Anchor channels with supplementary reinforcement

$$V_{Rk,cp} = 0,75 \cdot k_8 \cdot N_{Rk,c} \qquad (7.29)$$

7.3.5 Concrete edge failure

The characteristic resistance of one anchor loaded perpendicular to the edge corresponds to

$$V_{Rk,c} = V^0_{Rk,c} \times \psi_{ch,s,V} \times \psi_{ch,c,V} \times \psi_{ch,h,V} \times \psi_{ch,90°,V} \times \psi_{re,V} \qquad (7.30)$$

The various factors of Equation (7.30) are given in the following. 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:

$$V^0_{Rk,c} = k_{12} \cdot \sqrt{f_{ck}} \cdot c_1^{4/3} \qquad (7.31)$$

with

k_{12} = $k_{cr,v}$ for cracked concrete

= $k_{ucr,v}$ for uncracked concrete

$k_{cr,v}$ and $k_{ucr,v}$ are given in the relevant ETA.

The influence of neighbouring anchors on the concrete edge resistance is taken into account by the factor $\psi_{ch,s,V}$ according to Equation (7.32):

$$\psi_{ch,s,V} = \frac{1}{1 + \sum_{i=1}^{n_{ch,V}} \left[\left(1 - \frac{s_i}{s_{cr,V}}\right)^{1,5} \cdot \frac{V_i}{V_0} \right]} \leq 1,0 \qquad (7.32)$$

with (see Figure 7.8):

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

$\leq s_{cr,V}$

$s_{cr,V} = 4\ c_1 + 2\ b_{ch}$, where the conditions $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$ are fulfilled (7.33)

$s_{cr,V}$ = to be taken from the relevant ETA 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 Equation (7.33)

V_i = shear force of an influencing anchor

V_0 = shear force of the anchor under consideration

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

It should be noted that in Equation (7.32) it is assumed that all shear forces on the anchors are acting towards the edge. Shear forces on anchors acting away from the edge may be neglected.

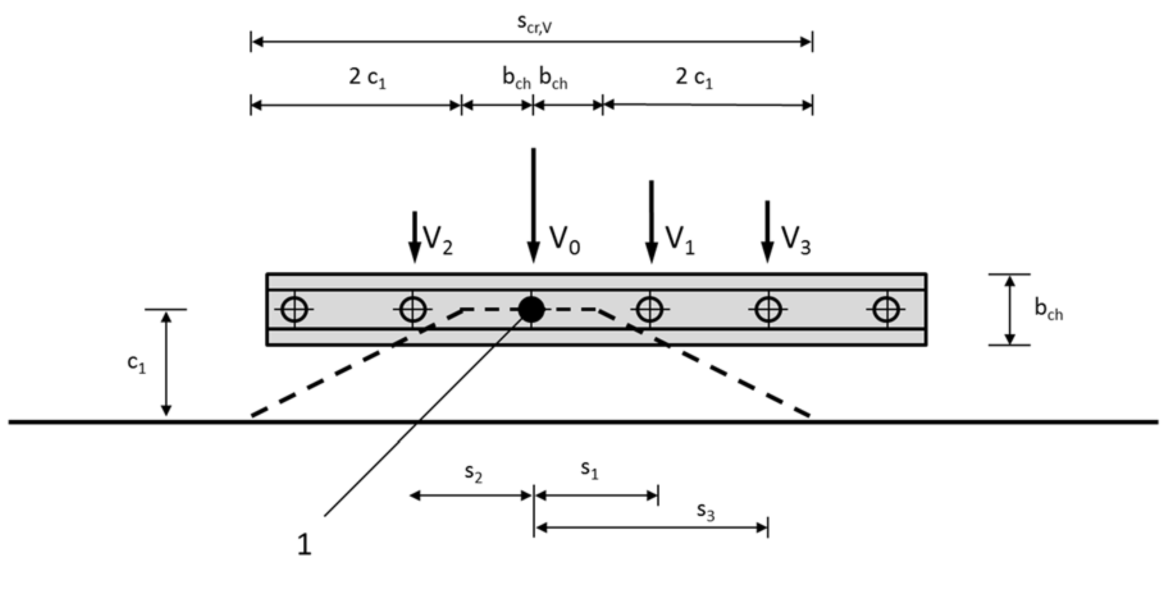


Figure 7.8 Anchor channel with different anchor shear forces - example

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

$$\psi_{ch,c,V} = \left(\frac{c_2}{c_{cr,V}}\right)^{0,5} \leq 1 \tag{7.34}$$

with

$$c_{cr,V} = 0,5\, s_{cr,V} \tag{7.35}$$

If an anchor is influenced by two corners (Figure 7.9 b)), the factor $\psi_{ch,c,V}$ according Equation (7.34) shall be calculated for each corner and the product shall be inserted in Equation (7.30).

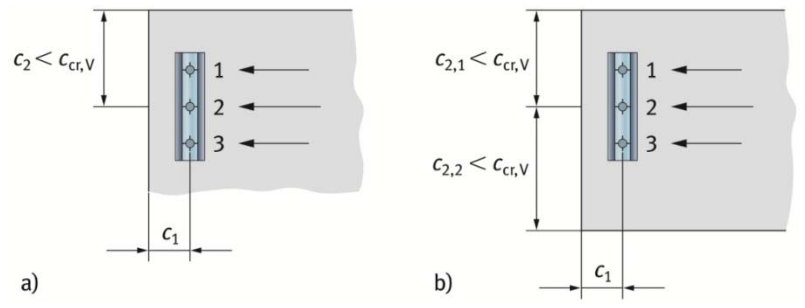


Figure 7.9 Anchor channel with anchors influenced by one (a)) or two (b)) corners, anchor 2 is under consideration - example

The factor $\psi_{ch,h,V}$ accounts for the influence of a member thickness $h < h_{cr,V}$.

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0,5} \leq 1 \tag{7.36}$$

with

$h_{cr,V} = 2\, c_1 + 2\, h_{ch}$ (see Figure 7.10); if $h_{ch}/h_{ef} \leq 0,4$ and $b_{ch}/h_{ef} \leq 0,7$ are fulfilled (7.37)

$h_{cr,V}$ = to be taken from the relevant ETA if $h_{ch}/h_{ef} > 0,4$ and/or $b_{ch}/h_{ef} > 0,7$. The value of $h_{cr,V}$ used in design shall not be smaller than the value according to Equation (7.37).

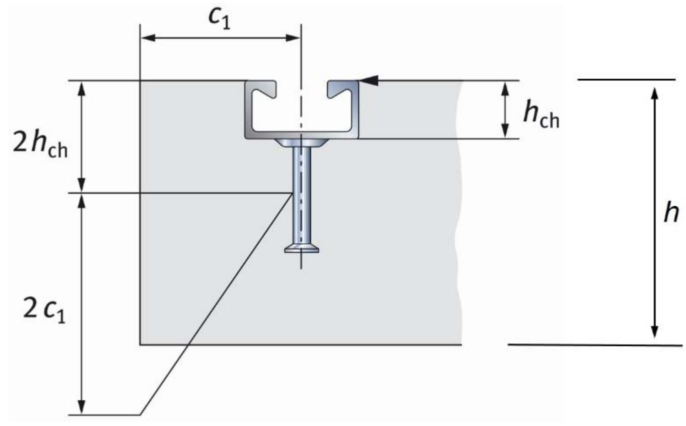


Figure 7.10 Anchor channel influenced by the member thickness – example

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

$\psi_{re,V} = 1{,}0$ anchor channels in cracked concrete without edge reinforcement or stirrups as well as in uncracked concrete

$\psi_{re,V} = 1{,}2$ anchor channels in cracked concrete with edge reinforcement ($d_s \geq 12$ mm)

$\psi_{re,V} = 1{,}4$ anchor channels in cracked concrete with edge reinforcement and closely spaced stirrups or wire mesh with a spacing $a \leq 100$ mm and $a \leq 2c_1$

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.

The factor $\psi_{ch,90°,V}$ takes into account the influence of shear loads acting parallel to the edge (Figure 7.11).

$$\psi_{ch,90°,V} = 2{,}5 \tag{7.38}$$

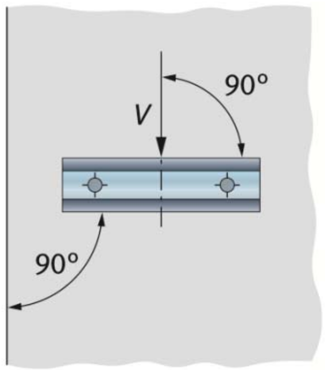


Figure 7.11 Anchor channel loaded parallel to the edge

For an anchor channel in a narrow thin member (see Figure 7.12) with $c_{2,max} \leq c_{cr,V}$ ($c_{cr,V}$ according to Equation (7.35)) and $h < h_{cr,V}$ ($h_{cr,V}$ according to Equation (7.37)), the calculation according to Equation (7.30) leads to conservative results. More precise results are achieved if the edge distance c_1 is limited to c_1' :

$$c_1' = max\left\{\frac{c_{2,max} - b_{ch}}{2}; \frac{h - 2h_{ch}}{2}\right\} \tag{7.39}$$

with

$c_{2,max}$ = max {$c_{2,1}$; $c_{2,2}$}, largest of the two edge distances parallel to the direction of load

The value c_1' is inserted in Equations (7.31), (7.33) and (7.37).

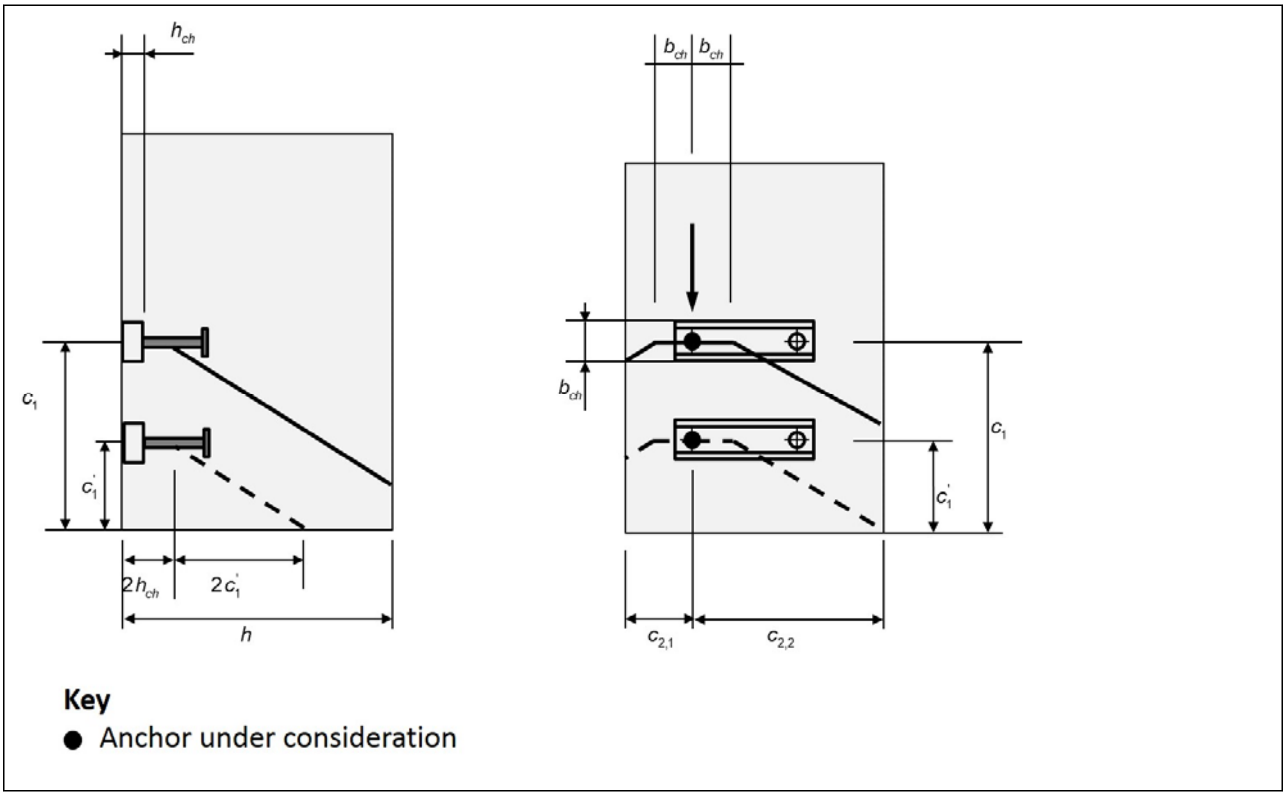


Figure 7.12 Illustration of an anchor channel influenced by two corners and member thickness (in this example $c_{2,2}$ is decisive for the determination of c_1')

7.3.6 Supplementary reinforcement

7.3.6.1 Steel failure

In case of steel failure of the supplementary reinforcement the relevant provision of section 7.2.8.1 applies.

Alternatively the verifications acc. to Annex A may be applied.

7.3.6.2 Anchorage failure

In case of anchorage failure of the supplementary reinforcement in the concrete cone the relevant provision of section 7.2.8.2 applies.

Alternatively the verifications acc. to Annex A may be applied.

7.4 Combined tension and shear loads

7.4.1 Anchor channels without supplementary reinforcement

The required verifications in the following sections shall be carried out separately for each steel failure mode and in addition for all concrete failure modes. All verifications shall be fulfilled.

7.4.1.1 Steel failure of channel bolts

The following verification shall be fulfilled:

$$\left(\frac{N_{Ed}^{cb}}{N_{Rd,s}}\right)^2 + \left(\frac{V_{Ed}^{cb}}{V_{Rd,s}}\right)^2 \leq 1 \qquad (7.40)$$

The characteristic steel resistances $N_{Rd,s}$ and $V_{Rd,s}$ of the channel bolt shall be taken from the relevant ETA. This verification is not required in case of shear load with lever arm as Equation (7.26) accounts for the interaction.

7.4.1.2 Steel failure of channel lips and flexural failure of channel

The following verification shall be fulfilled.

$$max\left(\frac{N_{Ed}^{cb}}{N_{Rd,s,l}};\frac{M_{Ed}^{ch}}{M_{Rd,s,flex}}\right)^{k_{13}}+\left(\frac{V_{Ed}^{cb}}{V_{Rd,s,l}}\right)^{k_{13}}\le 1 \qquad (7.41)$$

with

k_{13} = 2,0 if $V_{Rd,s,l} \le N_{Rd,s,l}$
= to be taken from the relevant ETA if $V_{Rd,s,l} > N_{Rd,s,l}$,
= 1,0 as a conservative assumption

The design resistances $N_{Rd,s,l}$, $M_{Rd,s,flex}$ and $V_{Rd,s,l}$ shall be determined from the corresponding characteristic values given in the relevant ETA.

7.4.1.3 Steel failure of anchor and connection between anchor and channel

The following verification shall be fulfilled

$$max\left(\frac{N_{Ed}^{a}}{N_{Rd,s,a}};\frac{N_{Ed}^{a}}{N_{Rd,s,c}}\right)^{k_{14}}+max\left(\frac{V_{Ed}^{a}}{V_{Rd,s,a}};\frac{V_{Ed}^{a}}{V_{Rd,s,c}}\right)^{k_{14}}\le 1 \qquad (7.42)$$

with

k_{14} = 2,0 if max ($V_{Rd,s,a};V_{Rd,s,c}$) ≤ min ($N_{Rd,s,a}$, $N_{Rd,s,c}$)
= to be taken from the relevant ETA if max ($V_{Rd,s,a};V_{Rd,s,c}$) > min ($N_{Rd,s,a}$, $N_{Rd,s,c}$)
= 1,0 as a conservative assumption

The design resistances $N_{Rd,s,a}$, $N_{Rd,s,c}$, $V_{Rd,s,a}$ and $V_{Rd,s,c}$ shall be determined from the corresponding characteristic values given in the relevant ETA.

7.4.1.4 Concrete failure modes

The following interaction equation shall be fulfilled:

$$\left(\frac{N_{Ed}^{a}}{N_{Rd}}\right)^{1,5}+\left(\frac{V_{Ed}^{a}}{V_{Rd}}\right)^{1,5}\le 1 \qquad (7.43)$$

Alternatively, Equation (7.44) may be used.

$$\left(\frac{N_{Ed}^{a}}{N_{Rd}}\right)+\left(\frac{V_{Ed}^{a}}{V_{Rd}}\right)\le 1,2 \qquad (7.44)$$

The largest value $\left(N_{Ed}^{a}/N_{Rd,i}\right)\le 1$ for the tension failure modes (concrete cone, pull-out, splitting and blow-out failure) and $\left(V_{Ed}^{a}/V_{Rd,i}\right)\le 1$ for the failure modes under shear loading (concrete edge failure, pry-out failure) shall be inserted for $\left(N_{Ed}^{a}/N_{Rd}\right)$ and $\left(V_{Ed}^{a}/V_{Rd}\right)$ in Equation (7.43) and Equation (7.44), respectively.

7.4.2 Anchor channels with supplementary reinforcement

The verifications for each failure mode shall be carried out separately and all verifications shall be fulfilled. The verifications for steel failure of the channel bolt and the anchor channel shall be done according to sections 7.4.1.1 to 7.4.1.3. The verification for concrete failure is given in the following.

7.4.2.1 Supplementary reinforcement to take up tension loads and shear loads

For anchor channels with supplementary reinforcement to take up both tension and shear, the verification according to section 7.4.1.4 shall be carried out replacing both, $N_{Ed}/N_{Rd,i}$ for concrete cone failure mode (tension) and $V_{Ed}/V_{Rd,i}$ for concrete edge failure mode (shear) by the corresponding values for failure of supplementary reinforcement.

7.4.2.2 Supplementary reinforcement to take up tension loads or shear loads

For anchor channels with supplementary reinforcement to take up tension or shear loads the interaction Equation (7.45) replaces Equations (7.43) and (7.44) in the verification according to section 7.4.1.4.

$$\left(\frac{N_{Ed}^{a}}{N_{Rd,i}}\right)+\left(\frac{V_{Ed}^{a}}{V_{Rd,i}}\right)\le 1 \qquad (7.45)$$

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 FIRE RESISTANCE

The verification of anchor channels under fire exposure shall include all failure modes of the cold state (see section 8). The relevant requirements of EN 1992-1-2 [7], e.g. partial factors and load combinations, shall be observed. A design method for anchor channels complementing EN 1992-1-2 is given in the following.

Anchor channels under fire exposure shall have an ETA for use in cracked concrete. The characteristic resistances under fire exposure should be taken from the relevant ETA. In absence of such data conservative values for concrete and pull-out failure modes are given in section 8.3. The verification for steel failure shall be based on the values given in the relevant ETA.

The fire resistance is classified according to EN 13501-2 [9] using the Standard ISO time-temperature curve (STC).

The design method covers anchor channels 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 anchor channel is both, $c \geq 300$ mm and $c \geq 2h_{ef}$. In general, the design under fire exposure is carried out according to the design method for ambient temperature. However, partial factors and characteristic resistances under fire exposure are used instead of the corresponding values under ambient temperature. Spalling of concrete due to fire exposure has to be prevented by appropriate measures or taken into account in the design.

8.1 Partial factors

Partial factors for materials $\gamma_{M,fi}$ may be found in a Country's National Regulation.

Note: The recommended value is $\gamma_{M,fi} = 1,0$.

8.2 Actions

Actions on fastenings under fire exposure should be determined using the load combinations for accidental loads given in EN 1990.

8.3 Resistance

8.3.1 Tension load

8.3.1.1 Pull-out failure

The characteristic resistance of anchor channels installed in concrete classes C20/25 to C50/60 may be obtained from Equations (8.1) and (8.2).

$N_{Rk,p,fi(90)} = 0,25 \cdot N_{Rk,p}$ for fire exposure up to 90 minutes (8.1)

$N_{Rk,p,fi(120)} = 0,20 \cdot N_{Rk,p}$ for fire exposure between 90 and 120 minutes (8.2)

where

$N_{Rk,p}$ = characteristic resistance given in the relevant ETA in cracked concrete C20/25 under ambient temperature

8.3.1.2 Concrete cone failure

The characteristic resistance for concrete cone failure should be determined according to section 7.2.5 with the following modifications. The characteristic resistance of an anchor of anchor channels $N^0_{Rk,c,fi}$ not influenced by neighbouring anchors or edges of the concrete member installed in concrete classes C20/25 to C50/60 may be obtained using Equations (8.3) and (8.4).

$$N^0_{Rk,c,fi(90)} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c} \text{ for fire exposure up to 90 minutes} \quad (8.3)$$

$$N^0_{Rk,c,fi(120)} = 0,8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c} \text{ for fire exposure between 90 and 120 minutes} \quad (8.4)$$

where

h_{ef} = effective embedment depth

$N^0_{Rk,c}$ = characteristic resistance of a single anchor in cracked concrete C20/25 under ambient temperature according to Equation (7.6).

The characteristic spacing and edge distance for anchor channels under fire exposure shall be taken as $s_{cr,N,fi} = 2\ c_{cr,N,fi}$ according to Equation (7.8) but not smaller than 4 h_{ef}.

8.3.1.3 Splitting failure

The assessment of splitting failure due to loading under fire exposure is not required because the splitting forces are assumed to be taken up by the reinforcement.

8.3.1.4 Blow-out failure

The assessment of blow-out failure is not required because of the required edge distance.

8.3.2 Shear load

8.3.2.1 Concrete pry-out failure

The characteristic resistance in case of anchor channels installed in concrete classes C20/25 to C50/60 may be obtained using Equations (8.5) and (8.6).

$V_{Rk,cp,fi(90)} = k_8 \cdot N_{Rk,c,fi(90)}$ for fire exposure up to 90 min (8.5)

$V_{Rk,cp,fi(120)} = k_8 \cdot N_{Rk,c,fi(120)}$ for fire exposure between 90 min and 120 min (8.6)

with

k_8 = factor to be taken from the relevant ETA (ambient temperature)

$N_{Rk,c,fi(90)}$, $N_{Rk,c,fi(120)}$ = calculated according to section 8.3.1.2.

8.3.2.2 Concrete edge failure

The characteristic resistance of an anchor of an anchor channel installed in concrete classes C20/25 to C50/60 should be calculated according to section 7.3.5 with the following modification as expressed in Equations (8.7) and (8.8).

$V^0_{Rk,c,fi(90)} = 0{,}25 \cdot V^0_{Rk,c}$ for fire exposure up to 90 min (8.7)

$V^0_{Rk,c,fi(120)} = 0{,}20 \cdot V^0_{Rk,c}$ for fire exposure between 90 min and 120 min (8.8)

where

$V^0_{Rk,c}$ = initial value of the characteristic resistance of a single anchor in cracked concrete C20/25 under ambient temperature according to section 7.3.5.

8.3.3 Combined tension and shear load

The verifications according to section 7.4 for anchor channels may be used. However, the design actions and design resistances used in these verifications shall correspond to fire exposure.

9 VERIFICATION OF SERVICEABILITY LIMIT STATE

The required verifications are stated in section 4.2. The admissible displacement C_d shall be evaluated by the designer taking into account the type of application at hand (e.g. the structural element to be fastened). The displacements C_d may be assumed to be a linear function of the applied load. In the case of combined tension and shear load, the displacements for the shear and tension components of the resultant load shall be added vectorially.

The characteristic displacement of the anchor channel located in cracked or uncracked concrete under given tension and shear loads shall be taken from the relevant ETA. Loading on anchor channels with supplementary reinforcement may induce cracks locally at SLS and hence shall be taken into account. However, the crack widths are generally acceptable as they are implicitly accounted for in the detailing requirements of the supplementary reinforcement.

10 ADDITIONAL RULES FOR VERIFICATION OF CONCRETE ELEMENTS DUE TO LOADS APPLIED BY ANCHOR CHANNELS

10.1 General

Compliance with the design methods given in this document will result in satisfactory transmission of the loads on the fixture to the concrete member. Safe transmission of the loads applied to the anchor channel to the supports of the concrete member shall be demonstrated for the ultimate limit state and the serviceability limit state according to EN 1992-1-1. The provisions in section 10.2 clarify the methods of complying with EN 1992-1-1, 6.2.1 (9).

10.2 Verification of the shear resistance of the concrete member

In the following it is assumed that the loads on the anchor channel are applied to the tension face of a concrete element.

No additional verification for local transmission of loads is required, if one of the following conditions is met:

a) The shear force V_{Ed} at the support caused by the design actions including the loads acting on the anchor channel is

$V_{Ed} \leq 0{,}8\ V_{Rd,c}$ for a member without shear reinforcement (10.1)

$V_{Ed} \leq 0{,}8 \cdot \min(V_{Rd,s}, V_{Rd,max})$ for a member with shear reinforcement (10.2)

with

$V_{Rd,c}, V_{Rd,s}\ V_{Rd,max}$ = shear resistance according to EN 1992-1-1

b) Under the characteristic combination of actions on the fixture, the resultant tension force N_{Ek} of the tensioned anchor channel is $N_{Ek} \leq 30$ kN and the spacing a between the outermost anchors of adjacent anchor channels satisfies Equation (10.3).

$a \geq 200\ \sqrt{N_{Ek}}$ (10.3)

with N_{Ek} inserted in [kN]

c) The loads acting on the anchor channel 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 anchor 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 anchor channel is $h_{ef} \geq 0{,}8\ h$.

If none of the above conditions a) to d) are fulfilled, the shear forces $V_{Ed,a}$ caused by anchor channel loads shall fulfil the following condition

$V_{Ed,a} \leq 0{,}4\ V_{Rd,c}$ for a member without shear reinforcement (10.4)

$V_{Ed,a} \leq 0{,}4 \cdot min\ (V_{Rd,s}, V_{Rd,max})$ for a member with shear reinforcement (10.5)

When calculating $V_{Ed,a}$ the loads acting on the anchor channel shall be assumed as point loads with a width of load application $t_1 = a_1 + 2\ h_{ef}$, with a_1 equal to the spacing between the outer anchors of an anchor channel in the longitudinal direction 1 . The active width over which the shear force is transmitted shall be calculated according to the theory of elasticity.

If under the characteristic combination of actions on the fixture the resultant tension force N_{Ek} is $N_{Ek} > 60$ kN, the conditions in c) or d) shall be complied with.

11 REFERENCES

[1] CEN/TS 1992-4 series, Design of fastenings for use in concrete, European Committee for Standardization (CEN), Brussels, Belgium, 2009.

[2] EAD 330008-01-0601: Anchor channels.

[3] EN 206:2013 Concrete - Specification, performance, production and conformity, European Committee for Standardization (CEN), Brussels, Belgium.

[4] EN 1990: Eurocode – Basis of structural design, European Committee for Standardization (CEN), Brussels, Belgium.

[5] EN 1991, Eurocode 1: Actions on structures, European Committee for Standardization (CEN), Brussels, Belgium.

[6] EN 1992-1-1:2004, Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings, European Committee for Standardization (CEN), Brussels, Belgium, 2004.

[7] EN 1992-1-2, Eurocode 2: Design of concrete structures – Part 1-2: General rules – Structural fire design, European Committee for Standardization (CEN), Brussels, Belgium.

[8] FprEN 1992-4:2015, Design of Fastenings for Use in Concrete, European Committee for Standardization (CEN), Brussels, Belgium (in CEN Formal Vote process, not yet published).

[9] EN 13501-2, Fire classification of construction products and building elements – Part 2: Classification using data from fire resistance tests, excluding ventilation services, European Committee for Standardization (CEN), Brussels, Belgium.

[10] fib bulletin 58, Design of anchorages in concrete, International Federation for Structural Concrete (fib), Lausanne, Switzerland, 2011.

ANNEX A VERIFICATION OF THE SUPPLEMENTARY REINFORCEMENT

A.1 Verifications according to EOTA TR 047, Tab. 7.2

The following verifications only apply in case of loading perpendicular to the edge.

$N^{a}_{Ed,re} \leq N_{Rd,re}$ (1)

and

$N^{a}_{Ed,re} \leq N_{Rd,a}$ (2)

with

$N^{a}_{Ed,re}$ according to EOTA TR 047, Eq. (6.6)

$N_{Rd,re} = N_{Rk,re} / \gamma_{Ms}$ (3)

$N_{Rd,a} = N_{Rk,a} / \gamma_{Mc}$ (4)

with

$N_{Rk,re}$ = characteristic tension resistance of the stirrups effective for the anchor to be verified in case of steel failure acc. to Equation (5)

$N_{Rk,a}$ = characteristic tension resistance of the stirrups effective for the anchor to be verified for bond failure acc. to Equation (6)

$N_{Rk,re} = n \cdot A_s \cdot f_{yk} \leq V_{Rk,re,max}$ (5)

$$N_{Rk,a} = \sum_{i=1}^{n} N_{Rk,a,i} \leq V_{Rk,re,max} \quad (6)$$

with

n = number of stirrups crossing the assumed concrete break-out body with $l_{1,i} \geq 4\,\phi$ (see Fig. A.1 and A.2)

$N_{Rk,a,i}$ = characteristic tension resistance of one stirrup acc. to Equation (8)

$V_{Rk,re,max} = k_{ch} \cdot V_{Rk,c}$ (7)

k_{ch} = 2,50 if h_{ch} > 17mm

= 1,25 if $h_{ch} \leq$ 17mm

$V_{Rk,c}$ according to EOTA TR047, Eq. 7.30

$N_{Rk,a,i} = \psi_{cr} \cdot (N_{Rk,hook,i} + N_{Rk,bond,i}) \leq A_{s,i} \cdot f_{yk}$ (8)

with

$N_{Rk,hook,i} = \psi_1 \cdot \psi_2 \cdot \psi_3 \cdot A_{s,i} \cdot f_{yk} \cdot (f_{ck} / 25)^{0,1}$ (9)

$N_{Rk,bond,i} = \pi \cdot \phi \cdot l'_{1,i} \cdot f_{bk}$ (10)

with

Ψ_1 = 0,67
effectiveness factor for stirrups crossing the assumed break-out crack under an angle of 90° (stirrups 1 in Fig. 1 and Fig. 2) or stirrups inclined to the assumed break-out crack but closest to the anchor under consideration (stirrups 2 in Fig. 1 and Fig. 2)

= 0,11
effectiveness factor for stirrups other than considered for ψ_1 = 0,67 (stirrups 3 in Fig. 2)

$$\Psi_2 = \left(\frac{l_1}{c_1}\right)^{0,4} \cdot \left(\frac{10}{\phi}\right)^{0,25}$$

$\Psi_3 = (\phi_l / \phi)^{2/3} \leq 1,15$

Ψ_{cr}	=	1,0 for fastening in uncracked concrete
	=	0,7 to account for cracks along the longitudinal axis of the stirrups
ϕ	=	diameter of stirrups [mm]
ϕ_l	=	diameter of edge reinforcement [mm]
$l'_{1,i}$	=	$l_{1,i}$ - 3 ϕ [mm]
$l_{1,i}$	=	anchorage length of a stirrup i in the assumed break-out body [mm]
		= $c_1 - c_c - 0.7 \cdot (e_i - b_{ch}) \geq 4\ \phi$ for stirrups crossing the assumed failure crack under an angle < 90°
		= $c_1 - c_c \geq 4\ \phi$ for stirrups crossing the assumed failure crack under an angle of 90°
c_1	=	edge distance [mm]
c_c	=	concrete cover of stirrups in direction to the edge (see Fig. 1 and 2) [mm]
e_i	=	distance of the stirrup leg from the anchor under consideration [mm]
b_{ch}	=	width of the anchor channel [mm]
A_s	=	cross section of one leg of the stirrup [mm²]
f_{yk}	=	characteristic yield strength of the reinforcement [N/mm²]
f_{ck}	=	characteristic compressive cylinder strength of the concrete [N/mm²]
f_{bk}	=	characteristic bond strength = $\gamma_c \cdot f_{bd}$ [N/mm²]
f_{bd}	=	design bond strength according to EN 1992-1 [N/mm²]
a	=	spacing of stirrups [mm]

A.2 Requirements on the supplementary reinforcement

(1) spacing of stirrups:

$$50\,\text{mm} \leq a \leq \begin{cases} s \\ 150\,\text{mm} \\ (c_1 - c_c + 0{,}7 \cdot b_{ch} - 4 \cdot \phi)/0{,}35 \\ c_1 - c_c \end{cases}$$

(2) diameter of stirrups: 6 mm ≤ ϕ ≤ 16 mm
every stirrup with the same diameter

(3) diameter of edge reinforcement $\phi_l \geq \phi$

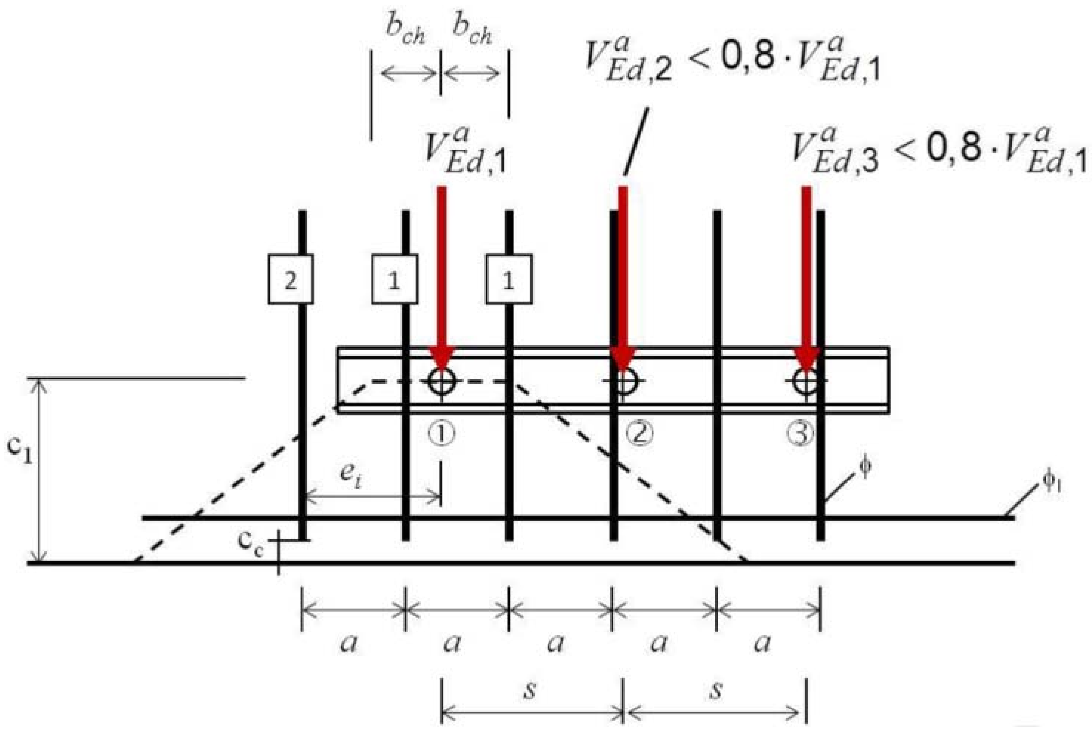


Fig. A.1: Verification of most unfavourable anchor 1 - $V^a_{Ed,2} < 0,8 \cdot V^a_{Ed,1}$. crack formation independent of anchor spacing s

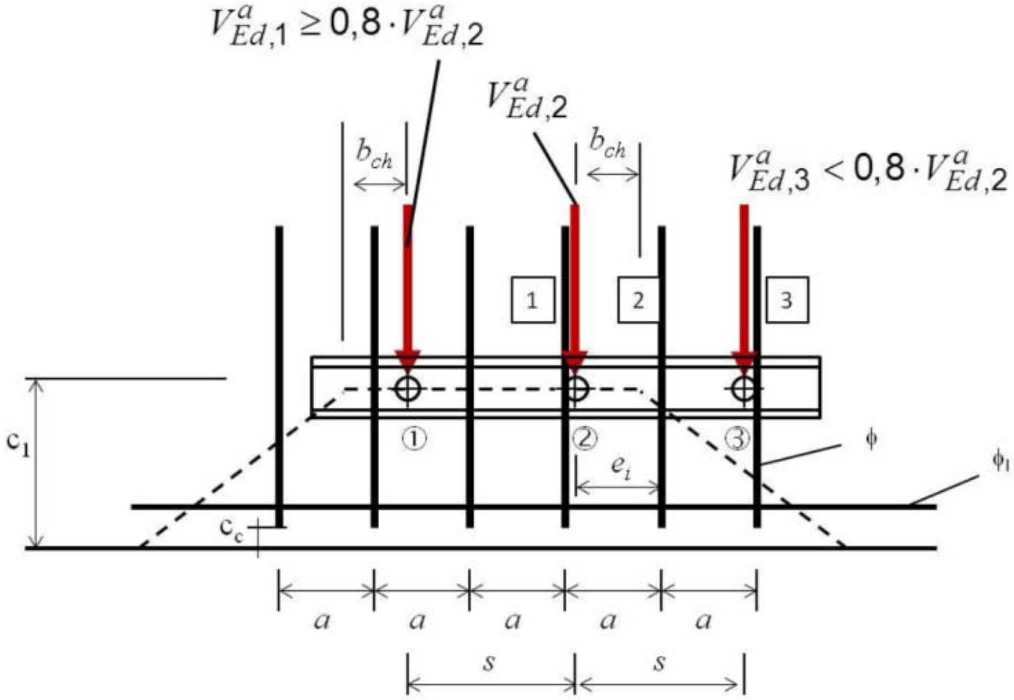


Fig. A.2: Verification of most unfavourable anchor 2 - $V_{aEd,1} \geq 0,8 \cdot V_{aEd,2}$ and $V_{aEd,3} < 0,8 \cdot V_{aEd,2}$ and $s < s_{cr,V}$

ANNEX B VERIFICATION OF SHEAR LOADS ACTING IN DIRECTION OF THE LONGITUDINAL AXIS OF THE CHANNEL

B.1 Introduction

This Annex provides supplementary rules for the design of anchor channels for cases not currently covered by EOTA/TR 047, namely,

— the design of anchor channels subject to shear force acting in the longitudinal direction of the channel;

— the design for the combined action of longitudinal shear, transverse shear and tension load acting on the anchor channel; and

NOTE The proposed design method for shear loading acting in longitudinal direction of the channel can be realized only if the relevant parameters as specified in this Annex, e.g. characteristic resistances and product dependent partial factors are given in a European Technical Product Specification.

B.2 Scope

EOTA/TR 047 covers anchor channels located in cracked or uncracked concrete subjected to tensile loads and/or shear loads transverse to the longitudinal channel axis as well as combinations of these loads. Shear loads acting in direction of the longitudinal axis of the channel and combinations of shear loads acting transverse and in direction of the longitudinal axis of the channel, combinations of tensile loads and shear loads acting in direction of the longitudinal axis of the channel and combinations of loads in all three directions are excluded.

This Annex provides design rules for anchor channels under static and quasi-static shear loads acting in direction of the longitudinal channel axis and all possible combinations of shear and tension loads acting on the channel. All relevant failure modes are considered and shall be verified.

The design rules in this document are only valid for anchor channels with a European Technical Product Specification. The design provisions for shear loads acting in direction of the longitudinal axis of the channel cover the following anchor channels and applications:

— Anchor channels with 2 or 3 anchors.

— Anchor channels where the shear load in the longitudinal axis of the channel is transferred to the channel by corresponding locking channel bolts creating mechanical interlock by means of a notch in the channel lips or serrated channel bolts which interlock with serrated lips of the channel (Figure B.1).

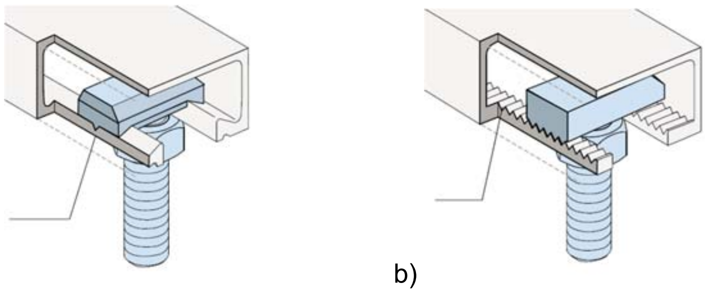
— Anchor channels produced from steel with at least two metal anchors rigidly connected to the back of the channel (e.g. by welding, forging or screwing). The anchor channels are placed flush with the concrete surface. A fixture is connected to the anchor channel by channel bolts with nut and washer.

— Anchor channels close to the edge placed either parallel or transverse to the edge of the concrete member. The design provisions for concrete edge failure do not cover channel orientations inclined to the concrete edge.

The design method for anchor channels loaded in shear in direction of the longitudinal axis of the channel follows closely the existing design model for headed fasteners. For reasons of simplicity modifications specific for anchor channels are used where necessary.

The design provisions for the supplementary reinforcement to take up shear loads in case of anchor channels situated parallel to the edge and loaded in shear transverse to the longitudinal axis apply to anchor channels with unlimited number of anchors.

Examples of anchor channels and channel bolts ensuring mechanical interlock are given in Figure B.1.



a) b)

Fig. B.1: Anchor channels with mechanical interlock – Examples
a) notching channel bolt creating a notch in the channel
b) channel with serrated lips and matching serrated channel bolt

B.3 Additional terms, definitions and symbols

For the purposes of this annex, the terms and definitions given in EOTA/TR 047 and the following apply.

NOTE This clause includes only terms, definitions and symbols supplementary to EOTA/TR 047.

B.3.1 Terms and definitions

notching channel bolt
channel bolt creating a notch in the channel lip to transfer a shear load by mechanical interlock in the longitudinal axis of the channel (Figure B.1a)).

locking channel bolt
channel bolt interlocking with serrated channels by means of matching serrations (Figure B.1b)).

serrated channel
anchor channel with special serrations formed into the lips of the channel. The channel bolts used to fix to this channel have matching serrations (Figure B.1b)).

direction x
direction in the longitudinal axis of the channel

direction y
direction transverse to the longitudinal axis of the channel

B.3.2 Symbols

N_{Ed}^{a}	design tension force acting on the anchor
N_{Ed}^{cb}	design tension force acting on the channel bolt
N_{Ed}^{ch}	design tension force acting on the channel
$N_{Rd,i}$	design tension resistance for a certain failure mode
$N_{Rd,s}$	design tension resistance for steel failure modes, in general
$N_{Rd,s,a}$	design tension steel resistance of the anchor
$N_{Rd,s,c}$	design tension steel resistance of the connection between channel and anchor
$N_{Rd,s,cb}$	design tension steel resistance of the channel bolt
$N_{Rd,s,l}$	design tension steel resistance of the channel lip and mechanical interlock

$V^{a}_{Ed,x}$	design shear force acting on the anchor in direction of the channel axis
$V^{a}_{Ed,y}$	design shear force acting on the anchor transverse to the channel axis
$V^{cb}_{Ed,x}$	design shear force acting on the channel bolt in direction of the channel axis
$V^{cb}_{Ed,y}$	design shear force acting on the channel bolt transverse to the channel axis
$V_{Rd,s}$	design shear resistance for steel failure modes, in general
$V_{Rd,s,a}$	design shear steel resistance of the anchor
$V_{Rd,s,a,x}$	design shear steel resistance of the anchor in direction of the x-axis
$V_{Rd,s,a,y}$	design shear steel resistance of the anchor in direction of the y-axis
$V_{Rd,s,c,x}$	design shear steel resistance of the connection between anchor and channel in direction of the x-axis
$V_{Rd,s,c,y}$	design shear steel resistance of the connection between anchor and channel in direction of the y-axis
$V_{Rk,s,l,x}$	characteristic steel resistance of the local flexure of the channel in x-direction
$V_{Rk,s,l,y}$	characteristic steel resistance of the local flexure of the channel in y-direction
$V_{Rd,s,l,x}$	design steel resistance of the local flexure of the channel in x-direction
$V_{Rd,s,l,y}$	design steel resistance of the local flexure of the channel in y-direction
$V_{Rk,s,a,x}$	characteristic steel shear resistance of the anchor in direction of the x-axis
$V_{Rk,s,a,y}$	characteristic steel shear resistance of the anchor in direction of the y-axis
$V_{Rk,s,c,x}$	characteristic steel shear resistance of the connection between anchor and channel in direction of the x-axis
$V_{Rd,s,c,x}$	design steel shear resistance of the connection between anchor and channel in direction of the x-axis
$V_{Rk,s,c,y}$	characteristic steel shear resistance of the connection between anchor and channel in direction of the y-axis
$V_{Rk,s,M}$	characteristic steel shear resistance for shear force with lever arm
$V_{Rd,s,M}$	design steel shear resistance for shear force with lever arm
ψ_{cr}	factor to account for cracks along the longitudinal axis of the stirrups
$s_{l,V}$	characteristic spacing for channel lip failure under shear
s_{cbo}	spacing of channel bolts
$A_{s,a}$	stressed cross section area of the anchor
$A_{s,cb}$	stressed cross section area of the channel bolt
$f_{uk,a}$	nominal ultimate steel strength of the anchor
$f_{uk,cb}$	nominal ultimate steel strength of the channel bolt
$\gamma_{Ms,l,x}$	partial factor for steel failure of the channel lips in x-direction
c_{ch}	distance between end of the channel and concrete edge
n_a	number of anchors of an anchor channel
t_w	web thickness of I-anchor
w_A	width (cutting length) of I-anchor

B.4 Basis of design

EOTA/TR 047 applies generally.

The transfer of shear load acting in the direction of the longitudinal axis of the channel by mechanical interlock from the channel bolt to the channel is more sensitive to installation than in the cases of tension and transverse shear loading. For this reason, an additional factor is incorporated in the partial factor for material as follows

$$\gamma_{Ms,l,x} = \gamma_{inst} \cdot \gamma_{Ms,l} \qquad \text{(B.4.1)}$$

where

γ_{inst} product dependent factor to account for sensitivity to installation, given in the relevant European Technical Product Specification.

Anchor channels should provide safe and effective resistance to load. This is ensured by considering the effect of installation conditions on the design resistance via the factor γ_{inst}. For anchor channels that have been qualified to resist shear loads in the longitudinal direction, the value of the factor γ_{inst} which takes into account the sensitivity of the anchor channel to installation to be applied to the verification of the channel lip and mechanical interlock between channel lip and notching channel bolt (Figure B.1a)) or serrated channel lip and matching locking channel bolt (Figure B.1b)) depends mainly on the conversion of torque to tension force on the channel bolt and on inaccuracies in the placement of the channel such as recessed anchor channels. The relationship between torque and tension force can vary considerably for different products. In the prequalification procedure the following parameters governing the installation safety should be considered:

Therefore γ_{inst} must be determined as part of the prequalification of the anchor channel. It is product dependent.

The value of γ_{inst} should not be altered. For the ideal case of anchor channels completely insensitive to installation and installation conditions, γ_{inst} is 1,0. For anchor channels that show sensitivity to the quality of the installation, the value of γ_{inst} is higher.

B.5 Derivation of forces acting on anchor channels - Analysis

B.5.1 General

The loads may act at any arbitrary position of the anchor channel within the length provided by the European Technical Product Specification.

The load directions covered in EOTA/TR 047 and this annex are shown in Figure B.2. The loads may occur in any combination.

Anchor channels transfer tension by means of a channel bolt into the channel and from the channel via anchors fixed to the bottom of the channel profile into the concrete. Shear loads are transferred by means of channel bolt into the channel and from the channel and the anchors into the concrete. For reasons of simplicity in the latter case it is assumed that only the anchors contribute to the load transfer into the concrete. This facilitates the determination of the resistance in case of combined shear and tension loads acting on the anchor channel.

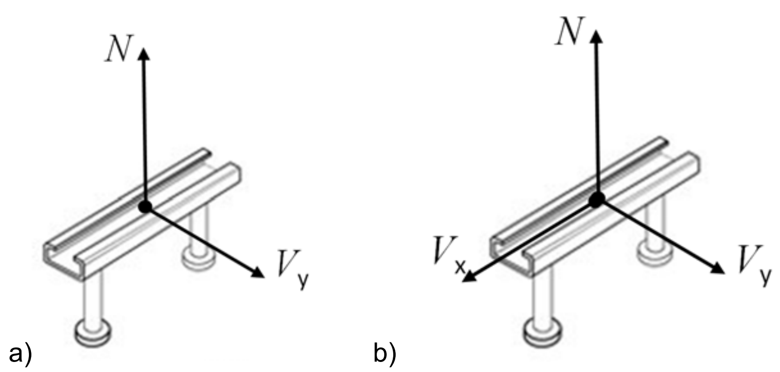


Fig. B.2: Load directions

a) EOTA/TR 047, main part

b) this Annex in conjunction with EOTA/TR 047, main part

The load distribution to the anchors of an anchor channel depends on the load direction and the location of the anchor channel.

For tensile loads and shear loads acting transverse to the longitudinal axis of the channel the loads on the anchors depend on the stiffness of the anchor channel independent of the location of the anchor channel with respect to the edge of the concrete member, see EOTA/TR 047, 6.3.

For shear loads acting in direction of the longitudinal channel axis the following shall be observed:

- In case of anchor channels situated remote from the edge it is assumed that the shear loads are distributed equally to all anchors of the anchor channel, see B.5.3.2.1.
- In case of anchor channels installed transverse and close to the concrete edge for the verification of concrete edge failure only the anchor closest to the edge is considered to carry the shear load (see B.5.3.2.2.1). For the verification of concrete pry-out failure and steel failure of the anchors the shear loads are distributed as for anchor channels remote from the edge.
- In case of anchor channels installed parallel and close to the concrete edge the shear loads are distributed equally to all anchors of the anchor channel, see B.5.3.2.2.3.

B.5.2 Tension loads

EOTA/TR 047, 6.2 applies.

B.5.3 Shear loads

B.5.3.1 Shear loads $V_{Ed,y}$ acting transverse to the longitudinal axis of the channel

EOTA/TR 047, 6.3 applies. V_{Ed} shall be replaced by $V_{Ed,y}$.

B.5.3.2 Shear loads $V_{Ed,x}$ acting in direction of the longitudinal axis of the channel

B.5.3.2.1 Anchor channels remote from edges

Anchor channels are assumed remote from edges if the edge distance in all directions is $c \geq \max(10\ h_{ef}$ or $60\ d_a)$ (Figure B.3).

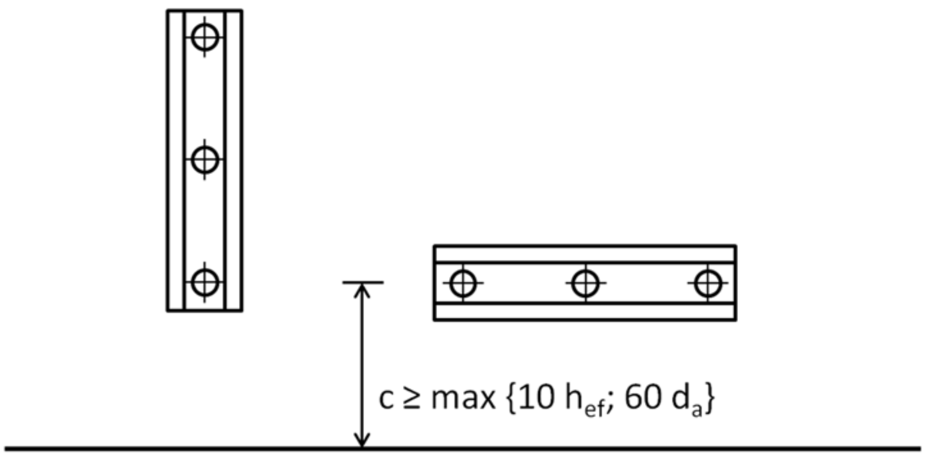


Fig. B.3: Anchor channels remote from the edge – Definition

The shear load $V^a_{Ed,x}$ on each anchor caused by a shear load acting on the channel is calculated according to Equation (B.6.1), which assumes a uniform load distribution on all anchors of the anchor channel ($n_a \leq 3$) (Figure B.4).

$$V_{Ed,x}^{a} = \frac{1}{n_a} \cdot \sum V_{Ed,x}^{cb} \quad \text{(B.6.1)}$$

NOTE In the example given in Figure B.4 the load is distributed equally to n_a = 3 anchors.

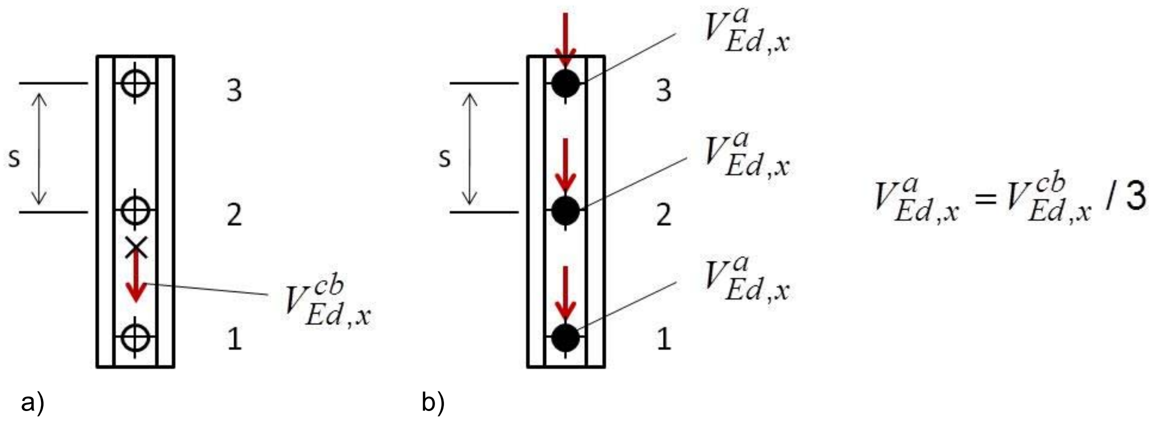


Fig. B.4: Distribution of the acting shear load to the anchors for anchor channels remote from the edge – Example
a) acting shear load
b) load considered acting on the anchor

B.5.3.2.2 Anchor channels situated near an edge

B.5.3.2.2.1 General

Anchor channels are assumed near to the edge if the condition in B.5.3.2.1 is not fulfilled.

B.5.3.2.2.2 Anchor channels installed transverse to the edge

In case of steel failure and concrete pry-out failure the load distribution according to B.5.3.2.1 applies.

In case of concrete edge failure or verification of supplementary reinforcement (B.6.2.3.2) only the anchor closest to the edge is assumed to be effective for the verification of concrete edge failure. Therefore, all shear loads $V_{Ed,x}^{cb}$ acting in direction of the anchor channel (Figure B.5a)) are considered to act on the anchor closest to the edge (Figure B.5b)). This is also valid for anchor channels in narrow concrete members ($c_1 > c_{2i}$; see Figure B.5c)).

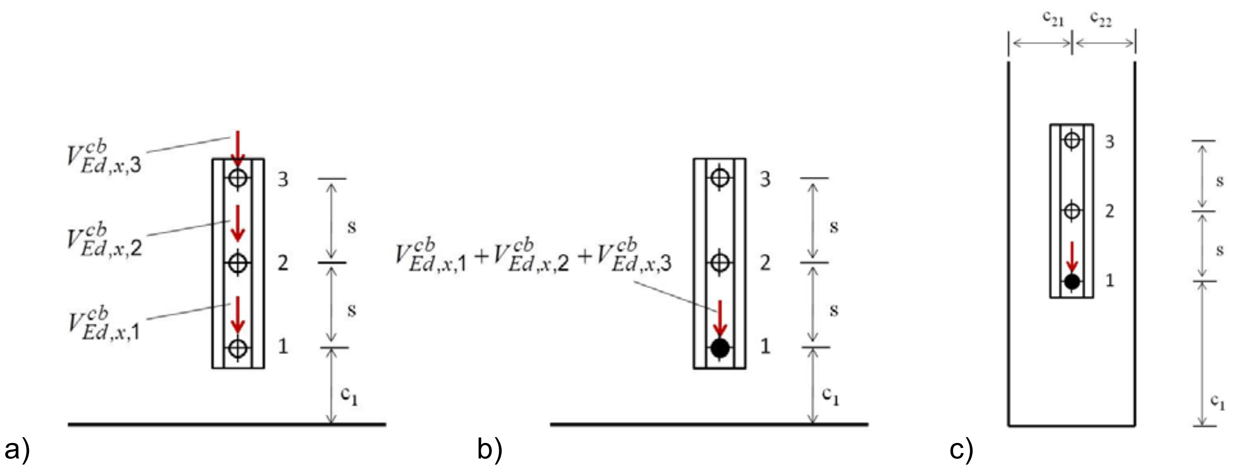


Fig. B.5: Determination of the shear load for anchor channels situated and loaded transverse to the edge

a) acting loads

b) load considered acting on the anchor closest to the edge for verification of concrete edge failure

c) load considered acting on the anchor closest to the verified edge for verification of concrete edge failure in narrow concrete members

B.5.3.2.2.3 Anchor channels installed parallel to the edge

The load distribution according to B.5.3.2.1 applies. An example is given in Figure B.6.

NOTE In the example given in Figure B.6 the load is distributed equally to all 3 anchors of the anchor channel.

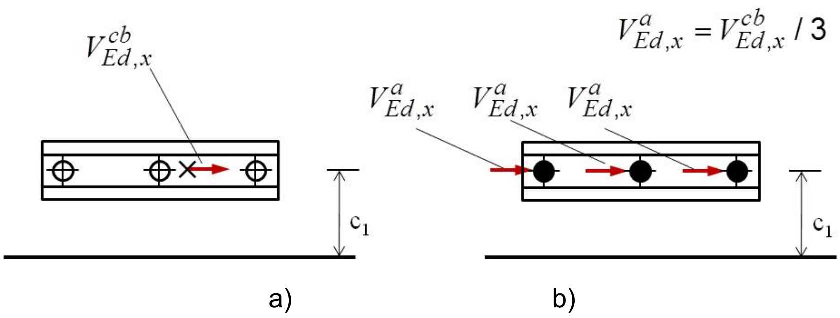


Fig. B.6: Distribution of the shear load to the individual anchors of anchor channels situated parallel to the edge and loaded in direction of the longitudinal axis of the channel

a) acting load

b) load distribution to the anchors

B.6 Verification of ultimate limit state

B.6.1 Tension load

EOTA/TR 047, 7.2 applies.

B.6.2 Shear load

B.6.2.1 Shear loads $V_{Ed,y}$ acting transverse to the longitudinal axis of the channel

EOTA/TR 047, 7.3 applies. V_{Ed} shall be replaced by $V_{Ed,y}$. $V_{Rd,i}$ shall be replaced by $V_{Rd,i,y}$ with index i representing the various failure modes. A refined model for the verification of the resistance of anchor channels with supplementary reinforcement arranged perpendicular to the channel axis is given in Annex A.

B.6.2.2 Shear loads $V_{Ed,x}$ acting in direction of the longitudinal axis of the channel

B.6.2.2.1 Required verifications

The verifications of Table B.1 apply.

- Table B.1, lines 1 to 7 for anchor channels without supplementary reinforcement
- Table B.1, lines 1 to 6 and 8, 9 for anchor channels with supplementary reinforcement

B.6.2.2.2 Steel failure

B.6.2.2.2.1 Channel bolt without lever arm

EOTA/TR 047, 7.3.3 applies

B.6.2.2.2.2 Anchor

The characteristic resistance of an anchor in case of steel failure $V_{Rk,s,a,x}$ for the verification according to Table B.1, line 2 shall be taken from the relevant European Technical Product Specification.

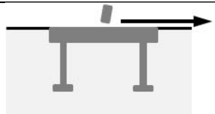
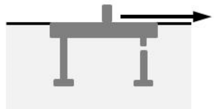
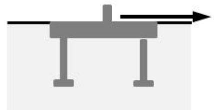
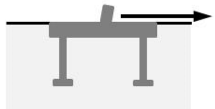
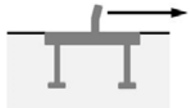
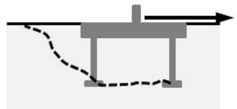
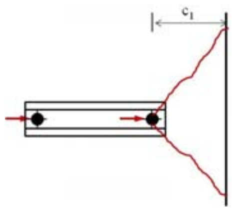
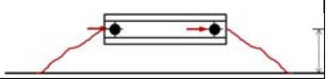
B.6.2.2.2.3 Connection between anchor and channel

The characteristic resistance $V_{Rk,s,c,x}$ of the connection between anchor and channel for the verification according to Table B.1, line 3 shall be taken from the relevant European Technical Product Specification.

B.6.2.2.2.4 Connection between channel bolt and channel

The characteristic resistance $V_{Rk,s,l,x}$ of the channel lips and the mechanical interlock for the verification according to Table B.1, line 4 shall be taken from the relevant European Technical Product Specification.

Table B.1: Verifications for anchor channels under shear load $V_{Ed,x}$ acting in longitudinal axis of the channel

	failure mode			channel	most unfavourable anchor or channel bolt	Failure modes illustrated for anchor channels with n_a = 2 anchors
1	steel failure	shear force without lever arm	channel bolt	-	$V_{Ed,x}^{cb} \leq V_{Rd,s} = V_{Rk,s}/\gamma_{Ms}$	
2			anchor	-	$V_{Ed,x}^{a} \leq V_{Rd,s,a,x} = V_{Rk,s,a,x}/\gamma_{Ms}$	
3			connection between anchor and channel	-	$V_{Ed,x}^{a} \leq V_{Rd,s,c,x} = \frac{V_{Rk,s,c,x}}{\gamma_{Ms,ca}}$	
4			connection between channel bolt and channel lip	$V_{Ed,x}^{cb} \leq V_{Rd,s,l,x} = V_{Rk,s,l,x}/\gamma_{Ms,l,x}$	-	
5		shear force with lever arm	channel bolt	-	$V_{Ed,x}^{cb} \leq V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	
6	pry-out failure			-	$V_{Ed,x}^{a} \leq V_{Rd,cp,x} = V_{Rk,cp,x}/\gamma_{Mc}$ **)	
7	concrete edge failure			-	$V_{Ed,x}^{a} \leq V_{Rd,c,x} = \frac{V_{Rk,c,x}}{\gamma_{Mc}}$ **)	 or 
8	steel failure of supplementary reinforcement			-	$N_{Ed,re,x}^{h} \leq N_{Rd,re} = N_{Rk,re}/\gamma_{Ms,re}$ *)	-
9	anchorage failure of supplementary reinforcement			-	$N_{Ed,re,x}^{h} \leq N_{Rd,a}$ *)	-

*) verification for most loaded anchor. The tension force acting on the reinforcement shall be calculated from V_{Ed} according to EOTA/TR 047, Section 6.4.3, Equ. (6.6)

**) the load on the anchor in conjunction with the edge distance and spacing should be considered in determining the most unfavourable anchor

NOTE The values of the partial factors are given in EOTA/TR 047, Section 4.3.2

B.6.2.2.2.5 Channel bolt with lever arm

The characteristic resistance of the channel bolt in case of steel failure $V_{Rk,s,M}$ for the verification according to Table B.1, line 5 shall be calculated according to EOTA/TR 047, Section 7.3.3.2.

NOTE The influence of the shear load with lever arm on lip failure is covered by the European Technical Product Specification of the anchor channel

B.6.2.2.3 Pryout failure

For the calculation of the characteristic resistance $V_{Rk,cp,x}$ EOTA/TR 047, 7.3.4 applies accordingly.

B.6.2.2.4 Concrete edge failure

B.6.2.2.4.1 General

For reasons of simplicity it is assumed that the shear load acting in the direction of the longitudinal channel axis is taken up by the anchors only. The resistance of the anchors is calculated as for headed anchors assuming the channel profile does not negatively influence the resistance.

B.6.2.2.4.2 Anchor channels installed transverse to the edge

The characteristic resistance of the anchor channel loaded towards the edge is calculated according to Equation (B.6.1).

$$V_{Rk,c,x} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{re,V} \qquad \text{(B.6.1)}$$

The different factors of Equation (B.6.1) are given below.

The initial value of the characteristic resistance of one anchor loaded perpendicular to the edge is calculated as:

$$V^0_{Rk,c} = k_9 \cdot d_a^{\alpha} \cdot h_{ef}^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1,5} \qquad \text{(B.6.2)}$$

with

k_9 = *1,7* for cracked concrete
= *2,4* for uncracked concrete

$$\alpha = 0,1 \cdot \left(\frac{h_{ef}}{c_1} \right)^{0,5}$$

$$\beta = 0,1 \cdot \left(\frac{d_a}{c_1} \right)^{0,2}$$

The value h_{ef} is given in the relevant European Technical Product Specification. With $h_{ef} \leq 12\, d_a$.

For round anchors the value d_a is given in the relevant European Technical Product Specification.

For I-shaped anchors the value of d_a shall be taken as a function of the web thickness (t_w)

$$d_a = \sqrt[4]{\frac{w_A \cdot t_w^3}{12} \cdot \frac{64}{\pi}} \quad \text{and} \qquad \text{(B.6.2a)}$$

the edge distance c_1 shall be taken from the leading edge of the anchor.

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

$= 4,5 \cdot c_1^2$

$A_{c,V}$ is the area of the idealized concrete breakout body, limited by the overlapping concrete cones of adjacent anchors ($s \leq 3c_1$) as well as by edges parallel to the assumed loading direction ($c_2 \leq 1,5c_1$) and by member thickness ($h \leq 1,5c_1$).

The factor ratio $\psi_{s,V}$ takes account of the disturbance of stresses in the concrete due to further edges of the concrete member on the shear resistance. For anchor channels 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 Equation (B.6.3)

$$\psi_{s,V} = 0,7 + 0,3 \cdot \frac{c_2}{1,5 \cdot c_1} \leq 1 \quad \text{(B.6.3)}$$

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

$$\psi_{h,V} = \left(\frac{1,5 \cdot c_1}{h}\right)^{0,5} \geq 1 \quad \text{(B.6.4)}$$

$\psi_{re,V}$ according to Section 7.3.5.

When calculating $V^0_{Rk,c}$, $\psi_{s,V}$, $\psi_{h,V}$, $A_{c,V}$, $A^0_{c,V}$ the edge distance c_1 between front anchor and edge (see Figure B.7) shall be used.

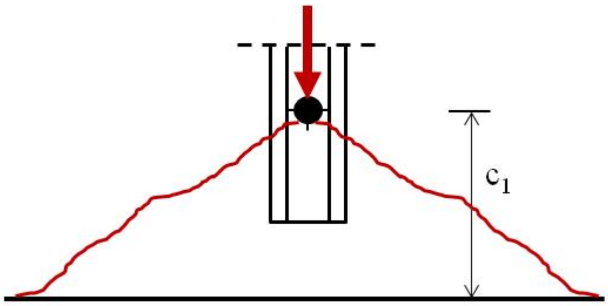


Fig. B.7: Anchor channel configuration

For anchor channels in a narrow, thin member with $c_{2,max} \leq 1,5c_1$ and $h \leq 1,5c_1$ the calculation according to Equation (B.6.1) leads to conservative results. More precise results are achieved if c_1 is replaced by:

$$c_1' = \max\left\{\frac{c_{2,max}}{1,5}; \frac{h}{1,5}\right\} \quad \text{(B.6.5)}$$

where

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

B.6.2.2.4.3 Anchor channels installed parallel to the edge

The characteristic resistance $V_{Rk,c}$ of the most unfavourable anchor for concrete edge failure shall be calculated according to Equation (B.6.6).

$$V_{Rk,c,x} = 2 \cdot V_{Rk,c}^{0} \cdot \frac{A_{c,V}}{A_{c,V}^{0}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{re,V} / n_a \quad \text{(B.6.6)}$$

$V_{Rk,c}^{0}$, $A_{c,V}^{0}$, $A_{c,V}$, $\psi_{s,V}$, $\psi_{h,V}$, $\psi_{re,V}$ see Section B.6.2.2.4.2.

NOTE When calculating the edge resistance of anchor channels loaded in shear in the longitudinal direction of the channel axis it is assumed that the anchors act similar to headed anchors. For a group of headed anchors the resistance is calculated for the whole group. For anchor channels the most loaded anchor is verified. The resistance of one anchor is determined by dividing the group resistance by the number of anchors of the anchor channel loaded in shear (n_a) for which the group resistance is calculated.

B.6.2.2.5 Anchor channels close to an edge with supplementary reinforcement loaded in shear acting in the direction of the longitudinal channel axis

B.6.2.2.5.1 General

The detailing of the supplementary reinforcement shall comply with EOTA/TR 047, 7.3.2.

Only surface reinforcement (stirrups and edge reinforcement) (see EOTA/TR 047, Fig. 7.7) shall be used as supplementary reinforcement.

B.6.2.2.5.2 Anchor channels arranged parallel to the edge

When the design shear force acts parallel to the edge (Fig. B.8) or inclined and away from the edge the supplementary reinforcement may conservatively be designed by assuming that the component of the design shear force parallel to the edge is acting perpendicular and towards to the edge (see EOTA/TR 047, 6.4.3).

The characteristic resistance for steel failure and anchorage failure of the supplementary reinforcement shall be calculated according to EOTA/TR 047, 7.2.8.

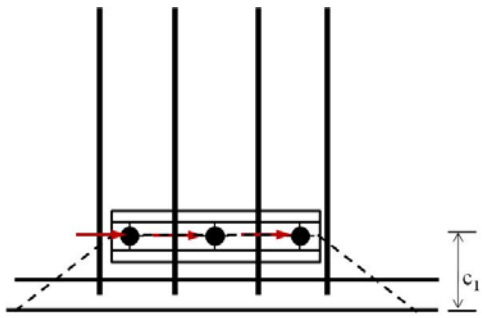


Fig. B.8: Anchor channel with shear load in the longitudinal direction of the channel - Example

B.6.2.2.5.3 Anchor channels arranged perpendicular to the edge

The design is based on the assumption that a load acting in direction of the longitudinal axis of the channel is transferred from the anchor closest to the edge to the stirrups (Figure B.9). Only stirrups with a distance ≤ $0{,}75c_1$ from the anchor shall be assumed as effective.

The characteristic resistance in case of steel failure and in case of anchorage failure of the supplementary reinforcement shall be calculated in accordance with EOTA/TR 047, 7.2.8.

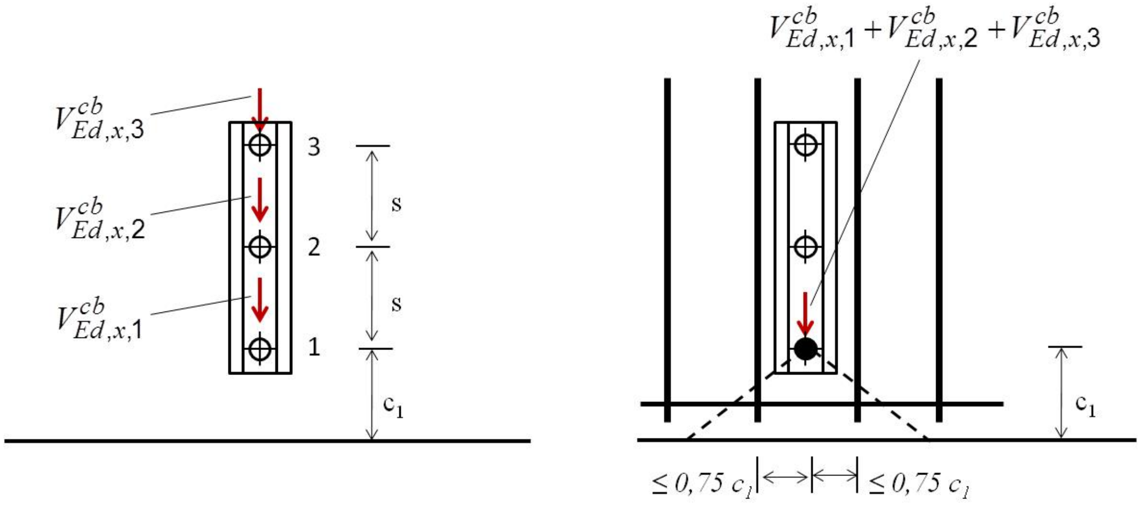


Fig. B.9: Anchor channel with shear load transverse to the edge directed in the longitudinal direction of the channel - Example

B.6.3 Combined tension and shear loads

B.6.3.1 Anchor channels without supplementary reinforcement

B.6.3.1.1 General

The required verifications are given in the following sections. Verifications shall be carried out separately for each steel failure mode and in addition for all failure modes other than steel. All verifications shall be fulfilled. All verifications shall be fulfilled for the most unfavourable anchor. If the most unfavourable anchor cannot be determined the verification shall be fulfilled for all anchors.

B.6.3.1.2 Steel failure of channel bolts

The following verification shall be fulfilled:

$$\left(\frac{N^{cb}_{Ed}}{N_{Rd,s,cb}}\right)^2 + \left(\frac{V^{cb}_{Ed}}{V_{Rd,s,cb}}\right)^2 \leq 1 \qquad \text{(B.6.7)}$$

where:

$$V^{cb}_{Ed} = \left[\left(V^{cb}_{Ed,x}\right)^2 + \left(V^{cb}_{Ed,y}\right)^2\right]^{0,5} \qquad \text{(B.6.8)}$$

The characteristic steel resistances $N_{Rd,s,cb}$ and $V_{Rd,s,cb}$ of the channel bolt shall be taken from the relevant European Technical Product Specification.

Equation (B.6.8) is valid for channel bolts with the same characteristic shear resistances in x-direction and in y-direction.

B.6.3.1.3 Steel failure of channel lips and flexural failure of channel

The following verification shall be fulfilled.

$$\max\left(\frac{N^{cb}_{Ed}}{N_{Rd,s,l}};\frac{M^{ch}_{Ed}}{M_{Rd,s,flex}}\right)^{k_{13}} + \left(\frac{V^{cb}_{Ed,y}}{V_{Rd,s,l,y}}\right)^{k_{13}} \leq \left(1-\frac{V^{cb}_{Ed,x}}{V_{Rd,s,l,x}}\right)^{k_{13}} \qquad \text{(B.6.9)}$$

with

k_{13} = 2,0 if $V_{Rd,s,l,y} \leq N_{Rd,s,l}$
= to be taken from the European Technical Product Specification if $V_{Rd,s,l,y} > N_{Rd,s,l}$, conservatively k_{13} = 1,0 may be taken.

NOTE The basic interaction concept according to Equ. (B.6.9) for anchor channels loaded in either 2 or all 3 directions is shown in Fig. B.10.

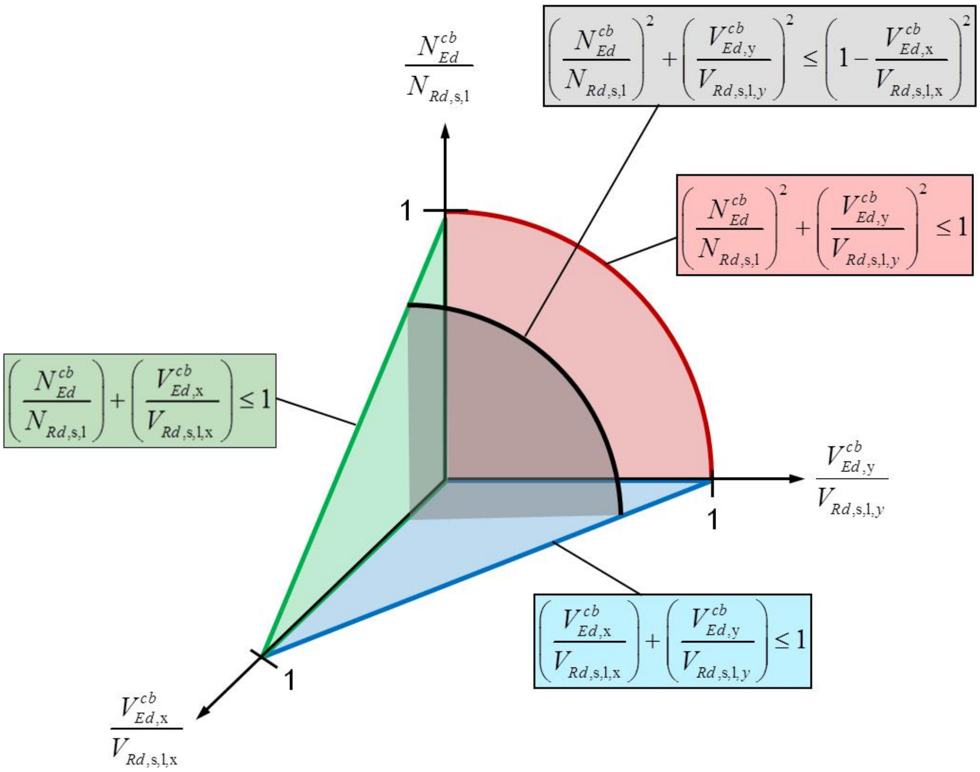


Fig. B.10: Interaction concept for anchor channels

B.6.3.1.4 Steel failure of anchor and connection between anchor and channel

The following verification shall be fulfilled

$$\max\left(\frac{N^a_{Ed}}{N_{Rd,s,a}};\frac{N^a_{Ed}}{N_{Rd,s,c}}\right)^{k_{14}} + \max\left(\frac{V^a_{Ed,y}}{V_{Rd,s,a,y}};\frac{V^a_{Ed,y}}{V_{Rd,s,c,y}}\right)^{k_{14}} \leq \left(1-\max\left(\frac{V^a_{Ed,x}}{V_{Rd,s,a,x}};\frac{V^a_{Ed,x}}{V_{Rd,s,c,x}}\right)\right)^{k_{14}} \qquad \text{(B.6.10)}$$

with

k_{14} = 2,0 if max ($V_{Rd,s,a,y}$;$V_{Rd,s,c,y}$) ≤ min ($N_{Rd,s,a}$, $N_{Rd,s,c}$)
= to be taken from the European Technical Product Specification if max ($V_{Rd,s,a,y}$;$V_{Rd,s,c,y}$) > min ($N_{Rd,s,a}$, $N_{Rd,s,c}$), conservatively k_{14} = 1,0 may be taken.

NOTE The basic interaction concept according to Equ. (B.6.10) for anchor channels loaded in either 2 or all 3 directions is shown in Fig. B.10.

B.6.3.1.5 Concrete failure modes

The following interaction equation shall be fulfilled:

$$\left(\frac{N^a_{Ed}}{N_{Rd}}\right)^{1,5} + \left(\frac{V^a_{Ed,x}}{V_{Rd,x}}\right)^{1,5} + \left(\frac{V^a_{Ed,y}}{V_{Rd,y}}\right)^{1,5} \leq 1 \qquad \text{(B.6.11)}$$

The largest value $\left(N_{Ed}^{a} / N_{Rd}\right)$ for the tension failure modes (concrete cone, pullout, splitting and blow-out failure) and $\left(V_{Ed,x}^{a} / V_{Rd,x}\right)$ as well as $\left(V_{Ed,y}^{a} / V_{Rd,y}\right)$ for the failure modes under shear loading (concrete edge failure, pry-out failure) shall be taken in Eq. (B.6.11).

B.6.3.2 Anchor channels with supplementary reinforcement

B.6.3.2.1 General

The verifications for steel failure of the channel bolt and the anchor channel shall be done according to B.6.3.1.2 to B.6.3.1.4.

The verification for concrete failure is given in the following.

B.6.3.2.2 Supplementary reinforcement to take up tension loads <u>and</u> shear loads in x-direction and y-direction

The interaction equation (B.6.11) shall be fulfilled. However, the following modifications shall be applied:

- the design resistance $N_{Rd,c}$ for concrete cone failure is replaced by the design resistance of the supplementary reinforcement to take up tension loads (minimum value for bond and yielding);
- the design resistance $V_{Rd,c}$ for concrete edge failure for loading in x or y direction is replaced by the corresponding design resistance of the supplementary reinforcement to take up shear loads (minimum value for bond and yielding).

B.6.3.2.3 Supplementary reinforcement to take up tension loads <u>or</u> shear loads in x-direction and y-direction

The interaction equation (B.6.12) shall be fulfilled.

$$\left(\frac{N_{Ed}^{a}}{N_{Rd}}\right)+\left(\frac{V_{Ed,x}^{a}}{V_{Rd,x}}\right)+\left(\frac{V_{Ed,y}^{a}}{V_{Rd,y}}\right)\leq 1 \qquad \text{(B.6.12)}$$

The design resistance $N_{Rd,c}$ for concrete cone failure is replaced by the design resistance of the supplementary reinforcement to take up tension loads (minimum value for bond and yielding) where applicable. The design resistance $V_{Rd,c}$ for concrete edge failure for loading in x and/or y direction is replaced by the corresponding design resistance of the supplementary reinforcement to take up shear loads (minimum value for bond and yielding) where applicable.

B.7 Verification of serviceability limit state

EOTA/TR 047, 9 applies. Furthermore, cracking of the concrete for anchor channels with supplementary reinforcement and for anchor channels installed close to an edge loaded in shear shall be considered.

NOTE In the In case of anchor channels situated transverse to the edge and loaded in shear in direction of the longitudinal channel axis a sufficient gap or cushion in front of the face of the channel prevents premature cracking. This is only valid for anchor channels without supplementary reinforcement.