JORDAHL®

DESIGN OF ANCHOR CHANNELS

VBBF

CONTENT

1 GENERAL

Until now, the design of anchor channels has been carried out on the basis of building approvals from DIBt (Deutsches Institut für Bautechnik – the German institute for structural engineering) [1], [2]. In these approvals, the permissible loads are given in a table (see [1], [2]). They are derived from the results of tests in uncracked concrete using a global safety factor. The permissible loads may also be used in cracked concrete according to the approvals. The approvals only take an imprecise account of effects from the formation of cracks, as the concrete breaking load is reduced by cracks in the concrete (see [13]). It is recommended with high tensile loads to install a reinforcement for anchoring tensile loads and for attachment near the edge to surround the component edge with straight rods and stirrups for taking up shear loads.

In the future, the design will be made according to a CEN Technical Specification (pre-standard) ([5], [6]) in conjunction with a European Technical Approval (ETA, [11], [12]). The CEN-TS ([5], [6]) has appeared in the meantime and has also been published in Europe. The design is based on the safety concept with partial safety factors. As a rule, the characteristic resistances are calculated with design equations. With certain types of failure (e.g. failure of the connection between anchor and channel or local flexure of the channel lips), where the failure load cannot be calculated with sufficient accuracy, tests are carried out [3]. The characteristic resistances obtained from the test results and the minimum edge distance and axis spacings, as well as the minimum component thickness are given in the ETA ([11], [12]).

During the design, a differentiation is made between the direction of the loads and the type of failure. The following application cases are not dealt with in [6]:

- Loads in the direction of the longitudinal axis of the channel
- Fatigue loads
- Seismic loads

The design model shown below applies **exclusively** to anchor channels with a valid ETA ([11], [12]) and thus fulfill the required tests and demands in accordance with CUAP [3].

2 SAFETY CONCEPT

For verification of the load-bearing capacity, the value of design action must not exceed the design value of the resistance (equation (2.1)).

$$E_d \leq R_d \tag{2.1}$$

with
E_d = value of design action
R_d = value of design resistance

The value of design actions corresponds to the applied load multiplied by the partial safety factor for the load (equation (2.2)). The partial safety factors from EN 1990 apply, [4].

$$E_d = \sum \gamma_G \cdot G_k + \gamma_{Q,1} \cdot Q_{k,1} + \sum_{i>1} \gamma_{Q,i} \cdot \psi_{0,i} \cdot Q_{k,i} \tag{2.2}$$

γ_G = partial safety factor for permanent actions ($\gamma_G = 1.35$)
γ_Q = partial safety factor for variable action ($\gamma_G = 1.50$)
G_k = characteristic value of the permanent actions
$Q_{k,1}$ = characteristic value of the largest variable action
$Q_{k,i}$ = characteristic value for further variable actions
ψ_0 = combination factor for infrequent effects

Equation (2.2) applies to a permanent load and multiple variable loads in the same direction as the continuous load. For other combinations of loads, see [4]. Internal forces resulting from restraint to deformation of the attached component must be taken into consideration. $\gamma_{ind} = 1.2$ for concrete failure and $\gamma_{ind} = 1.0$ for other types of failure are recommended as partial safety factors in [5].

The design value of the resistances under tensile and shear loads is calculated from the characteristic resistances under tensile or shear load divided by the material safety factor (equation (2.3)). The value depends on the type of failure.

$$R_d = \frac{R_k}{\gamma_M} \tag{2.3}$$

with R_k = characteristic resistance

  γ_M = material safety factor

The partial safety factors recommended in [5] for the individual types of failure are summarised in Table 2.1 (tensile load) and Table 2.2 (shear load).

The serviceability is proven if the design value of the action does not exceed the rated value of a component property (equation (2.4)).

$$E_d \leq C_d \tag{2.4}$$

with E_d = value of design action (e.g. design value of the anchor displacement)

  C_d = nominal value (e.g. limit of the displacement)

The design value of the anchor displacement E_d is given in the respective ETA for a specific load acting on the anchor N_{Ek}. The load applied to the channel is calculated with the equation (2.2) with $\gamma_G = \gamma_Q = 1.0$ and the combination factor ψ_1 for frequent effects. The anchor loads are determined in accordance with section 3.1 or 3.2. A linear relationship between the displacements E_d and the anchor load can be assumed. For combined tensile and shear loads, the tensile and shear parts of the displacements are added vectorially. The nominal value of the displacement C_d is given by the planner, taking account of the respective conditions of use. $\gamma_M = 1$ is recommended as the material safety factor in [5].

No.	Type of failure		Partial safety factor	Equation
1	Steel failure	Anchors	$\gamma_{Ms} = 1.2 \cdot \dfrac{f_{uk}}{f_{yk}} \geq 1.4$	(2.5)
2		Connection between anchor and channel	$\gamma_{Ms,c} = 1.8$	
3		Local flexure of the channel lip	$\gamma_{Ms,l} = 1.8$	
4		Hook head or hammerhead screw	$\gamma_{Ms} = 1.2 \cdot \dfrac{f_{uk}}{f_{yk}} \geq 1.4$	(2.5)
5		Bending of the channel	$\gamma_{Ms,flex} = 1.15$	
6	Pull-out		$\gamma_{Mp} = \gamma_{Mc}$	
7	Concrete cone failure		$\gamma_{Mc} = \gamma_c \cdot \gamma_{inst}$ with $\gamma_c = 1.5$ $\gamma_{inst} = 1.0$ (systems with high installation safety)	(2.6)
8	Splitting		$\gamma_{Msp} = \gamma_{Mc}$	
9	Blow-out failure		$\gamma_{Mcb} = \gamma_{Mc}$	
10	Steel failure of supplementary reinforcement		$\gamma_{Ms,re} = 1.15$	
11	Anchorage failure of the supplementary reinforcement		$\gamma_{M,a} = \gamma_c$	

Table 2.1   Partial safety factors for anchor channels under tensile loads in accordance with [5]

	Type of failure		Partial safety factor	Equation
1	Without lever arm	Hook head or hammerhead screw and anchor	for $f_{uk} \leq 800$ N/mm² and $f_{yk}/f_{uk} \leq 0.8$: $$\gamma_{Ms} = 1.0 \cdot \frac{f_{uk}}{f_{yk}} \geq 1.25$$ for $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0.8$: $$\gamma_{Ms} = 1.5$$	(2.7) (2.8)
2	Steel failure	Local flexure of the channel lip	$\gamma_{Ms,h} = 1.8$	
3	With lever arm	Hook head or hammerhead screw	for $f_{uk} \leq 800$ N/mm² and $f_{yk}/f_{uk} \leq 0.8$: $$\gamma_{Ms} = 1.0 \cdot \frac{f_{uk}}{f_{yk}} \geq 1.25$$ for $f_{uk} > 800$ N/mm² or $f_{yk}/f_{uk} > 0.8$: $$\gamma_{Ms} = 1.5$$	(2.8) (2.8)
4	Pry-out failure		$\gamma_{Mcp} = \gamma_c$	
5	Concrete edge failure		$\gamma_M = \gamma_c$	
6	Steel failure in supplementary reinforcement		$\gamma_{Ms,re} = 1.15$	
7	Anchorage failure of the supplementary reinforcement in the failure cone		$\gamma_{M,a} = \gamma_c$	

Table 2.1   Partial safety factors for anchor channels under shear loads in accordance with [5]

For serviceability limit state, $\gamma_M = 1.0$ applies. With anchor channels, an installation safety factor of $\gamma_{inst} = 1.0$ can be applied if the following conditions are adhered to. These must be given in detailed installation instructions from the manufacturer.

1. As a rule, anchor channels are to be attached to the formwork in such a way that they do not move while installing the reinforcement or applying and compacting the concrete.
2. The concrete must be properly compacted, particularly under the head of the anchor.
3. Anchor channels must not be installed by pressing into the concrete. They may, however, be vibrated into the fresh concrete (directly after pouring) if the following conditions are adhered to.
   - The length of the anchor channel may not exceed 1 m to ensure that the channel sinks evenly into the concrete along its entire length.
   - The concrete must be compacted particularly carefully in the area of the anchor channel and the head of the anchor to prevent cavities under the channel caused by the anchor channel sinking down.

- The anchor channel may not be moved after installation and compacting of the concrete.
4. The correct installation of the anchor channels must be carried out by qualified personnel, particularly if the anchor channels are vibrated in. The installation must also be monitored.

The partial safety factors shown in Table 2.1 and Table 2.2 are provided in the approval.

2.1 Uncracked and cracked concrete

Anchor channels can be used both in cracked and uncracked concrete. As a rule, cracked concrete can be assumed. When evaluating whether cracked or uncracked concrete is present, all load combinations must be taken account of, particularly stresses caused by heat, contraction, settlement, etc.

Uncracked concrete can be assumed in serviceability limit state cases if the anchor channel lies in uncracked concrete for the whole anchoring depth. This verification is fulfilled if equation (2.9) is fulfilled for every attachment point for the whole anchoring depth.

$$\sigma_L + \sigma_R \leq \sigma_{adm} \tag{2.9}$$

with:

σ_L = stresses in the concrete caused by external loads, including loads from the attachment

σ_R = stresses in the concrete caused by imposed deformations (e.g. shrinkage of the concrete) or caused by external forced movements (e.g. as a result of support movements or temperature changes). If no verification is provided, $\sigma_R = 3$ N/mm^2 is to be assumed.

σ_{adm} = permissible tensile stress

The calculation of stresses σ_L and σ_R is carried out for uncracked concrete. For components with load transfer in two axes (e.g. slabs, walls, shells), equation (2.9) must be fulfilled for both directions. The value for σ_{adm} is provided in the national appendices to the CEN. The recommended value is $\sigma_{adm} = 0$.

When calculating the stresses σ_L and σ_R, uncracked concrete must be assumed. If tensile or shear loads > 60 kN are applied to the anchor channel in use, cracked concrete must always be assumed.

3 ACTIONS

Using the value of design action on the anchor channel according to equation (2.2), the forces in the anchors, the bending moments of the channel and the tensile loads in any supplementary reinforcement present are calculated as described below.

3.1 Tensile loads on the anchor channel

For anchor channels with two anchors, the tensile loads on the anchors may be approximated on a simply supported beam on two supports, i.e. the partial fixing can be ignored. With anchor channels with more than two anchors, the determination of the measured values for the anchor loads $N^a_{Ed,i}$ is made using equation (3.1). The evaluations of appropriate tests with channels from DKG and Halfen in [9] and [10] show that for the channels from these two manufacturers, the load distribution model according to equation (3.1) can also be used for anchor channels with 2 anchors.

$$N^a_{Ed,i} = k \cdot A^{'}_j \cdot N_{Ed} \qquad (3.1)$$

with

$N^a_{Ed,i}$ =   design value of the anchor tensile load from anchor i

$$k = \frac{1}{\sum A^{'}_j} \qquad (3.1a)$$

A_i =   ordinate of the triangle with height 1 at the point of load N_{Ed} and base length $2\,l_i$ for anchor i. The constraint length l_i is calculated using equation (3.2)
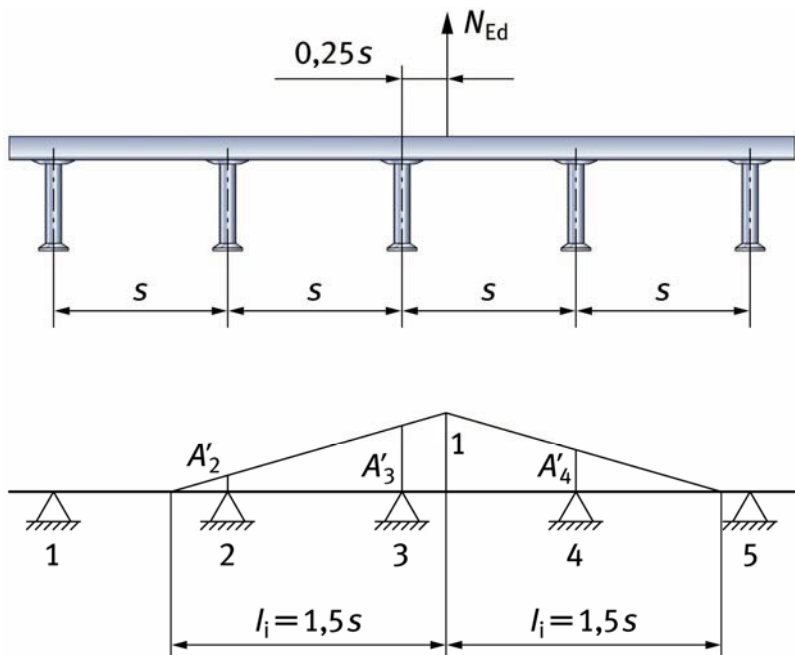
N_{Ed} =   measured value of the tensile load acting on the anchor channel according to equation (2.2)

$$l_i = 13 \cdot l_y^{0,05} \cdot s^{0,5} \geq s \qquad \text{[mm]} \qquad (3.2)$$

n =   number of anchors on the channel in the constraint length l_i on both sides of the applied load. See figure 3.1

l_y =   moment of inertia of the channel [mm^4]

s =   anchor spacing

$$A'_2 = \frac{l - 1{,}25s}{l} = \frac{1}{6}$$

$$N^a_{Ed,1} = N^a_{Ed,5} = 0$$

$$A'_3 = \frac{l - 0{,}25s}{l} = \frac{5}{6}$$

$$N^a_{Ed,2} = \frac{1}{6} \cdot \frac{2}{3} \cdot N = \frac{1}{9} N_{Ed}$$

$$A'_4 = \frac{l - 0{,}75s}{l} = \frac{1}{2}$$

$$N^a_{Ed,3} = \frac{5}{6} \cdot \frac{2}{3} \cdot N = \frac{5}{9} N_{Ed}$$

$$k = \frac{1}{A'_2 + A'_3 + A'_4} = \frac{2}{3}$$

$$N^a_{Ed,4} = \frac{1}{2} \cdot \frac{2}{3} \cdot N = \frac{1}{3} N_{Ed}$$

Figure 3.1: Example for the calculation of the anchor tensile forces according to the constraint length method for an anchor channel with 5 anchors. The assumed constraint length is $l_i = 1.5\ s$

The moment of inertia is to be taken from the respective ETA. With multiple applied tensile loads on the anchor channel, the values $N^a_{Ed,i}$ are to be added (linear superposition).

If the exact position of the loads applied is not known, for each failure type the most adverse position is to be assumed (e.g. load applied above an anchor for steel failure in the anchor or pulling out, and application of the load between the anchors for bending failure of the channel).

3.2   Shear loads on the anchor channel

Section 3.1 applies. However, in equation (3.1), N_{Ed} is replaced by V_{Ed}.

It can be assumed that a shear load without a lever arm is applied to the anchor channel if the attachment is attached directly to the anchor channel or the concrete, or the thickness of any mortar layer present ≤ 0.5 d, and diameter d_f of the through hole in the attachment does not exceed the values according to [5].

If the conditions specified are not met, it must be assumed that the shear load is applied at a distance from the anchor channel. The bending moment in the anchor depends on whether the attachment can rotate (compare figure 4.9).

3.3   Bending load on the anchor channel

The bending moment in the channel can be calculated independently of the number of anchors on a simply supported beam on two supports with a support spacing corresponding to the anchor spacing. This rule does not correspond to the actual load-bearing characteristics because the partial fixing at the end of the channels and the rope effect with anchor channels with more than two anchors disregards the effect of continuity after yielding of the channels. To compensate, the calculated bending resistances shown in the ETA are adapted. They are higher than the plastic section modulus. The approach has been selected to be able to calculate the bending moment in a simply way.

3.4   Supplementary reinforcement
3.4.1   Tensile loads on the anchor channel

The design value of the tensile force $N_{Ed,re}$ of the supplementary reinforcement of anchor i corresponds to the value $N_{Ed,i}^a$ of the anchor considered.

3.4.2 Shear loads on the anchor channel

The tensile force in supplementary reinforcement $N_{Rd,re}$ of anchor i is found with equation (3.3). If the supplementary reinforcement is not in the direction of the applied shear load, this must be taken account of when determining the tensile force in the reinforcement.
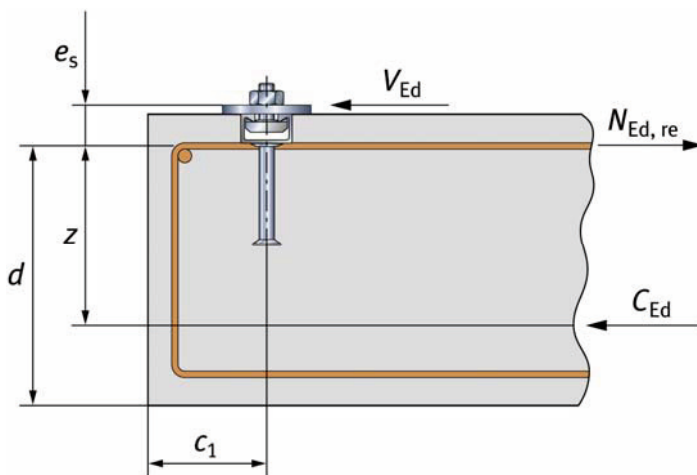
$$N_{Ed,re} = V_{Ed} \left(\frac{e_s}{z} + 1 \right) \tag{3.3}$$

with

e_s = distance between shear load and supplementary reinforcement

z = internal lever arm
$\approx 0.85 \cdot h'$
$\approx 0.85 \cdot (h - h_{ch} - 0.5\, d_s)$

$$h' \leq \min \begin{cases} 2h_{ef} \\ 2c_1 \end{cases}$$

If the anchors are subject to different shear loads, equation (3.3) is calculated using the shear load of the most loaded anchor V_{Ed}^h. This leads to $N_{Ed,re}^h$.
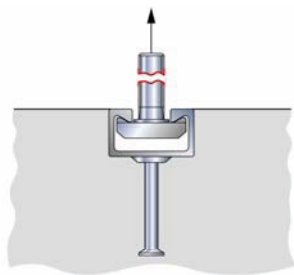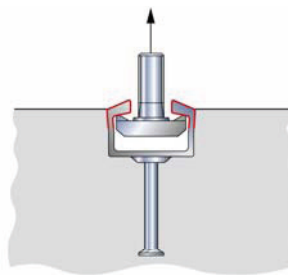
4 CHARACTERISTIC ANCHOR CHANNEL RESISTANCES

4.1 Tensile load

4.1.1 General

The failure types arising under tensile load are shown in figure 4.1. The necessary verification for all failure types is listed in table 4.1. For applications without supplementary reinforcement, the verification is to be provided according to table 4.1, lines 1 to 9. For applications with supplementary reinforcement, the load-bearing capacity must be provided according to table 4.1, lines 1 to 6 and lines 8 to 11. The proof for concrete cone failure is thus replaced by the proof for failure of the supplementary reinforcement. It is assumed at the same time that the anchor load is only taken up by the supplementary reinforcement.

a) Steel failure special screw

b) Local flexure of the channel lip
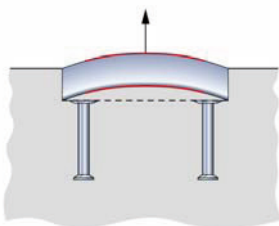
c) Failure due to flexure of the channel

d) Failure of the channel-anchor connection

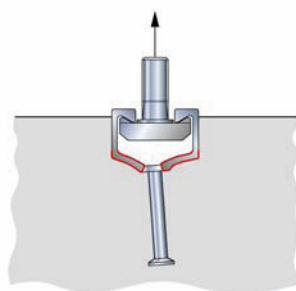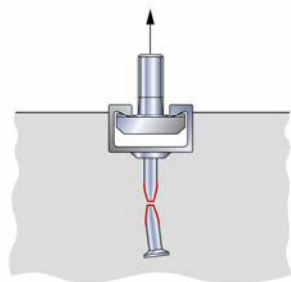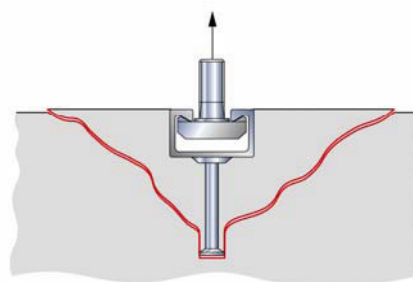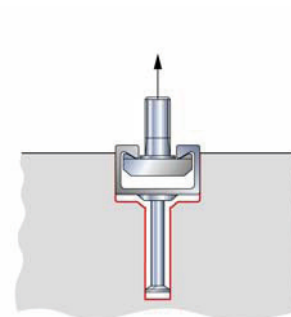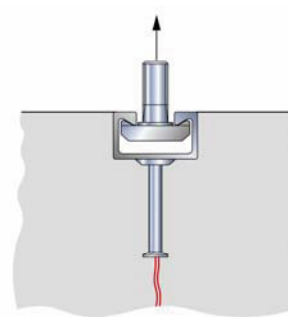e) Steel failure of anchor

f) Concrete cone failure

g) Pull-out

h) Splitting
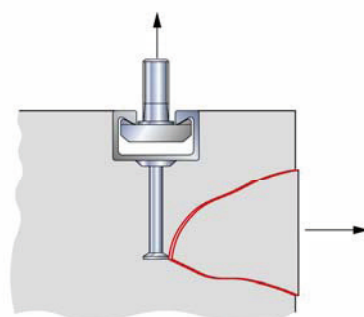
i) Blow-out

Figure 4.1:   Failure types for anchor channels under tensile load

	Failure types		Channel	Most unfavourable anchor or screw
1	Steel failure	Anchor		$N_{Ed}^a \leq N_{Rd,s,a} = \dfrac{N_{Rk,s,a}}{\gamma_{Ms,a}}$ [b]
2		Connection between anchor and channel		$N_{Ed}^a \leq N_{Rd,s,c} = \dfrac{N_{Rk,s,c}}{\gamma_{Ms,c}}$ [b]
3		Local flexure of the lip	$N_{Ed} \leq N_{Rd,s,l} = \dfrac{N_{Rk,s,l}}{\gamma_{Ms,l}}$	
4		Hook head or hammerhead screw		$N_{Ed} \leq N_{Rd,s,s} = \dfrac{N_{Rk,s,s}}{\gamma_{Ms}}$ [b]
5		Bending of the channel	$M_{Ed} \leq M_{Rd,s,flex} = \dfrac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$	
6	Pull-out			$N_{Ed}^a \leq N_{Rd,p} = \dfrac{N_{Rk,p}}{\gamma_{Mc}}$ [b]
7	Concrete cone failure			$N_{Ed}^a \leq N_{Rd,c} = \dfrac{N_{Rk,c}}{\gamma_{Mc}}$ [c]
8	Splitting			$N_{Ed}^a \leq N_{Rd,sp} = \dfrac{N_{Rk,sp}}{\gamma_{Mc}}$ [c]
9	Blow-out failure [a]			$N_{Ed}^a \leq N_{Rd,cb} = \dfrac{N_{Rk,cb}}{\gamma_{Mc}}$ [c]
10	Steel failure in supplementary reinforcement			$N_{Ed}^a \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$ [b]
11	Failure of the supplementary reinforcement in the failure cone			$N_{Ed}^a \leq N_{Rd,a} = \dfrac{N_{Rk,a}}{\gamma_{Mc}}$ [b]

[a]   not required for anchors with edge distance c > 0.5hef
[b]   most loaded anchor or special screw
[c]   the load on the anchor in conjunction with the edge distance and spacing should be considered in determining the most unfavourable anchor

Table 4.1   Required verification for anchor channels under tensile load

4.1.2   Arrangement of a supplementary reinforcement

If the load applied to an anchor $N_{Ed,i}^{a}$ is greater than the design value of the resistance for concrete cone failure $N_{Rd,c,}$ the anchor tensile force can be taken up by a supplementary reinforcement. A supplementary reinforcement may only be considered effective if the following requirements are fulfilled (compare figure 4.2):

    a)   The supplementary reinforcement of all anchors must consist of stirrups or loops, have the same diameter, be constructed from ribbed reinforcement steel ($f_{yk} \leq 500$ N/mm^2) with diameter ds $\leq$ 16 mm and adhere to the bending roll diameter according to [7] (EN 1992-1-1).

    b)   The supplementary reinforcement should be arranged as near to the anchor as possible. It should enclose the surface reinforcement as far as possible. Only reinforcement rods with a spacing ≤ 0.75 h_{ef} from the anchor may be viewed as effective.

    c)   The minimum anchoring length in the assumed failure cone is min $l_1 = 4$ d_s (with hooks or angle hooks) or min $l_1 = 10$ d_s (straight rods or without welded cross rods).

    d)   The anchoring of the supplementary reinforcement outside of the concrete failure cone must be undertaken with anchoring length l_{bd} according to [7].

    e)   The splitting forces from the effect of the framework must be taken up by a surface reinforcement that limits the crack widths to the permitted value ($w_k \approx 0.3$ mm).
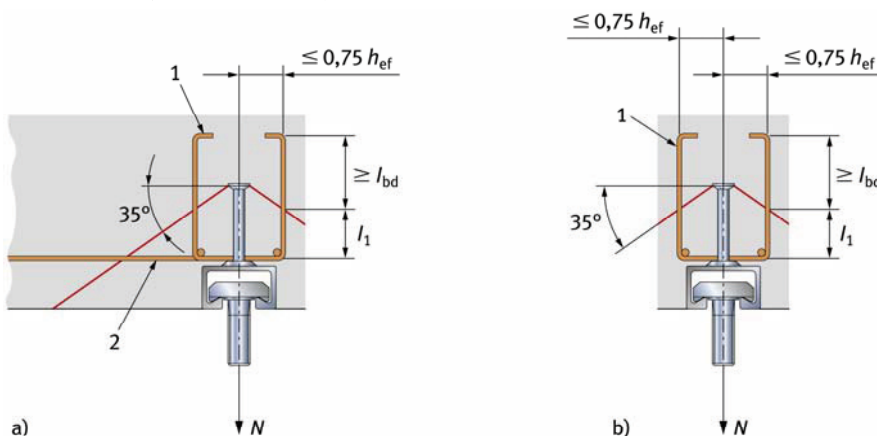
1 = Supplementary reinforcement
2 = Surface reinforcement

Figure 4.2:   Anchor channels with supplementary reinforcement from stirrups at the component edge

With anchor channels parallel to the component edge or in a narrow component, the suspension stirrup should be arranged on the longitudinal axis of the channels (compare figure 4.2).

4.1.3 Steel failure of anchors, anchor channels or hook head or hammerhead screws

The characteristic resistances $N_{Rk,s,a}$ (anchor fracture), $N_{Rk;s,c}$ (failure of the connection between channel and anchor), $N_{Rk,s,l}$ (local flexure of the channel lip), $N_{Rk,s,s}$ (screw failure) and $M_{Rk,s,flex}$ (failure due to bending failure of the channel) are shown in the ETA.

4.1.4 Pull-out

The characteristic resistance for pull-out is given in the respective ETA. It is limited by the concrete pressure under the anchor head.

$$N_{Rk,p} = 6 \cdot A_h \cdot f_{ck,cube} \cdot \psi_{ucr,N} \qquad (4.1)$$

with

A_h =   load application surface of the anchor head

      = $\dfrac{\pi}{4}\left(d_h^2 - d^2\right)$ for round anchor heads

$f_{ck,cube}$ =   nominal value of the concrete compression strength (cube with an edge length of 150 mm)

$\psi_{ucr,N}$ =   1.0   cracked concrete

      =   1.4   uncracked concrete

4.1.5 Concrete cone failure

The characteristic resistance of an anchor in cracked concrete for concrete cone failure is taken from the equation (4.2). For attachments in uncracked concrete, the characteristic resistance may be multiplied by the factor $\psi_{ucr,N} = 1.4$.

$$N_{Rk,c} = N_{Rk,c}^0 \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N} \qquad [N] \qquad (4.2)$$

with   (4.3)

$$N_{Rk,c}^0 = 8,5 \cdot \alpha_{ch} \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1,5} \qquad [N]$$

$f_{ck,cube}$ = nominal value of the concrete compression strength (cube with an edge length of 150 mm) [N/mm^2]

α_{ch} = Factor for taking account of the influence of the channel on the concrete failure cone load

$$= \left(\frac{h_{ef}}{180}\right)^{0,15} \leq 1,0 \tag{4.4}$$

$\alpha_{s,N}$ = influence of the neighbouring anchor on the concrete cone failure load

$$= \frac{1}{1+\sum\limits_{i=1}^{n}\left[\left(1-\frac{s_i}{s_{cr,N}}\right)^{1,5}\cdot\frac{N_i}{N_0}\right]} \tag{4.5}$$

with

s_i = distance of the anchor in question to the neighbouring anchor

$\leq$ $s_{cr,N}$ $\tag{4.6}$

$s_{cr,N}$ = $2\cdot\left(2,8-1,3\cdot\dfrac{h_{ef}}{180}\right)\cdot h_{ef} \geq 3\cdot h_{ef}$

$N_{Sd,i}$ = design value of the tensile force of anchor i

$N_{Sd,0}$ = design value of the tensile force of the anchor in question

n = number of anchors within a distance $s_{cr,N}$, which influences the concrete cone failure of anchor 0
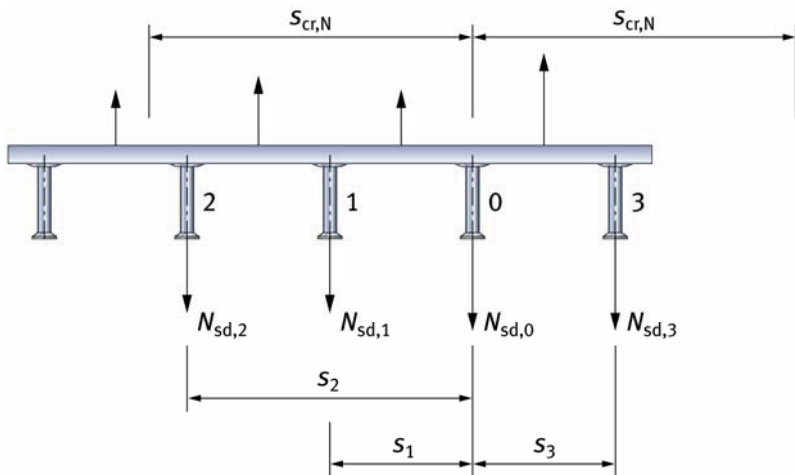
Figure 4.3: Examples for an anchor channel with different tensile forces on the individual anchors

$\alpha_{e,N}$ = factor for taking account of the influence of a component edge ($c_1 < c_{cr,N}$)

$$= \left(\frac{c_1}{c_{cr,N}}\right)^{0,5} \leq 1 \qquad (4.7)$$

c_1 = edge distance of anchor 1 (see figure 4.4)

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

$$= 0,5 \cdot s_{cr,N} = \left(2,8 - 1,3 \cdot \frac{h_{ef}}{180}\right) \cdot h_{ef} \geq 1,5 \cdot h_{ef} \qquad (4.8)$$

a)   b)
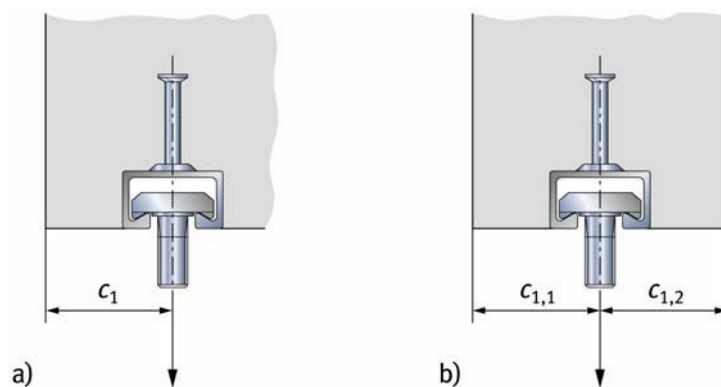
Figure 4.4:   Anchor channel at an edge (a)) or in a narrow concrete element (b))

$\alpha_{c,N}$ = factor for taking account of the influence of a corner ($c_2 < c_{cr,N}$)

$$= \left(\frac{c_2}{c_{cr,N}}\right)^{0,5} \leq 1 \qquad (4.9)$$

c_2 = distance of the anchor in question to the corner (see figure 4.5)
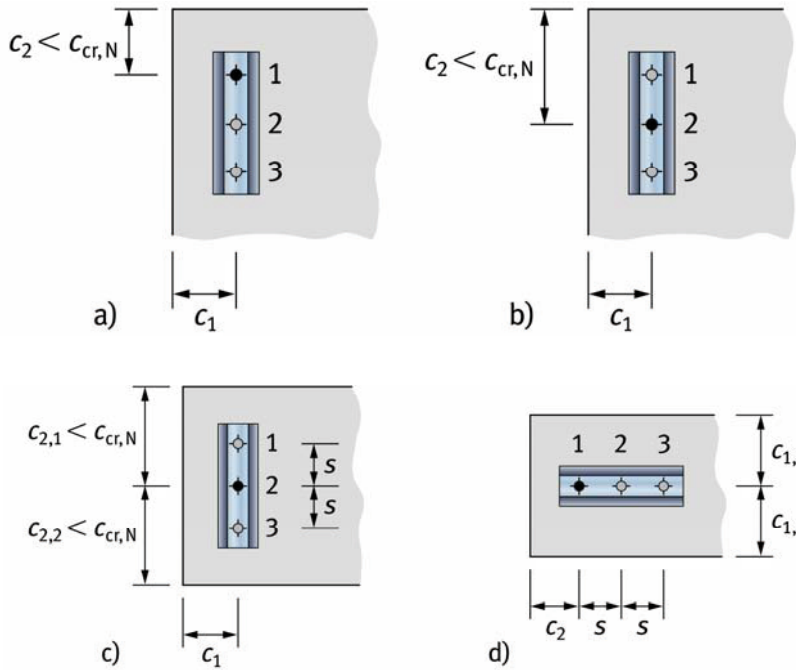
Figure 4.5:   Anchor channel influenced by one or two corners
      a)   anchor 1 is calculated   c)   anchor 2 is calculated
      b)   anchor 2 is calculated   d)   anchor 1 is calculated

Factor $\psi_{re,N}$ takes account of the influence of dense reinforcement for anchoring depths $h_{ef} < 100$ mm:

$$\psi_{re,N} = 0,5 + \frac{h_{ef}}{200} \leq 1 \tag{4.10}$$

with h_{ef} in mm.

Factor $\psi_{re,N}$ may taken as to $\psi_{re,N} = 1.0$ following cases.
- the reinforcement (independent of diameter) is arranged with a spacing ≥150 mm; or
- the reinforcement with diameter $d_s \leq 10$ mm is arranged with a spacing ≥ 100 mm.

$\psi_{ucr,N}$ =   factor for taking account of the position of the anchor channel in cracked or uncracked concrete

$\psi_{ucr,N}$ = 1.0   with the anchor channel positioned in cracked concrete   (4.11)

       = 1.4   with the anchor channel positioned in uncracked concrete

Where an anchor is influenced by two corners ($c_{2,i} < c_{cr,N}$), the factor $\alpha_{c,N}$ for the two corners must be calculated and the product used in equation (4.2).

For applications with anchor channels with anchoring depth $h_{ef} \geq 180$ mm with an influence from a component edge ($c_1 < c_{cr,N}$) and two component corners ($c_2 < c_{cr,N}$) for the anchor in question (for example, see figure 4.5 c)) with an edge distance $c < c_{cr,N}$, the measurement according to equation (4.2) gives results that are on the safe side. Exact results are obtained if for the anchoring depth h_{ef} the value h'_{ef} according to equation (4.12) is applied in equation (4.2 a) and in the equations for determining $\alpha_{s,N}$, $\alpha_{e,N}$ and $\alpha_{c,N}$.

$$h'_{ef} = \max \cdot \left(\frac{c_{max}}{c_{cr,N}} \cdot h_{ef} \quad ; \quad \frac{s_{max}}{s_{cr,N}} \cdot h_{ef} \right) \qquad \geq 180 \text{ mm} \qquad (4.12)$$

with

c_{max} = maximum edge distance of the anchor channel to a component edge or to a component corner

      $\leq$ $c_{cr,N}$ = 0.5 $s_{cr,N}$ according to equation (4.6)

s_{max} = largest spacing of the anchor measured from the middle of the anchor

      $\leq$ $s_{cr,N}$ according to equation (4.6)

This verification is not required for the channels dealt with here from DKG and Halfen, as currently only channels with $h_{ef} \leq 179$ mm are supplied.

4.1.6 Splitting of the concrete
4.1.6.1 Splitting of the concrete during installation

Splitting failure during the installation of the hook head or hammerhead screws is avoided by adhering to the minimum edge distances and spacing and the minimum component thicknesses including the requirements of the edge reinforcement. The minimum measurements and the requirements for the edge reinforcement are given in the ETA (compare [11], [12]).

4.1.6.2   Splitting of the concrete due to the effect of loads

No verification for splitting failure is not required if this is stated in the respective ETA (compare [11], [12]) or if at least one of the following conditions are fulfilled:

a) The edge distance in all directions is $c \geq 1.0c_{cr,sp}$ for anchor channels with one anchor, and for anchor channels with ≥ 2 anchors, $c \geq 1.2c_{cr,sp}$. The characteristic edge distance $c_{cr,sp}$ applies to the minimum component thickness. It is shown in the respective approval.

b) The characteristic resistance for concrete cone, blow-out and pull-out failure is determined on the assumption of cracked concrete and a reinforcement is present that takes up the splitting forces and limits the crack width to $w_k \leq 0.3$ mm.

If proof for splitting failure is required and if not both of the above conditions a) and b) are fulfilled, the characteristic resistance of an anchor channel anchor must be determined using equation (4.13).

$$N_{Rk,sp} = N_{Rk,c}^0 \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N} \cdot \psi_{h,sp} \qquad \text{[N]} \qquad\qquad (4.13)$$

with

$$N_{Rk,c}^0 = \min \begin{cases} N_{Rk,p} \\ N_{Rk,c}^0 \end{cases}$$

$N_{Rk,p}$ according to equation (4.1)

$N_{Rk,c}^0$ $\alpha_{s,N}$, $\alpha_{e,N}$, $\alpha_{c,N}$, $\psi_{re,N}$, $\psi_{ucr,N}$ according to section 4.1.5. However, the values $c_{cr,N}$ and $s_{cr,N}$ are replaced by the values $c_{cr,sp}$ and $s_{cr,sp}$. These values apply to member thickness h_{min} and are given in the respective approval. The factor $\psi_{h,sp}$ takes account of the influence of the component thickness h actually present on the resistance concerning the splitting failure type.

$\psi_{h,sp}$ = factor for taking account of the member thickness present on the splitting failure load

$$= \left(\frac{h}{h_{min}} \right)^{2/3} \leq \left(\frac{2h_{ef}}{h_{min}} \right)^{2/3} \quad [-] \tag{4.14}$$

with

h_{min} = minimum component thickness according to approval

For anchor channels with various distances to member edges (e.g. in the corner or in narrow components), the smallest value for the edge distance c must be used in equation (4.14). If the edge distance between anchor channel and member edge is smaller than the value $c_{cr,sp}$, a longitudinal reinforcement should be provided along the edge of the component.

4.1.7 Blow-out failure

Proof concerning failure from blow-out failure only needs to be provided if the edge distance between anchor channel and member edge $c \leq 0.5h_{ef}$. For anchor channels from DKG and Halfen, the minimum edge distances have been determined such that the proof of blow-out failure is not required (compare [11], [12]).

If verification for blow-out failure is required, the characteristic resistance of an anchor in cracked concrete is determined using equation (4.15). For anchor channels arranged vertically to the member edge and uniformly loaded, proof is only required for the anchor closest to the edge.

$$N_{Rk,cb} = N^0_{Rk,cb} \cdot \alpha_{s,Nb} \cdot \psi_{g,Nb} \cdot \alpha_{c,Nb} \cdot \alpha_{h,Nb} \cdot \psi_{ucr,N} \quad [N] \tag{4.15}$$

with

$N^0_{Rk,cb}$ = characteristic resistance of an individual anchor closest to the edge with a large distance to the neighbouring anchor in cracked concrete

$$= 8 \cdot c_1 \cdot \sqrt{A_h} \cdot \sqrt{f_{ck,cube}} \quad [N] \tag{4.16}$$

A_h = load bearing area of the anchor [mm²]

$$= \frac{\pi}{4} \cdot \left(d_h^2 - d^2 \right) \quad \text{in case of a round anchor head [mm²]} \tag{4.17}$$

c_1 = edge distance of the anchor channel [mm]

21

$\alpha_{s,Nb}$ = factor for taking account of the influence of the neighbouring anchor. It is determined using equation (4.5), but the value $s_{cr,Nb}$ is used for the characteristic spacing instead of $s_{cr,N}$.

$s_{cr,Nb}$ = characteristic spacing for blow-out failure

= $4\,c_1$ (4.18)

$\alpha_{c,Nb}$ = factor for taking account of the influence of a corner

= $\left(\dfrac{c_2}{c_{cr,Nb}}\right)^{0,5} \leq 1$ [-] (4.19)

c_2 = distance of the anchor in question to the corner (see figure 4.5)

$c_{cr,Nb}$ = $0.5 \cdot s_{cr,Nb}$ (4.20)

If an anchor is influenced by 2 corners ($c_2 < c_{cr,N}$), the factor $\alpha_{c,Nb}$ must be determined for both edge distances $c_{2,1}$ and $c_{2,2}$ and the product of the factors $\alpha_{c,Nb}$ used in equation (4.15).

$\psi_{g,Nb}$ = factor for taking account of the influence of the load application surface of the neighbouring anchor

= $\sqrt{n} + \left(1 - \sqrt{n}\right) \cdot \dfrac{s_1}{4 \cdot c_1} \geq 1$ for $s_1 \leq 4c_1$ (4.21)

n = number of anchors under tensile load parallel to the edge

$\alpha_{h,Nb}$ = factor for taking account of the member thickness if the distance of the head to the upper or lower edge is $< 2\,c_1$ (see figure 4.6)

= $\dfrac{h_{ef} + f}{4c_1} \leq \dfrac{2c_1 + f}{4c_1} \leq 1$ [-] (4.22)

f = distance between the upper side of the anchor head (position of the load application) and the lower side of the member (see figure 4.6)

$\psi_{ucr,N}$ = see equation (4.11)
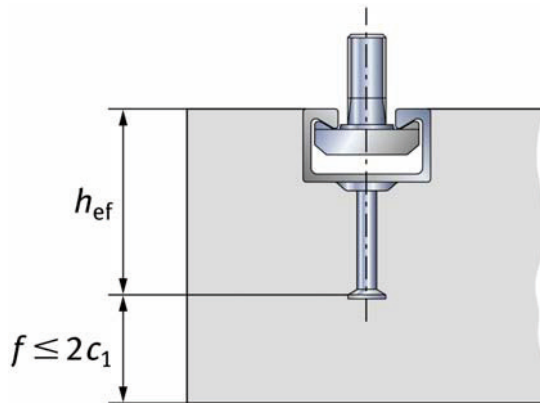
Figure 4.6:   Anchor channel in the corner of a thin component

4.1.8   Steel failure in supplementary reinforcement

The characteristic resistance of the supplementary reinforcement $N_{Rk,s,re}$ of an anchor is

$$N_{Rk,re} \quad = \quad n \cdot A_s \cdot f_{yk} \qquad\qquad \text{[N]} \qquad\qquad\qquad (4.23)$$

with

n	=	number of legs of the supplementary reinforcement for an anchor in the failure cone
A_s	=	Cross-section of a leg of the supplementary reinforcement
f_{yk}	=	nominal value of the yield point of the supplementary reinforcement ≤ 500 N/mm^2

4.1.9   Anchorage failure of the supplementary reinforcement in the failure cone

The characteristic resistance of the supplementary reinforcement for failure due to anchorage failure is calculated according to equation (4.24).

$$N_{Rd,a} = \sum_n \frac{l_1 \cdot \pi \cdot d_s \cdot f_{bd}}{\alpha} \qquad\qquad\qquad (4.24)$$

with

n	=	number of legs of the additional reinforcement effective for an anchor
l_1	=	Anchoring length of the supplementary reinforcement in the failure cone
	$\geq$	$l_{b,min}$ (see figure 4.2)
$l_{b,min}$	=	minimum anchoring length
	=	$4d_s$ (hooks or angle hooks)
	=	$10\ d_s$ anchoring with straight rods with or without welded cross rods
d_s	=	Diameter of the supplementary reinforcement
f_{bd}	=	Design value of the bond strength in accordance with EN 1992-1-1
	=	$f_{bk}\ /\ \gamma_c$
f_{bk}	=	characteristic value of the bond strength in accordance with EN 1992-1-1[7] taking account of the concrete cover of the supplementary reinforcement
α	=	influencing factor in accordance with EN 1992-1-1
	=	0.7 for reinforcement rods with hooks

4.2 Shear load

4.2.1 General

In this section, only shear loads acting vertically to the rail axis are taken into account. The failure types arising under shear load are shown in figure 4.7. The necessary verification concerning shear loads is listed in table 4.2. For applications without supplementary reinforcement, the verification is to be provided according to table 4.2, lines 1 to 5. For applications with supplementary reinforcement, the load-bearing capacity must be verified in accordance with table 4.2, lines 1 to 4 and 6 to 7, i.e. as with tensile loads, the proof concerning concrete edge failure is replaced by the proof concerning failure of the supplementary reinforcement. It is assumed at the same time that the complete shear load is taken up by the supplementary reinforcement.

a) Steel failure of the screw

b) Local flexure of the channel lip

c) Concrete edge failure

d) Concrete pryout failure

e) Steel failure of the anchor

f) Failure of the channel-anchor connection

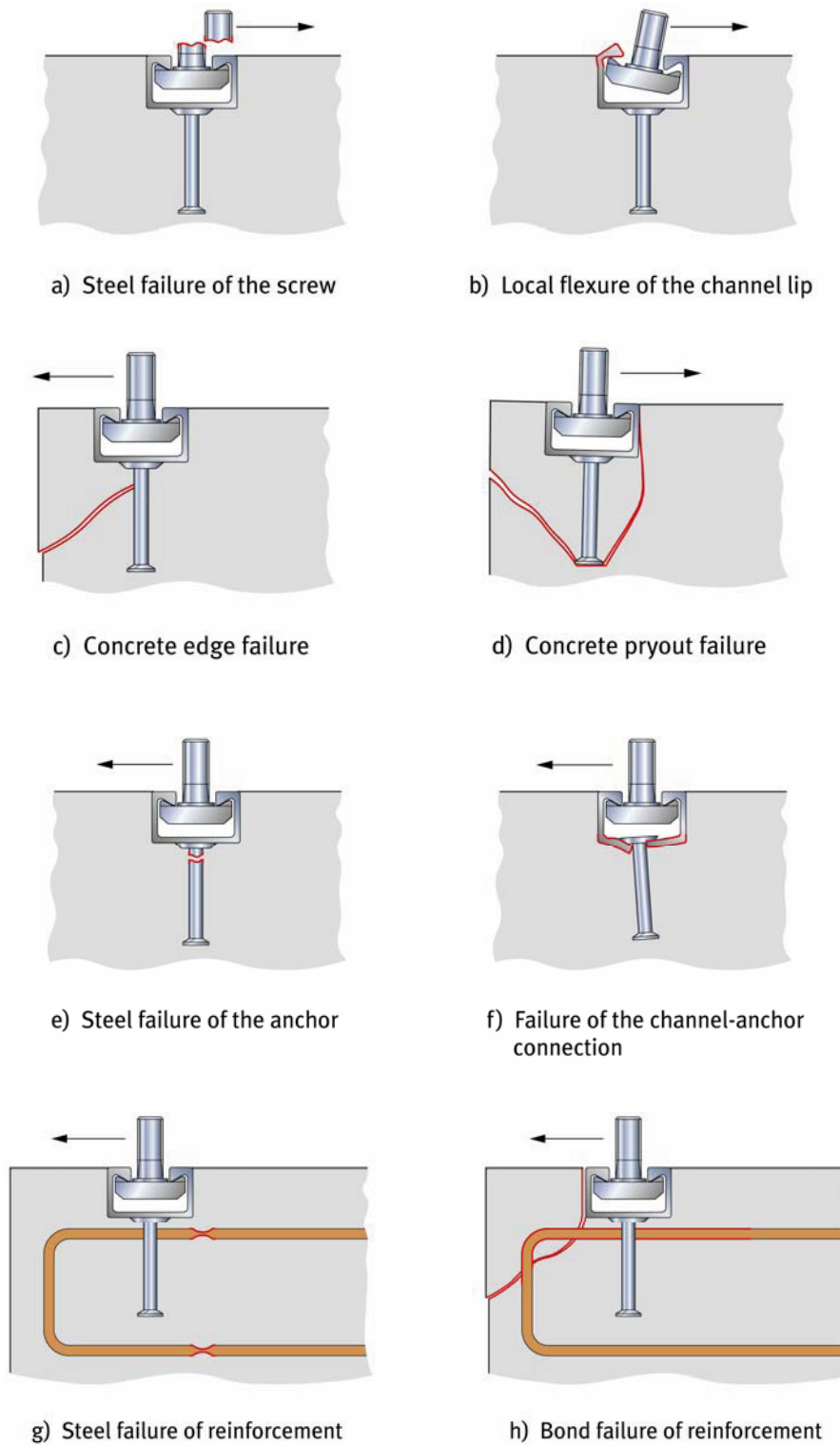g) Steel failure of reinforcement

h) Bond failure of reinforcement

Figure 4.7: Failure types for anchor channels under shear load

	Type of failure			Channel	Most unfavourable anchor or special screw
1	Steel failure	Shear load without lever arm	Hook head or hammerhead screw		$V_{Ed} \leq V_{Rd,s,s} = \dfrac{V_{Rk,s}}{\gamma_{Ms}}$ [a]
2			Anchor [1]		$V_{Ed} \leq V_{Rd,s,a} = \dfrac{V_{Rk,s,a}}{\gamma_{Ms}}$ [a] with $V_{Rk,s,a} = N_{Rk,s,a}$
3			Anchors/ Channel [1]		$V_{Ed} \leq V_{Rd,s,c} = \dfrac{V_{Rk,s,c}}{\gamma_{Ms}}$ [a] with $V_{Rk,s,c} = N_{Rk,s,c}$
4			Local flexure of the channel lip	$V_{Ed} \leq V_{Rd,s,l} = \dfrac{V_{Rk,s,l}}{\gamma_{Ms,l}}$ [a]	
5		Shear load with lever arm	Hook head or hammerhead screw		$V_{Ed} \leq V_{Rd,s,s} = \dfrac{V_{Rk,s}}{\gamma_{Ms}}$ [a]
6	Concrete cone failure on the side away from the load				$V_{Ed}^{a} \leq V_{Rd,cp} = \dfrac{V_{Rk,cp}}{\gamma_{Mc}}$ [b]
7	Concrete edge failure				$V_{Ed}^{a} \leq V_{Rd,c} = \dfrac{V_{Rk,c}}{\gamma_{Mc}}$ [b]
8	Steel failure of the additional reinforcement				$N_{Ed,re} \leq N_{Rd,re} = \dfrac{N_{Rk,re}}{\gamma_{Ms,re}}$ [a]
9	Failure of the additional reinforcement in the cone				$N_{Ed,re} \leq N_{Rd,a} = \dfrac{N_{Rk,a}}{\gamma_{Mc}}$ [a]
[a]	Most loaded anchor or special screw				
[b]	The load applied to the anchor is to be considered when determining the most unfavourable anchor in connection with edge distances and axis spacing				

[1] The verifications according to line 2 and 3 are not included in CEN/TS, but will be in the future.

Table 4.2 Required verification for anchor channels under shear load

The most unfavourable anchor is defined in the same way as for tensile load (compare section 4.1.1).

4.2.2 Design of supplementary reinforcement

If the design load applied to an anchor $V_{Ed,i}^a$ is greater than the design value of the concrete cone failure, the shear load on the anchor can be taken up by a supplementary reinforcement, which must be designed for the complete shear load. It must be made of ribbed concrete steel ($d_s \leq 16$ mm, $f_{yk} \leq 500$ N/mm^2) and the same rod diameter is to be used for all anchors. The bending roll diameter is selected in accordance with EN 1992-1-1 [7].

A supplementary reinforcement is only considered as effective if it fulfils the following requirements (compare figure 4.8).

a) The distance of the reinforcement rods from the anchor must be $\leq 0.75\, c_1$.

b) The anchoring length of the supplementary reinforcement in the concrete failure cone must be at least:
   min $l_1 = 10d_s$ straight reinforcement rods with or without welded transverse rods
   $= 4d_s$ bent reinforcement rods (hooks or angle hooks)

c) Along the edge of the component, there must be a longitudinal reinforcement for taking up the tensile forces arising from the effect of the strut and tie model (figure 4.8). For simplification, the angle of the struts can be assumed as 45°.
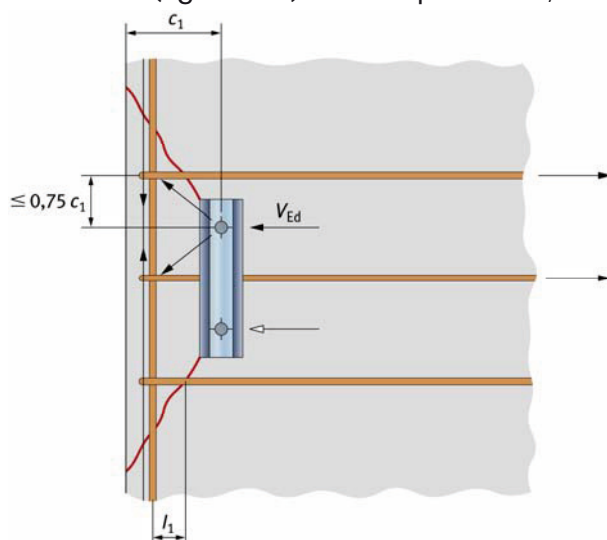

Figure 4.8:   Surface reinforcement for transfer of shear loads

4.2.3   Steel failure of hook head and hammerhead screw and local flexure of channel lips

4.2.3.1   Shear load without lever arm

The characteristic resistances for steel failure of hook head or hammerhead screw ($V_{Rk,s,s}$), steel failure of the anchor ($V_{Rk,s,a}$) and for failure as a result of local flexure of the channel lips ($V_{Rk,s,l}$) are given in the respective ETA.

4.2.3.2   Shear load with lever arm

The characteristic resistance of a hook head or hammerhead screw with steel failure is defined according to equation (4.25).

$$V_{Rk,s} = \frac{\alpha_M \cdot M_{Rk,s}}{l} \qquad (4.25)$$

with

α_M =   factor for taking account of the degree of restraint of the attachment

         =   1.0 no restraint, free rotation of the attachment possible, see figure 4.9 a

         =   2.0 completely fixed, no rotation of the attachment possible, see figure 4.9 b

l =   lever arm (see figure 4.9)

$M_{RK,s}$ =   characteristic resistance of the hook head or hammerhead screw for bending failure

$$= \quad M_{Rk,s}^0 \cdot \left(1 - \frac{N_{Ed}}{N_{Rd,s}} \right) \quad [Nm] \qquad (4.26)$$

$M_{Rk,s}^0$ =   Base value for the characteristic bending resistance of the hook head or hammerhead screw

$$N_{Rd,s} \quad = \quad \frac{N_{Rk,x}}{\gamma_{Ms}} \qquad (4.27)$$

$N_{Rk,s}$ =   characteristic resistance of the screw with tensile load

$\gamma_{M,s}$ =   material safety factor

The values $M_{Rk,s}^0$, $N_{Rk,s}$ and $\gamma_{M,s}$ are given in the approval.

If it is assumed that the attachment cannot rotate, the moment $M_{Ed} = V_{Ed} \cdot l \,/\, 2$ must be taken up by the attachment and transferred. If the shear load is applied with lever arm, the characteristic resistance of the hook head or hammerhead screw is generally smaller than the value for the failure type "local flexure of channel lips". Therefore, this verification is not required.
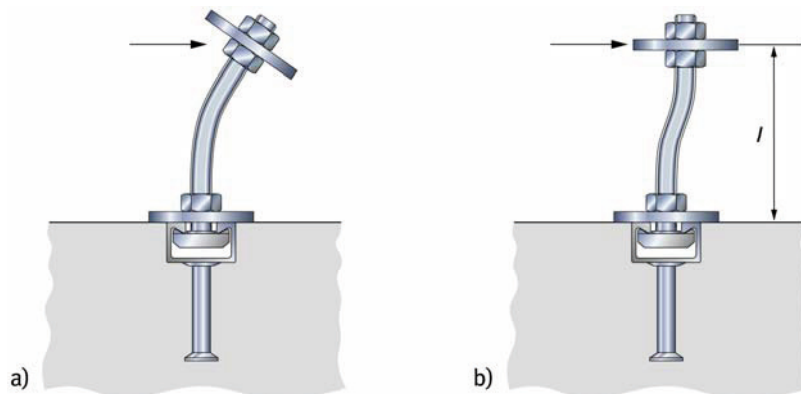
Figure 4.9: Anchor channel for which the shear load is applied with lever arm
a) freely rotatable attachment
b) non-rotatable attachment

4.2.4 Concrete pry-out failure

The characteristic resistance arises from the equation (4.28).

$$V_{Rk,cp} = k_5 \cdot N_{Rk,c} \qquad [Nm] \qquad (4.28)$$

with

k_5 = factor given in the respective approval. As a rule, it is
= 1.0 for $h_{ef} < 60$ mm
= 2.0 for hef ≥ 60 mm
For anchor channels with supplementary reinforcement for taking up shear loads, the factor k_5 in equation (4.28) should be multiplied with the factor 0.75.

$N_{Rk,c}$ = characteristic resistance of the anchor under tensile load for the failure mode concrete cone failure according to section 4.1.5. The most unfavourable anchor with an applied shear load must be verified.

4.2.5   Concrete edge failure

Verification for concrete edge failure is not necessary if the edge distance in all directions is $c \geq 10h_{ef}$ and $c \geq 60d$. The lower value is decisive.

The characteristic resistance of an anchor in cracked concrete is taken from the equation (4.29).

$$V_{Rk,c} = V_{Rk,c}^0 \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V} \cdot \alpha_{90°,V} \cdot \psi_{re,V} \qquad [N] \qquad (4.29)$$

with

$$V_{Rk,c}^0 = \alpha_p \cdot \sqrt{f_{ck,cube}} \cdot c_1^{1,5} \qquad [N] \qquad (4.30)$$

with

α_p = product factor $[N^{0.5}/mm]$. It is shown in the respective approval.

= 2.5 (guide value)

$f_{ck,cube}$ = nominal value of the concrete compressive strength (cubes with 150 mm side length)

The influence of neighbouring anchors on the concrete cone failure is taken account of with the factor $\alpha_{s,V}$ in accordance with (4.37)

$$\alpha_{s,V} = \cfrac{1}{1 + \sum\limits_{i=1}^{n}\left[\left(1 - \cfrac{s_i}{s_{cr,V}}\right)^{1,5} \cdot \cfrac{V_i}{V_0} \right]} \qquad (4.31)$$

with (see figure 4.10)

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

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

$$s_{cr,v} = 4 \cdot c_1 + 2 \cdot b_{ch} \qquad (4.32)$$

b_{ch} = width of the anchor channel

V_i = shear load of an influencing anchor

V_0 = shear load of the anchor in question

n = number of anchors within a distance of $s_{cr,V}$ on both sides of the anchor under consideration
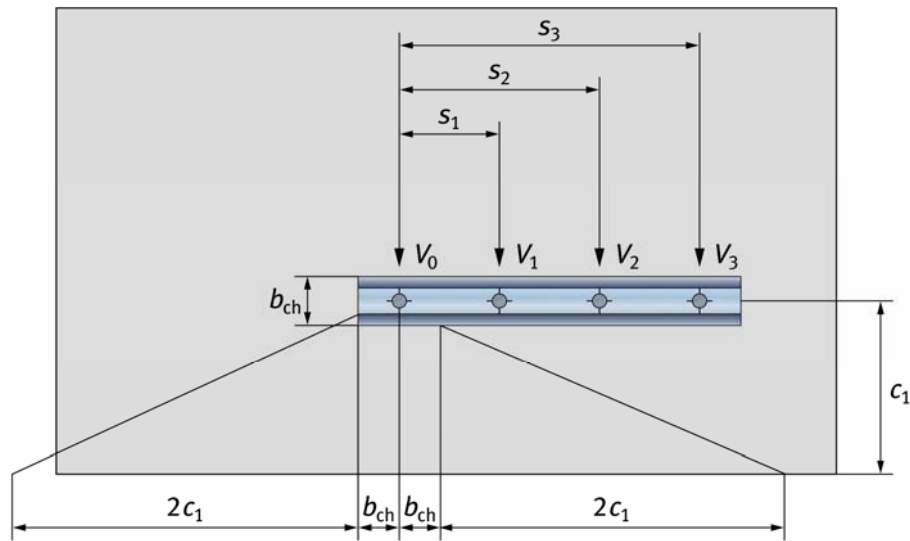
Figure 4.10: Example for an anchor channel with differing shear forces applied to the anchors

The influence of a member corner is taken account of with factor $\alpha_{c,V}$

$$\alpha_{c,V} = \left(\frac{c_2}{c_{cr,V}} \right)^{0,5} \leq 1 \tag{4.33}$$

with
$$c_{cr,V} = 0,5 \cdot s_{cr,V} = 2 \cdot c_1 + b_{ch} \tag{4.34}$$

If the anchor is influenced by two corners (see figure 4.11) the factor $\alpha_{c,V}$ in accordance with equation (4.33) must be calculated for each corner and the product used in equation (4.29).
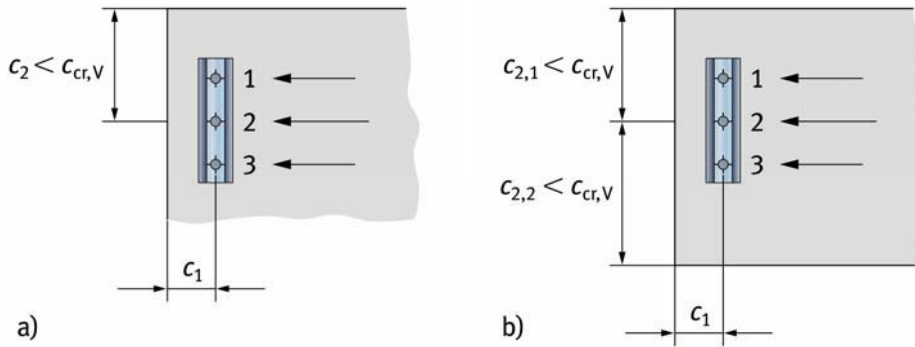
Figure 4.11: Example of an anchor channel with anchors influenced by a) one or b) two corners. Anchor 2 is the anchor in question.

The influence of a component thickness $h < h_{cr,V}$ is taken account of with factor $\alpha_{h,V}$

$$\alpha_{h,V} = \left(\frac{h}{h_{cr,V}} \right)^{\frac{2}{3}} \leq 1 \qquad (4.35)$$

with

$$h_{cr,V} = 2 \cdot c_1 + 2 \cdot h_{ch} \qquad \text{(see figure 4.12)} \qquad (4.36)$$

h_{ch} = height of the channel
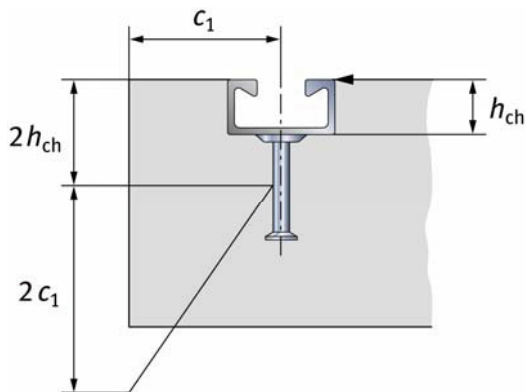
Figure 4.12: Example of an anchor channel influenced by the member thickness

The factor $\alpha_{90°,V}$ takes account of the influence of shear loads that are applied parallel to the edge (see figure 4.13)

$$\alpha_{90°,V} = 2,5 \tag{4.37}$$
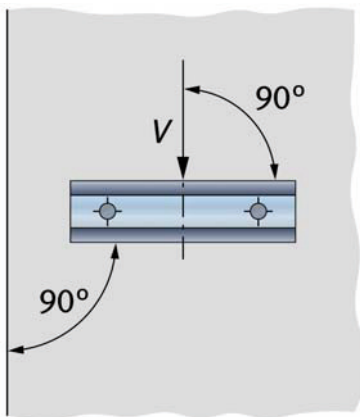
Figure 4.13: Anchor channel under load parallel to the component edge

The factor $\psi_{re,V}$ takes account of the state of the concrete (cracked or uncracked) and the type of reinforcement present at the edge.

$\psi_{re,V}$	=	1.0	anchor channel in cracked concrete without edge reinforcement or stirrups
	=	1.2	anchor channel in cracked concrete with straight edge reinforcement ($\geq \varnothing$ 12 mm) and height of the anchor channel $h_{ch} \geq 40$ mm
	=	1.4	anchor channel in cracked concrete with edge reinforcement and stirrups with small axis spacing or small-meshed reinforcement ($a \leq 100$ mm and $a \leq 2\ c_1$) or anchor channels in uncracked concrete

With anchor channels in a narrow, thin component (see figure 4.14) with $c_{2,max} \leq c_{cr,V}$ ($c_{cr,V} = 2\ c_1 + b_{ch}$) and $h < h_{cr,V}$ ($h_{cr,V} = 2\ c_1 + 2\ h_{ch}$) a determination of the characteristic resistance with equation (4.29) leads to results that are on the safe side. More exact results can be achieved by limiting the edge distance c_1 in equation (4.29) with the value c_1' in accordance with equation (4.38).

$$c_1' = \max\left[0{,}5 \cdot (c_{2,max} - b_{ch}) \; ; \; 0{,}5 \cdot (h - 2h_{ch})\right] \qquad [\text{mm}] \qquad (4.38)$$

with

$c_{2,max}$ = largest edge distance $c_{2,1}$ and $c_{2,2}$ parallel to the direction of the load

The value c_1' is used in the equations (4.30), (4.32), (4.34) and (4.36).
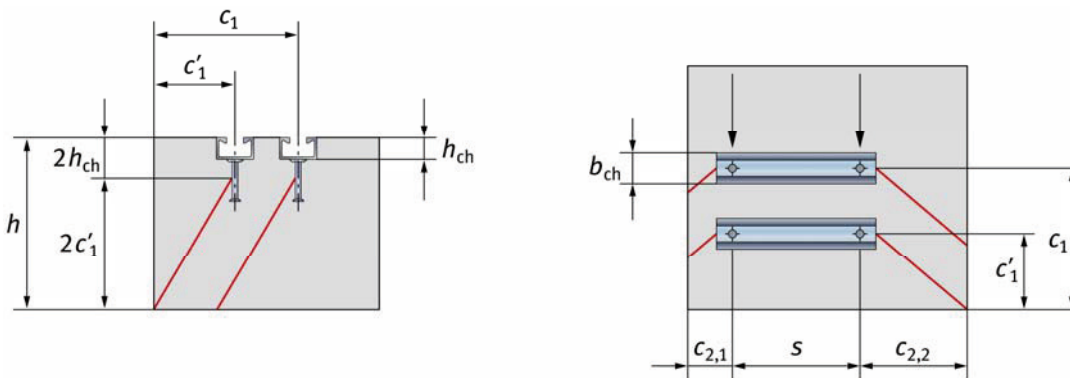
Figure 4.14: Example of an anchor channel where the concrete breaking load is influenced by two edges parallel to the shear load and by the component thickness

4.2.6 Steel failure in supplementary reinforcement

The determination of the characteristic resistance of the supplementary reinforcement during steel failure is carried out with the equation (4.23).

4.2.7 Bond failure of the supplementary reinforcement in the failure cone

The characteristic resistance of the supplementary reinforcement for failure due to anchorage failure from the failure section arises from the equation (4.24). With a supplementary reinforcement out of welded reinforcing steel mesh with welded cross bars in the failure section, the factor as with hooks is $\alpha = 0.7$. With a supplementary reinforcement of straight rods, $\alpha = 1.0$ may be assumed.

4.2.8   Alternative possibility in accordance with ETA ([11], [12]) to design the supplementary reinforcement

The verification for the shear load with additional reinforcement can be carried out in accordance with [11] and [12] either according to sections 4.2.6 and 4.2.7 or according to the following explanations. The approaches according to sections 4.2.6 an 4.2.7 are conservative and provide results that lie clearly on the safe side.

Results nearer to reality can be achieved with the model already in use for channels from DKG and Halfen in the ETA ([11], [12]) in accordance with Schmid ([15]). The calculation of the characteristic resistance of the supplementary reinforcement is as follows.
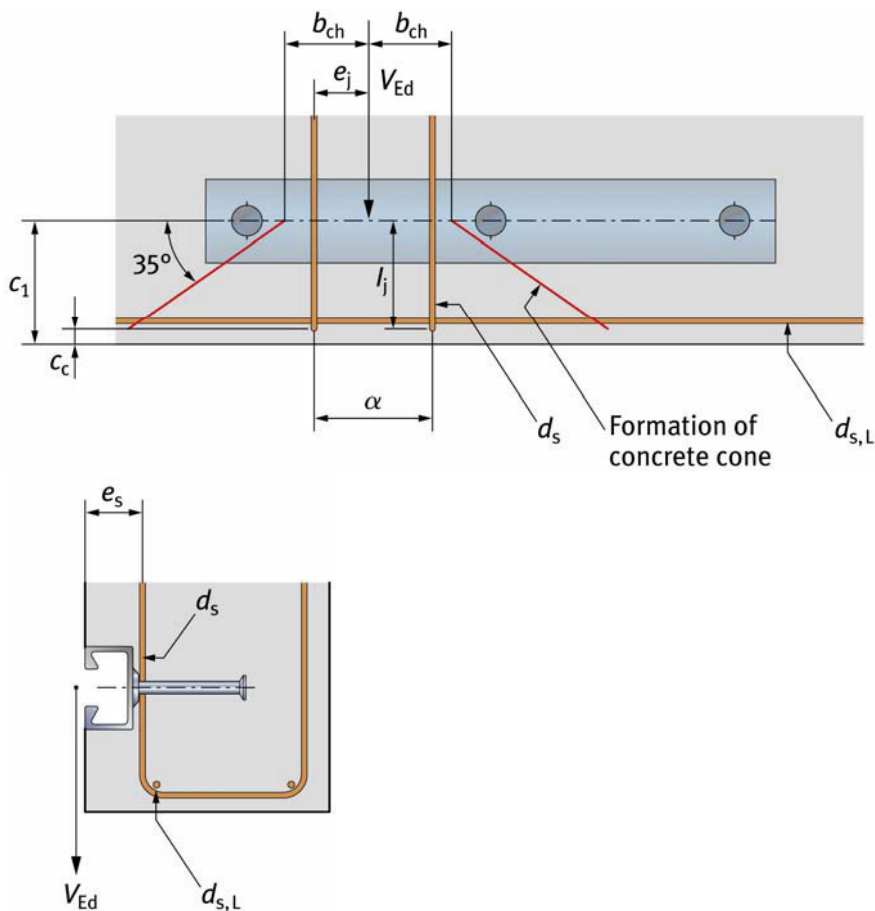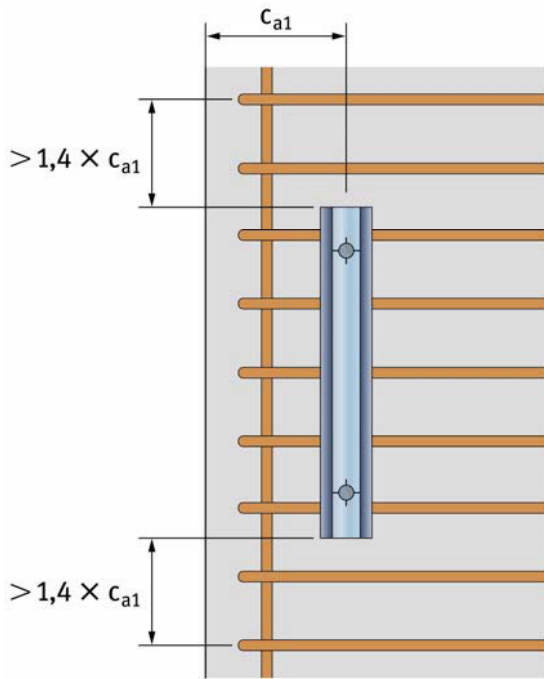
Figure 4.15:   Verification of anchor channels for shear loads with reinforcement (direction of load vertically to the component edge), in accordance with [11], [12]

$$V_{Ed} \leq V_{Rd,re} = V_{Rk,re} / \gamma_M \tag{4.39}$$

$$V_{Ed} = \max\left(V_{Ed}; V_{Ed}^a\right) \tag{4.40}$$

$$V_{Rk,re} = V_{Rk,c,re} / x \tag{4.41}$$

with

$$V_{Rk,c,re} = V_{Rk,c,hook} + V_{Rk,c,bond} \leq V_{Rk,c,re,max} \leq \sum_{m+n} A_s \cdot f_{y,k} \tag{4.42}$$

$$V_{Rk,c,hook} = \sum_{j=1}^{m}\left(\psi_1 \cdot \psi_3 \cdot \psi_4 \cdot A_s \cdot f_{y,k} \cdot \left(\frac{f_{ck}}{30}\right)^{0,1}\right) + \sum_{j=1}^{n}\left(\psi_2 \cdot \psi_3 \cdot \psi_4 \cdot A_s \cdot f_{y,k} \cdot \left(\frac{f_{ck}}{30}\right)^{0,1}\right) \tag{4.43}$$

$$V_{Rk,c,bond} = \sum_{j=1}^{m+n}\left(\pi \cdot d_s \cdot l_j \cdot f_{bk}\right) \tag{4.44}$$

$$V_{Rk,c,re,max} = 4,2 \cdot c_1^{-0,12} \cdot V_{Rk,c} \tag{4.45}$$

$$V_{Rk,c} = V_{Rk,c}^0 \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V} \tag{4.46}$$

$$50\text{mm} \leq a \leq \begin{cases} s \\ 150\text{mm} \\ \left(c_1 - c_c + 0,7 b_{ch} - 4 d_s\right) / 0,35 \\ c_1 - c_c \end{cases} \tag{4.47}$$

$$6\text{mm} \leq d_s \leq 20\text{mm} \tag{4.48}$$

ψ_1	=	Effectiveness factor	
	=	0.67 for stirrups directly next to the shear load	1
	•	for a stirrup under a shear load	3
	•	for a stirrup between 2 shear loads applied to an anchor channel (spacing of the loads $\leq s_{cr,V}$ in accordance with equation (4.32)	2
ψ_2	=	Effectiveness factor	
	=	0.11 for further stirrups in the failure cone	4
		(for designations see figure 4.16 and figure 4.17)	

$$\psi_3 = \left(d_{s,L} / d_s\right)^{2/3} \qquad \text{(see figure 4.15)} \tag{4.49}$$

$$\psi_4 = \left(\frac{l_j}{c_1}\right)^{0,4} \cdot \left(\frac{10}{d_s}\right)^{0,25} \tag{4.50}$$

d_s	=	stirrup diameter [mm]
$d_{s,L}$	=	rod diameter of the edge reinforcement [mm]
l_4	=	anchoring length of a stirrup in the failure cone [mm]
	=	$c_1 - c_c - 0,7 \cdot \left(e_j - b_{ch}\right)$ [mm] for stirrups crossed by the assumed crack
	=	$c_1 - c_c$ [mm] for stirrups directly under the load or for stirrups crossed at right angles by the assumed crack
		$\geq 4 \cdot d_s$
c_1	=	Edge distance [mm]
c_c	=	Concrete cover [mm]
e_j	=	distance of the stirrup from the loading point [mm]
b_{ch}	=	profile width [mm] (according to table 2)
A_s	=	cross section of a stirrup leg [mm^2]
$f_{y,k}$	=	characteristic yield point of the reinforcement [N/mm^2]
f_{ck}	=	characteristic concrete pressure resistance (determined on cubes with an edge length of 150 mm) [N/mm^2]
f_{bk}	=	characteristic bond strength [N/mm^2)
m	=	number of stirrups in the assumed failure cone with ψ_1

n	=	number of stirrups in the assumed failure cone with ψ_2	
α	=	stirrup spacing	
x	=	$e_s / z + 1 \; [-]$	(4.51)
		Factor to take account of the excentricity between reinforcement and the load applied	
e_s	=	distance between reinforcement and the shear force applied to the channel	
z	=	$0.85d \; [mm]$	
		Inner lever arm of the component	
d	=	$\min\left(2h_{ef}, 2c_1\right)$	
$V^0_{Rk,c}$	=	according to equation (4.30)	
V^a_{Ed}	=	design value of the load applied to an anchor of an anchor channel, see [5], Section 3.2.2	
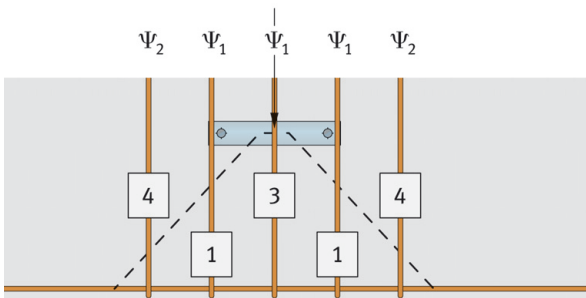
Figure 4.16: Effectiveness factors ψ_1 and ψ_2 for one load
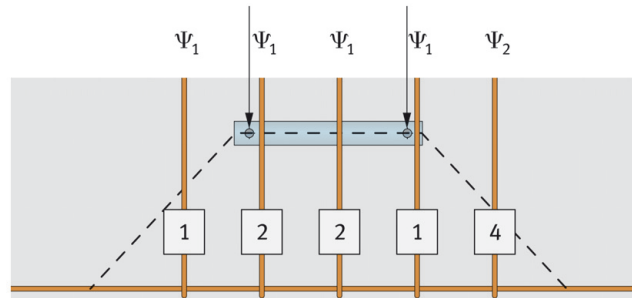
Figure 4.17: Effectiveness factors ψ_1 and ψ_2 for two loads

4.3 Combined tensile and shear load

4.3.1 *Anchor channels without supplementary reinforcement*

4.3.1.1 Steel failure decisive under tensile and shear load

With combined tensile and shear load on anchor channels without supplementary reinforcement, and steel failure in both directions, the interaction equation (4.52) must be fulfilled. In each case the largest value β_N and β_V for the individual failure types is to be used.

$$\beta_N^2 + \beta_V^2 \leq 1 \tag{4.52}$$

with

$$\beta_N = N_{Ed} / N_{Rd} \leq 1$$
$$\beta_V = V_{Ed} / V_{Rd} \leq 1$$

4.3.1.2 Other failure types decisive

In cases of different failure types under tensile and shear load, one of the following equations (4.53) or (4.54) must be fulfilled.

$$\beta_N + \beta_V \leq 1{,}2 \tag{4.53}$$
$$\beta_N^{1,5} + \beta_V^{1,5} \leq 1 \tag{4.54}$$

with
$$\beta_N = N_{Ed} / N_{Rd} \leq 1$$
$$\beta_V = V_{Ed} / V_{Rd} \leq 1$$

4.3.2 Anchor channels with supplementary reinforcement

With anchor channels with a supplementary reinforcement for taking up the tensile and shear loads, section 4.3.1 applies. For *anchor channels on the component edge* with a supplementary reinforcement for taking up shear loads, equation (4.55) (linear interaction) applies. The largest value β_N and β_V for the individual failure types is to be used.

$$\beta_N + \beta_V \leq 1{,}0 \tag{4.55}$$
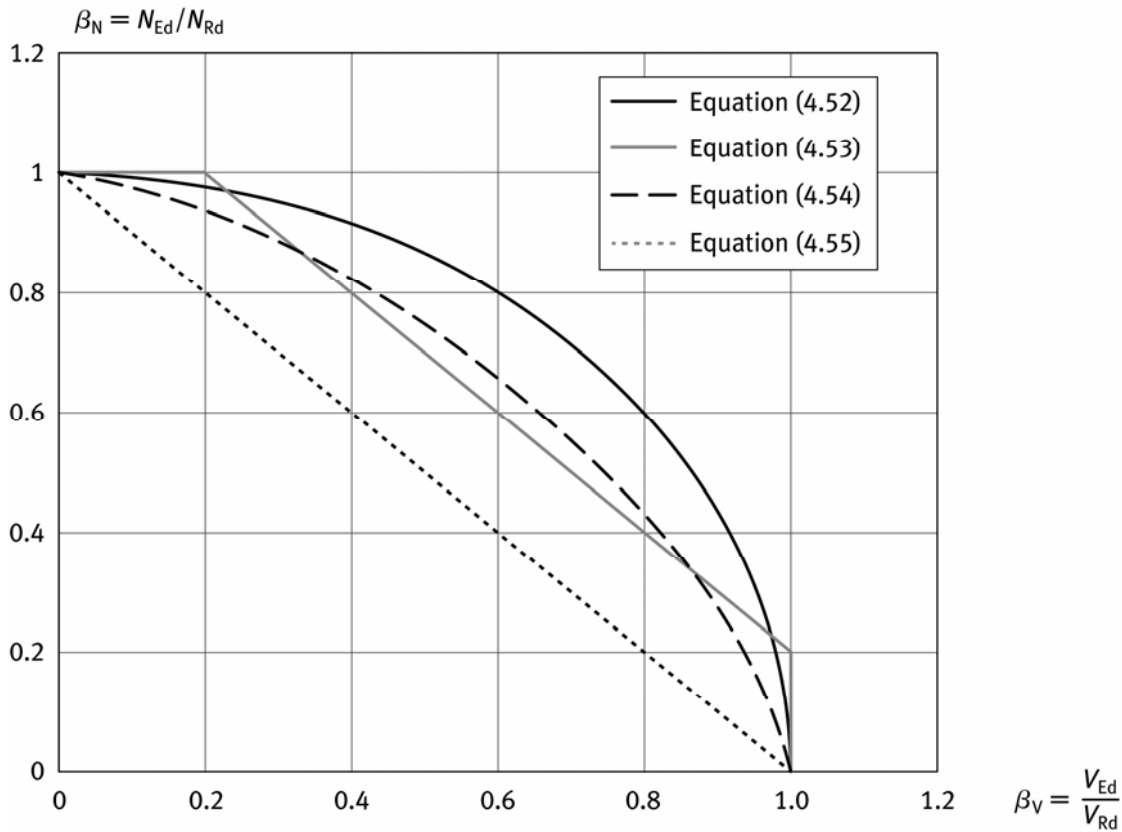
Figure 4.18:   Interaction diagram for combined tensile and shear load

4.3.3   New approach for anchor channels without supplementary reinforcement in accordance with fib Design Guide [16]

The equations (4.52), (4.53) and (4.54) generally provide very conservative results as they link differing failure types and the resulting stresses, which in addition appear at different points.

More precise results are achieved if equations (4.52) (steel failure) **and** (4.54) (concrete failure) are taken into account separately. Figure 4.19 illustrates the procedure. The grey area in figure 4.19 shows the difference to the approach according to equation (4.54).
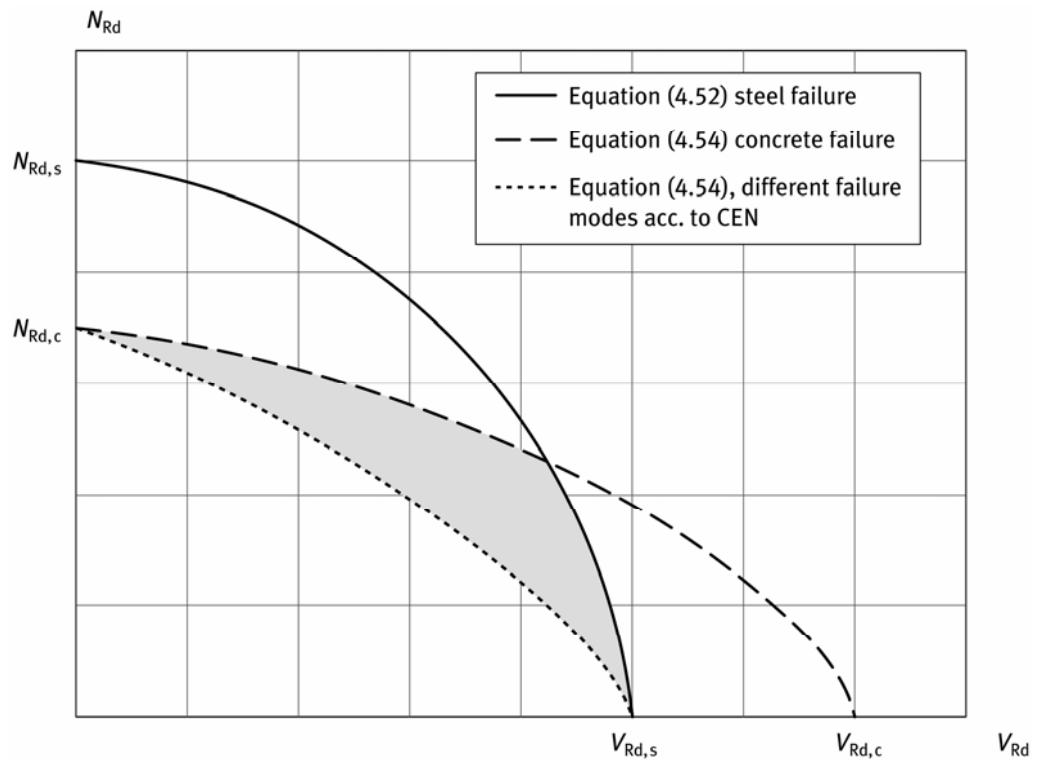
Figure 4.19:   Comparison of the interaction equations (4.52) and (4.53) with (4.54)

5 DESIGN EXAMPLES

5.1 Characteristic values from approval

dimension [mm]	Anchor channel										
	JTA K 28/15	JTA K 38/17	JTA W 40/22	JTA W 50/30	JTA W 53/34	JTA W 55/42	JTA W 72/48	JTA K 40/25	JTA K 50/30	JTA K 53/34	JTA K 72/48
b_{ch}	28,00	38,00	39,50	49,00	52,50	54,50	72,00	40,00	50,00	53,50	72,00
h_{ch}	15,25	17,50	23,00	30,00	33,50	42,00	48,50	25,00	30,00	33,00	49,00

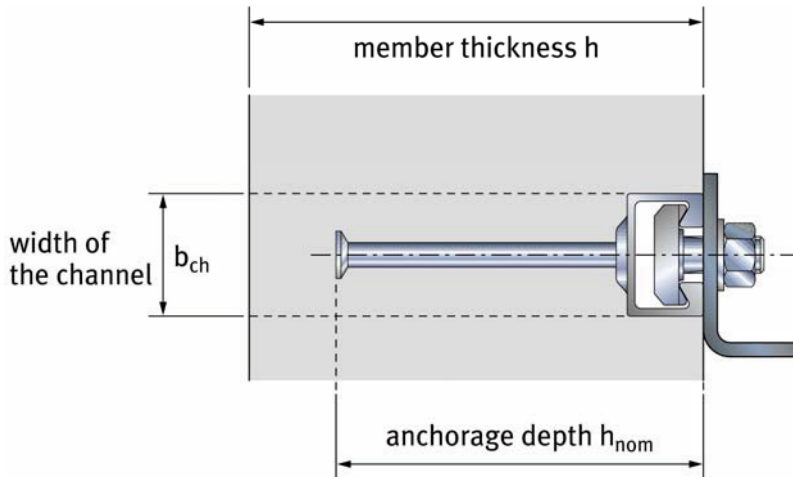|		Characteristic resistances - screws									
		M6	M8	M10	M12	M16	M20	M24	M27	M30	γ_{Ms}
4.6	$N_{Rk,s}$ [kN]	8,0	14,6	23,2	33,7	62,8	98,0	141,2	183,6	224,4	2,00
	$V_{Rk,s}$ [kN]	4,8	8,8	13,9	20,2	37,7	58,8	84,7	110,2	134,6	1,67
	$M^0_{Rk,s}$ [Nm]	6,3	15,0	29,9	52,4	133,2	259,6	449,0	665,8	899,6	1,67
8.8	$N_{Rk,s}$ [kN]	16,1	29,3	46,4	67,4	125,6	196,0	282,4	367,2	448,8	1,50
	$V_{Rk,s}$ [kN]	8,0	14,6	23,2	33,7	62,8	98,0	141,2	183,6	224,4	1,25
	$M^0_{Rk,s}$ [Nm]	12,2	30,0	59,8	104,8	266,4	519,3	898,0	1331,5	1799,2	1,25
A4 -50	$N_{Rk,s}$ [kN]	10,1	18,3	29,0	42,2	78,5	122,5	176,5	229,5	280,5	2,86
	$V_{Rk,s}$ [kN]	6,0	11,0	17,4	25,3	47,1	73,5	105,9	137,7	168,3	2,38
	$M^0_{Rk,s}$ [Nm]	7,6	18,7	37,4	65,5	166,5	324,5	561,3	832,2	1124,5	2,38
A4 -70	$N_{Rk,s}$ [kN]	14,1	25,6	40,6	59,0	109,9	171,5	247,1	321,3	392,7	1,87
	$V_{Rk,s}$ [kN]	8,4	15,4	24,4	35,4	65,9	102,9	148,3	192,8	235,6	1,56
	$M^0_{Rk,s}$ [Nm]	10,7	26,2	52,3	91,7	233,1	454,4	785,8	1165,1	1574,3	1,56

Hot-rolled profiles						
Profiles		JTA W 40/22	JTA W 50/30	JTA W 53/34	JTA W 55/42	JTA W 72/48
screws		M10 - M16	M10 - M20	M10 - M20	M10 - M24	M20 - M30
I_y normal steel	[mm^4]	19703	51904	93262	187464	349721
I_y stainless steel	[mm^4]	19759	51904	93262	-	349721
$N_{Rk,s,c}$	[kN]	20	31	55	80	100
$\gamma_{Ms,ca}$		1,8				
s_{slb}	[mm]	65	81	88	109	129
$N_{Rk,s,l}$	[kN]	20	31	55	80	100
$\gamma_{Ms,l}$		1,8				
$V_{Rk,s,c}$	[kN]	20	31	55	80	100
$\gamma_{Ms,ca}$		1,8				
$V_{Rk,s,l}$	[kN]	26	40,3	71,5	104	130
$\gamma_{Ms,l}$		1,8				
$M_{Rk,s,flex}$ normal steel	[Nm]	1076	2038	3373	6447	8593
$M_{Rk,s,flex}$ stainless steel	[Nm]	1080	2081	3445	-	8775
$\gamma_{Ms,flex}$		1,15				
$N_{Rk,p}$ in C12/15	[kN]	10,8	15,9	29,7	38,4	50,9
ψ_c		$(f_{ck,cube}/15)$				
γ_{Mp}		1,5				
α_{ch}		0,88	0,91	0,98	1,00	1,00
h_{ef}	[mm]	79	94	155	175	179
γ_{Mc}		1,5				
k_5		2,0				
$\alpha_p \cdot \psi_{re,V}$		3,0	3,5	3,5	3,5	4,0
Cracked concrete, straight rebars		3,5	4,1	4,1	4,1	4,7
Stirrups		4,0	4,7	4,7	4,7	5,3
$\alpha_{h,V}$		$(h/h_{cr,V})^{2/3}$				

Cold-formed profiles							
profiles		JTA K 28/15	JTA K 38/17	JTA K 40/25	JTA K 50/30	JTA K 53/34	JTA K 72/48
screws		M6 – M12	M10 - M16	M10 - M16	M10 - M20	M10 - M20	M20 - M30
I_y normal steel	[mm^4]	4060	8547	20570	41827	72079	293579
I_y stainless steel	[mm^4]	4060	8547	19097	41827	72079	293579
$N_{Rk,s,c}$	[kN]	9	18	20	31	55	100
$\gamma_{Ms,ca}$		1,8					
s_{slb}	[mm]	42	52	65	81	88	129
$N_{Rk,s,l}$	[kN]	9	18	20	31	55	100
$\gamma_{Ms,l}$		1,8					
$V_{Rk,s,c}$	[kN]	9	18	20	31	55	100
$\gamma_{Ms,ca}$		1,8					
$V_{Rk,s,l}$	[kN]	9	18	20	31	55	100
$\gamma_{Ms,flex}$		1,8					
$M_{Rk,s,flex}$ normal steel	[Nm]	317	580	1099	1673	2984	8617
$M_{Rk,s,flex}$ stainless steel	[Nm]	324	593	1071	1708	2984	8617
$\gamma_{Ms,l}$		1,15					
$N_{Rk,p}$ in C12/15	[kN]	6,7	14,7	10,8	15,9	29,7	50,9
ψ_c		$(f_{ck,cube}/15)$					
γ_{Mp}		1,5					
α_{ch}		0,81	0,88	0,88	0,91	0,98	1,00
h_{ef}	[mm]	45	76	79	94	155	179
γ_{Mc}		1,5					
k_5		2,0					
$\alpha_p \cdot \psi_{re,V}$		2,5	3,0	3,0	3,5	3,5	4,0
Cracked concrete, straight rebars		3,0	3,5	3,5	4,1	4,1	4,7
stirrups		3,5	4,0	4,0	4,7	4,7	5,3
$\alpha_{h,V}$		$(h/h_{cr,V})^{2/3}$					

5.2   Example 1
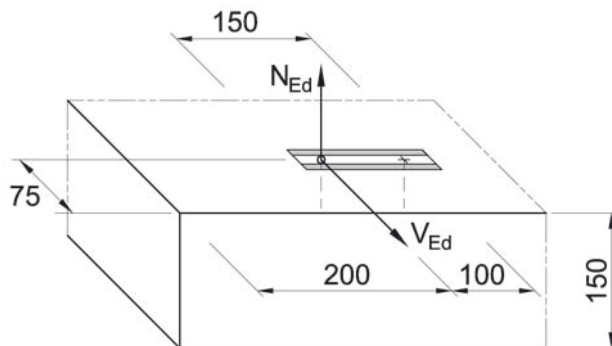
Profile 40/25, L = 150 mm, round anchors
Anchor spacing: s = 100 mm

1 screw M12 4.6
Concrete C30/37, cracked
Member thickness h = 150 mm
Edge distance c_1 = 75 mm
Edge distance c_2 = 200 mm

N_{Ed} = 5,00 kN, V_{Ed} = 5,50 kN

Given values according to ETA

Characteristic values	Partial safety factor
I_y = 20570 mm^4	
$N_{Rk,s,c}$ = 20,00 kN	$\gamma_{Ms,c}$ = 1,80
$N_{Rk,s,l}$ = 20,00 kN	$\gamma_{Ms,l}$ = 1,80
$N_{Rk,s,s}$ = 33,70 kN	$\gamma_{Ms,s}$ = 2,00
$M_{Rk,s,flex}$ = 109,9 kNcm	$\gamma_{Ms,flex}$ = 1,15
$N_{Rk,p}$ = 10,8 * 2,47 = 26,68 kN	γ_{Mc} = 1,50
h_{ef} = 79 mm	
α_{ch} = 0,88	
$s_{cr,N}$ = 352 mm	
$c_{cr,N}$ = 176 mm	
$V_{Rk,s,s}$ = 20,20 kN	γ_{Ms} = 1,67
$V_{Rk,s,l}$ = 20,00 kN	$\gamma_{Ms,l}$ = 1,80
$\alpha_p\ \psi_{re,V}$= 3,00	
b_{ch} = 40,00 mm	
h_{ch} = 25,00 mm	

1. Load distribution

Anchor loads according to constraint length method

$l_i = 13 \cdot I_y^{0,05} \cdot s^{0,5} = 13 \cdot 20570^{0,05} \cdot 100^{0,5} = 214$ mm   (eq. 3.2)

Load position: Screw is located directly above the first anchor

		Anker 1	Anker 2
1.1	Distance load to the ancor [mm]	0	100
1.2	$A'_i = (l_i{-}s)/l_i$	(214-0)/214 = 1,000	(214-100)/214 = 0,533
1.3	$k = 1/\Sigma A'_i$	1/(1,00+0,533) = 0,652	
1.4	$N^a_{Ed} = k \cdot A'_i \cdot N_{Ed}$	0,652·1,000·5,00 = **3,26**	0,652·0,533·5,00 = **1,74**
	Analog for shear: V^a_{Ed} [kN]	**3,59**	**1,91**

2. Verification

Tension

1)   Steel failure anchor (not decisive acc. to ETA annex 11)

2)   Connection anchor - channel

$N_{Rk,s,c}$ = 20,00 kN, $\gamma_{Ms,c}$ = 1,80, $N_{Rd,s,c}$ = 11,11 kN > 3,26 kN

$\beta_N = \dfrac{3,26}{11,11} = 0,29$

3)   Bending of the channel lips

$N_{Rk,s,l}$ = 20,00 kN, $\gamma_{Ms,l}$ = 1,80, $N_{Rd,s,l}$ = 11,11 > 5,00 kN

$\beta_N = \dfrac{5,00}{11,11} = 0,45$

4)   Steel failure screws

$N_{Rk,s,s}$ = 33,70 kN, $\gamma_{Ms,s}$ = 2,00, $N_{Rd,s,s}$ = 16,85 kN > 5,00 kN

$\beta_N = \dfrac{5,00}{16,85} = 0,30$

5)   Bending of the channel

Decisive load position: centered between the anchors

$M_{Ed} = \dfrac{1}{4} \cdot (5,00 \text{ kN} \cdot 10 \text{ cm}) = 12,5 \text{ kNcm}$

$M_{Rk,s,flex}$ = 109,9 kNcm, $\gamma_{Ms,flex}$ = 1,15, $M_{Rd,s,flex}$ = 95,57 kNcm

$\beta_N = \dfrac{12,50}{95,57} = 0,13$

6)   Pull-out failure

$N_{Rk,p}$ = 26,68 kN, γ_{Mc} = 1,5, $N_{Rd,p}$ = 17,78 kN > 3,26 kN

$\beta_N = \dfrac{3,26}{17,78} = 0,18$

7) Concrete cone failure

$$N_{Rk,c} = N^0_{Rk,c} \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N} \qquad \text{(eq. 4.2)}$$

embedment depth $\quad h_{ef} = 79$ mm
factor $\qquad\qquad\quad \alpha_{ch} = 0,88$

basic value
$$N^0_{Rk,c} = 8,5 \cdot \alpha_{ch} \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1,5} = 8,5 \cdot 0,88 \cdot \sqrt{37} \cdot 79^{1,5} = 31,94 \text{ kN}$$
$$\text{(eq. 4.3)}$$

<u>Influence of neighbouring anchor</u>
characteristic spacing
$s_{cr,N} \quad = 352$ mm

$$\alpha_{s,N} = \cfrac{1}{1 + \left(1 - \cfrac{s_2}{s_{cr,N}}\right)^{1,5} \cdot \cfrac{N_{aEd,2}}{N_{aEd,1}}} = \cfrac{1}{1 + \left(1 - \cfrac{100}{352}\right)^{1,5} \cdot \cfrac{1,74}{3,26}} = 0,76 \qquad \text{(eq. 4.5)}$$

<u>Influence of member edges</u>
characteristic edge distance
$c_{cr,N} \quad = 176$ mm
actual edge distance $c_1 = 75$ mm $< c_{cr,N}$
$\alpha_{e,N} \quad = (c_1/c_{cr,N})^{0,5} = (75/176)^{0,5} = 0,65 \qquad\qquad\qquad$ (eq. 4.7)

<u>Influence of member corner</u>
actual edge distance $c_2 = 200$ mm $> c_{cr,N}$
$\alpha_{c,N} \quad = 1,00 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (eq. 4.9)

<u>Influence of a dense reinforcement</u>
$\psi_{re,N} \quad = 1,00$ (it is assumed that reinforcement with a spacing of ≥ 150 mm is present) $\qquad$ (Gl. 4.10)

<u>Concrete condition</u>
$\psi_{ucr,N} \quad = 1,00 \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (eq. 4.11)

$N_{Rk,c} = N^0_{Rk,c} \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N}$

$N_{Rk,c} = 32,09 \text{ kN} \cdot 0,76 \cdot 0,65 \cdot 1,00 \cdot 1,00 \cdot 1,00 = 15,78 \text{ kN}$, $\gamma_{Mc} = 1,5$, $N_{Rd,c} = 10,52 \text{ kN} > 3,26 \text{ kN}$

$\beta_N = \dfrac{3,26}{10,52} = 0,31$

8) Splitting during installation and under load

    Verification not necessary

9) Blow-out

    Verification not necessary

<u>Shear load</u>

1) Steel failure screw

    $V_{Rk,s,s} = 20,20 \text{ kN}$, $\gamma_{Ms} = 1,67$, $V_{Rd,s,s} = 12,10 \text{ kN} > 6,50 \text{ kN}$

    $\beta_V = \dfrac{5,50}{12,10} = 0,45$

2) Anchor

    $V_{Rk,s,a} = N_{Rk,s,a}$ (not decisive acc. to ETA annex 11)

3) Steel failure connection between anchor and channel

    $V_{Rk,s,c} = 20,00 \text{ kN}$, $\gamma_{Ms,c} = 1,80$, $V_{Rd,s,c} = 11,11 \text{ kN} > 3,59 \text{ kN}$

    $\beta_V = \dfrac{3,59}{11,11} = 0,32$

4) Bending of the channel lips

    $V_{Rk,s,l} = 20,00 \text{ kN}$, $\gamma_{Ms,l} = 1,80$, $V_{Rd,s,l} = 11,11 \text{ kN} > 5,50 \text{ kN}$

    $\beta_V = \dfrac{5,50}{11,11} = 0,50$

5) Pry-out failure

$$V_{Rk,cp} = k_5 \cdot N_{Rk,c} \qquad \text{(eq. 4.28)}$$

$$V_{Rk,cp} = 2 \cdot 15{,}78 = 31{,}56 \text{ kN}, \; \gamma_{Mc} = 1{,}5, \; V_{Rd,cp} = 21{,}04 \text{ kN} > 4{,}24 \text{ kN}$$

$$\beta_V = \frac{3{,}59}{21{,}04} = 0{,}17$$

6) Concrete edge failure

cracked concrete, no supplementary reinforcement
$$V_{Rk,c} = V^0_{Rk,c} \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V} \cdot \psi_{re,V} \qquad \text{(eq. 4.29)}$$
$$\alpha_p \cdot \psi_{re,V} = 3{,}00$$
$$V^0_{Rk,c} \cdot \psi_{re,V} = \alpha_p \cdot \psi_{re,V} \cdot \sqrt{f_{ck,cube}} \cdot c_1^{1,5} = 3{,}0 \cdot \sqrt{37} \cdot 75^{1,5} = 11{,}85 \text{ kN}$$
$$\text{(eq. 4.30)}$$

Influence of neighbouring anchors
characteristic anchor spacing
$$s_{cr,V} = 4 \cdot c_1 + 2 \cdot b_{ch} = 4 \cdot 75 + 2 \cdot 40 = 380 \text{ mm} \qquad \text{(eq. 4.32)}$$

$$\alpha_{s,V} = \frac{1}{1 + \left(1 - \dfrac{s_2}{s_{cr,V}}\right)^{1,5} \cdot \dfrac{V_{aED,2}}{V_{aED,1}}} = \frac{1}{1 + \left(1 - \dfrac{100}{380}\right)^{1,5} \cdot \dfrac{1{,}91}{3{,}59}} = 0{,}75$$
$$\text{(eq. 4.31)}$$

Influence edge distance
$$c_{cr,V} = 2 \cdot c_1 + b_{ch} = 2 \cdot 75 + 40 = 190 \text{ mm} \qquad \text{(eq. 4.34)}$$

actual edge distance $c_2 = 200 \text{ mm} > c_{cr,V}$
$$\alpha_{c,V} = 1{,}00 \qquad \text{(eq. 4.33)}$$

Influence member thickness
$$h_{cr,V} = 2 \cdot c_1 + 2 \cdot h_{ch} = 2 \cdot 75 + 2 \cdot 23 = 196 \text{ mm} \qquad \text{(eq. 4.36)}$$

$$\alpha_{h,V} = (h/h_{cr,V})^{2/3} = (150/196)^{2/3} = 0{,}84 \qquad \text{(eq. 4.35)}$$

Concrete condition

$\psi_{re,V} = 1,00$

$V_{Rk,c} = 11,85$ kN$\cdot 0,75 \cdot 1,0 \cdot 0,84 \cdot 1,0 = 7,47$ kN, $\gamma_{Mc} = 1,5$, $V_{Rd,c}$ = 4,98 kN > 4,24 kN

$\beta_V = \dfrac{3,59}{4,98} = 0,72$

Combined tension and shear loading (interaction)

1)   Steel failure screws

     $\beta_N = 0,30$
     $\beta_V = 0,45$
     $\beta_N^2 + \beta_V^2 = 0,30^2 + 0,45^2 = 0,29 < 1$ (eq. 4.52)

2)   Steel failure channels (local failure)

     $\beta_N = 0,45$
     $\beta_V = 0,50$
     $\beta_N^2 + \beta_V^2 = 0,45^2 + 0,50^2 = 0,45 < 1$ (eq. 4.52)

3)   Steel failure anchors (anchor 1)

     $\beta_N = 0,29$
     $\beta_V = 0,32$
     $\beta_N^2 + \beta_V^2 = 0,29^2 + 0,32^2 = 0,19 < 1$

4)   Concrete failure (concrete cone – concrete edge failure)

     $\beta_N = 0,31$
     $\beta_V = 0,72$
     $\beta_N^{1,5} + \beta_V^{1,5} = 0,31^{1,5} + 0,72^{1,5} = 0,78 < 1,0$ (eq. 4.54)
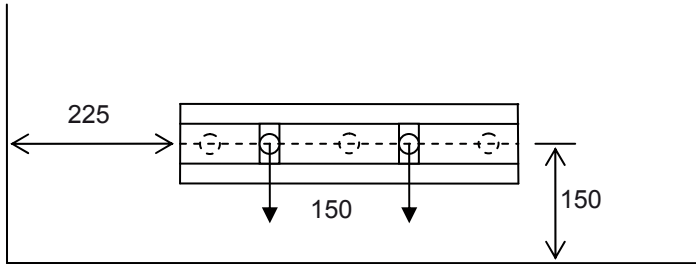
Verification fulfilled!

5.3 Example 2

Hot-rolled profile 50/30, L = 350 mm, 3 round anchors

Excess length: $x = 25$ mm

Anchor spacing: $s = 150$ mm

2 screws M16 4.6, screw spacing 150 mm

$N_{Ed} = 3{,}2$ kN, $V_{Ed} = 8{,}3$ kN

concrete C25/30, cracked

member thickness $h = 200$ mm

edge distance $c_1 = 150$ mm

edge distance $c_2 = 225+25 = 250$ mm

Given values according to ETA

| Characteristic values			Partial safety factor		
b_{ch}	=	49 mm			
h_{ch}	=	30 mm			
I_y	=	51904 mm^4			
$N_{Rk,s,a}$	=	-	γ_{Ms}	=	-
$N_{Rk,s,c}$	=	31,0 kN	$\gamma_{Ms,ca}$	=	1,8
$N_{Rk,s,l}$	=	31,0 kN	$\gamma_{Ms,l}$	=	1,8
s_{slb}	=	81 mm			
$M_{Rk,s,flex}$	=	2038 Nm	$\gamma_{Ms,flex}$	=	1,15
$N_{Rk,s,s}$	=	62,8 kN	γ_{Ms}	=	2,0
$N_{Rk,p}$	=	2,0·15,9 = 31,8 kN	γ_{Mc}	=	1,5
α_{ch}	=	0,91			
h_{ef}	=	94 mm			
$s_{cr,N}$	=	399 mm			
$c_{cr,N}$	=	199 mm			
$V_{Rk,s,l}$	=	40,3 kN	$\gamma_{Ms,l}$	=	1,8
k_5	=	2,0			
α_p	=	3,5			
$V_{Rk,s,s}$	=	37,7 kN	γ_{Ms}	=	1,67

<u>Load distribution</u>

<u>Anchor loads according to constraint length method</u>
Two load postions must be calculated to derive the decisive load position with regard ton anchor position and failure mode.

$$l_i = 13 \cdot l_y^{0,05} \cdot s^{0,5} = 13 \cdot 51904^{0,05} \cdot 150^{0,5} = 274 \text{ mm} \qquad \text{(eq. 3.2)}$$

<u>load position 1</u>
Both screws are placed directly over the first and second anchor. This gives screw position of 25 mm and 175 mm with reference to the end of the channel.
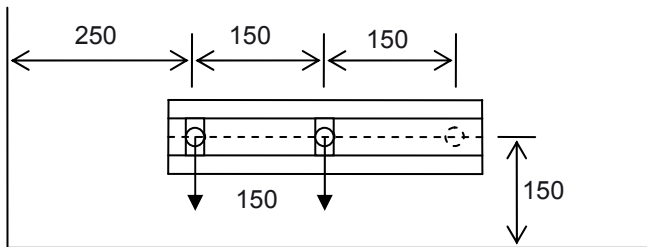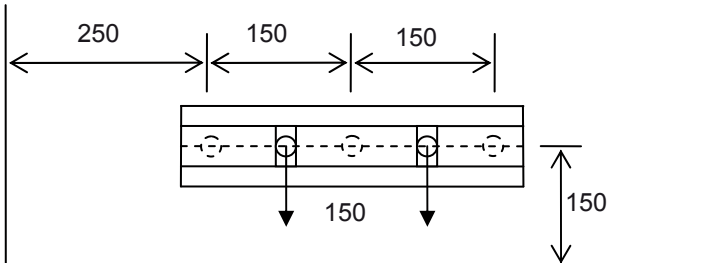
		anchor 1	anchor 2	anchor 3
1.1	Distance load at 25 mm to the anchor [mm]	0	150	300
1.2	$A'_i = 1 - s/l_i$	1	1-150/274 = 0,453	0
1.3	$k = 1/\Sigma A'_i$	$\dfrac{1}{1,00+0,453+0} = 0,688$		
1.4	$N^a_{Ed} = k \cdot A'_i \cdot N_{Ed}$	0,688·1·3,2 = 2,20	0,688·0,453·3,2 = 1,00	0
2.1	Distance load at 175 mm to the anchor [mm]	150	0	150
2.2	$A'_i = 1 - s/l_i$	1-150/274 = 0,453	1	1-150/274 = 0,453
2.3	$k = 1/\Sigma A'_i$	$\dfrac{1}{0,453+1+0,453} = 0,525$		
2.4	$N^a_{Ed} = k \cdot A'_i \cdot N_{Ed}$ [kN]	0,525·0,453·3,2 = 0,76	0,525·1·3,2 = 1,68	0,525·0,453·3,2 = 0,76
3	Resulting anchor load N^a_{Ed} (Zeile 1.4+2.4) [kN]	2,20+0,76 = **2,96**	1,00+1,68 = **2,68**	0+0,76 = **0,76**
	Analog for shear load V^a_{Ed} [kN]	**7,69**	**6,94**	**1,97**

Load position 2

The screws are positioned symmetrically with regard to the middle anchor. This gives screw position of 100 mm and 250 mm with reference to the end of the channel.

		anchor 1	anchor 2	anchor 3
1.1	Distance load at 100 mm to the anchor [mm]	75	75	225
1.2	$A'_i = (l_i-s)/l_i$	1-75/274 = 0,726	1-75/274 = 0,726	1-225/274 = 0,178
1.3	$k = 1/\Sigma A'_i$	$\frac{1}{0{,}726+0{,}726+0{,}178} = 0{,}613$		
1.4	$N^a_{Ed} = k \cdot A'_i \cdot N_{Ed}$	0,613·0,726·3,2 = 1,42	0,613·0,726·3,2 = 1,42	0,613·0,178·3,2 = 0,35
2.1	Distance load at 250 mm to the anchor [mm]	225	75	75
2.2	$A'_i = 1-s/l_i$	1-225/274 = 0,178	1-75/274 = 0,726	1-75/274 = 0,726
2.3	$k = 1/\Sigma A'_i$	$\frac{1}{0{,}178+0{,}726+0{,}726} = 0{,}613$		
2.4	$N^a_{Ed} = k \cdot A'_i \cdot N_{Ed}$ [kN]	0,613·0,178·3,2 = 0,35	0,613·0,726·3,2 = 1,42	0,613·0,726·3,2 = 1,42
3	Resulting anchor load N^a_{Ed} (line 1.4+2.4) [kN]	1,42+0,35 = **1,78**	1,42+1,42 = **2,85**	0,35+1,42 = **1,78**
	Analog for shear load V^a_{Ed} [kN]	**4,61**	**7,39**	**4,61**

Load position 2 is also decisive for the failure mode „bending of the channel"

$$M_{Ed} = \frac{N_{Ed} \cdot s}{4} = \frac{3{,}2 \cdot 150}{4} = 120 \text{ Nm}$$

<u>Verifications</u>

    <u>Tension load</u>

1)   Steel failure anchor

    not decisive (ETA, annex 11)

2)   Connection between anchor and channel (anchor 1, load position 1)

    $N_{Rk,s,c}$ = 31,0 kN, $\gamma_{Ms,c}$ = 1,8, $N_{Rd,s,c}$ = 17,2 kN > 2,96 kN

    $\beta_N = \dfrac{2,96}{17,2}$ = 0,170

3)   Bending of the channel lips

    screw spacing: 150 mm > s_{slb} = 81 mm

    the existing screw spacing demands no further reduction of the resistance

    $N_{Rk,s,l}$ = 31,0 kN, $\gamma_{Ms,l}$ = 1,8, $N_{Rd,s,l}$ = 17,2 kN > 3,2 kN

    $\beta_N = \dfrac{3,2}{17,2}$ = 0,186

4)   Steel failure screw

    $N_{Rk,s,s}$ = 62,8 kN, γ_{Ms} = 2,00, $N_{Rd,s,s}$ = 31,4 kN > 3,2 kN

    $\beta_N = \dfrac{3,2}{31,4}$ = 0,102

5)   Bending failure of the anchor channel

    $M_{Rk,s,flex}$ = 2038 Nm, $\gamma_{Ms,flex}$ = 1,15, $M_{Rd,s,flex}$ = 1772 Nm > 120 Nm

6)   Pull-out failure (anchor 1, load position 1)

    $N_{Rk,p}$ = 31,8 kN, γ_{Mc} = 1,5, $N_{Rd,p}$ = 21,2 kN > 2,96 kN

    $\beta_N = \dfrac{2,96}{21,2}$ = 0,140

7)   Concrete cone failure (anchor 2, load position 2)

    $N_{Rk,c} = N^0_{Rk,c} \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N}$ (eq. 4.2)

Basic value

embedment depth h_{ef} = 94 mm

factor α_{ch} = 0,91

$N^0_{Rk,c}$ = $8,5 \cdot \alpha_{ch} \cdot \sqrt{f_{ck,cube}} \cdot h_{ef}^{1,5}$ = $8,5 \cdot 0,91 \cdot 30^{0,5} \cdot 94^{1,5}$ = 38,6 kN   (eq. 4.3)

Influence of neighbouring anchors

characteristic spacing

$s_{cr,N}$ = 399 mm

$$\alpha_{s,N} = \frac{1}{1 + \left(1 - \dfrac{s_2}{s_{ce,N}}\right)^{1,5} \cdot \dfrac{N^a_{Ed,2}}{N^a_{Ed,1}} + \left(1 - \dfrac{s_3}{s_{cr,N}}\right)^{1,5} \cdot \dfrac{N^a_{Ed,3}}{N^a_{Ed,1}}} =$$

$$\frac{1}{1 + \left(1 - \dfrac{150}{399}\right)^{1,5} \cdot \dfrac{2,68}{2,96} + \left(1 - \dfrac{150}{399}\right)^{1,5} \cdot \dfrac{0,76}{2,96}} = 0,677 \qquad \text{(eq. 4.5)}$$

Influence of edges

characteristic edge distance

$c_{cr,N}$ = 199 mm

existing edge distance c_1 = 150 mm < $c_{cr,N}$

$\alpha_{e,N}$ = $(c_1/c_{cr,N})^{0,5}$ = $(150/200)^{0,5}$ = 0,867 <1   (eq. 4.7)

Influence of corners

existing edge distance c_2 = 250 mm > $c_{cr,N}$ (eq. 4.9)

Influence of a dense reinforcement

It is assumed that the spacing of the existing rebars is unknown but < 150 mm.

$\psi_{re,N}$ = $0,5 + h_{ef}/200$ = $0,5 + 94/200$ = 0,97 <1   (eq. 4.10)

Concrete condition

$\psi_{ucr,N}$ = 1   (eq. 4.11)

$N_{Rk,c}$ = $N^0_{Rk,c} \cdot \alpha_{s,N} \cdot \alpha_{e,N} \cdot \alpha_{c,N} \cdot \psi_{re,N} \cdot \psi_{ucr,N}$

$N_{Rk,c}$ = $38,6 \cdot 0,677 \cdot 0,867 \cdot 1,0 \cdot 0,97 \cdot 1,0$ = 22,00 kN, γ_{Mc} = 1,5, $N_{Rd,c}$

= 14,67 kN > 2,96 kN

$$\beta_N = \frac{2,96}{14,67} = 0,202$$

8) Splitting failure
Verification not necessary

9) Blow-out failure
Verification not necessary

Shear load

1)   Steel failure screw
$V_{Rk,s,s} = 37,7$ kN, $\gamma_{Ms} = 1,67$, $V_{Rd,s,s} = 22,6$ kN $> 8,3$ kN

$$\beta_N = \frac{8,3}{22,6} = 0,367$$

2)   Bending of channel lips
$V_{Rk,s,l} = 40,3$ kN, $\gamma_{Ms,l} = 1,8$, $V_{Rd,s,l} = 22,4$ kN $> 8,3$ kN

$$\beta_V = \frac{8,3}{22,4} = 0,371$$

3)   Connection anchor - channel (anchor 1, load position 1)
this verification is not yet included in CEN/TS, but will be included in the future.
Therefore $N_{Rk,s,c} = V_{Rk,s,c}$ is assumed.
$V_{Rk,s,c} = 31,0$ kN, $\gamma_{Ms,c} = 1,8$, $V_{Rd,s,c} = 17,2$ kN $> 7,69$ kN

$$\beta_V = \frac{7,69}{17,2} = 0,447$$

4)   Pry-out failure (anchor 2, load position 2)
$V_{Rk,cp} = k_5 \cdot N_{Rk,c}$ (eq. 4.28)
$k_5 = 2,0$
$V_{Rk,cp} = 2 \cdot 20,13 = 40,26$ kN, $\gamma_{Mc} = 1,5$, $V_{Rd,cp} = 26,84$ kN $> 7,39$ kN

$$\beta_V = \frac{7,39}{26,84} = 0,275$$

5) Concrete edge failure (anchor 1, load position 1)

$$V_{Rk,c} = V^0_{Rk,c} \cdot \psi_{re,V} \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V} \qquad \text{(eq. 4.29)}$$

<u>Basic value</u>
cracked concrete, no countable edge reinforcement

$$\alpha_p \cdot \psi_{re,V} = 3,5$$

$$V^0_{Rk,c} \cdot \psi_{re,V} = \alpha_p \cdot \psi_{re,V} \cdot \sqrt{f_{ck,cube}} \cdot c_1^{1,5} = 3,5 \cdot \sqrt{f_{ck,cube}} \cdot 150^{1,5} = 35,22 \text{ kN}$$

<u>Influence of neighbouring anchors</u>
characteristic spacing

$$s_{cr,V} = 4 \cdot c_1 + 2 \cdot b_{ch} = 4 \cdot 150 + 2 \cdot 49 = 698 \text{ mm} \qquad \text{(eq. 4.32)}$$

$$\alpha_{s,V} = \cfrac{1}{1 + \left(1 - \cfrac{s_2}{s_{cr,V}}\right)^{1,5} \cdot \cfrac{V^a_{Ed,2}}{V^a_{Ed,1}} + \left(1 - \cfrac{s_3}{s_{cr,V}}\right)^{1,5} \cdot \cfrac{V^a_{Ed,3}}{V^a_{Ed,1}}} =$$

$$\cfrac{1}{1 + \left(1 - \cfrac{150}{698}\right)^{1,5} \cdot \cfrac{6,94}{7,69} + \left(1 - \cfrac{300}{698}\right)^{1,5} \cdot \cfrac{1,97}{7,69}} = 0,575 \qquad \text{(eq. 4.31)}$$

<u>Influence of corner</u>
characteristic edge distance

$$c_{cr,V} = 2 \cdot c_2 + b_{ch} = 2 \cdot 150 + 49 = 349 \text{ mm} \qquad \text{(eq. 4.34)}$$

existing edge distance $c_2 = 250$ mm $< c_{cr,V}$

$$\alpha_{c,V} = (c_2/c_{cr,V})^{0,5} = (250/349)^{0,5} = 0,846 \qquad \text{(eq. 4.33)}$$

<u>Influence of member thickness</u>
characteristic member thickness

$$h_{cr,V} = 2 \cdot c_2 + 2 \cdot h_{ch} = 2 \cdot 150 + 2 \cdot 30 = 360 \text{ mm} \qquad \text{(eq. 4.36)}$$

existing member thickness $h = 200$ mm $< h_{cr,V}$

$$\alpha_{h,V} = (h/h_{cr,V})^{2/3} = (200/360)^{2/3} = 0,676 \qquad \text{(eq. 4.35)}$$

$V_{Rk,c} = V^0_{Rk,c} \cdot \psi_{re,V} \cdot \alpha_{s,V} \cdot \alpha_{c,V} \cdot \alpha_{h,V}$

$V_{Rk,c} = 35{,}22 \cdot 0{,}575 \cdot 0{,}846 \cdot 0{,}676 \cdot 1{,}0 = 11{,}58$ kN, $\gamma_{Mc} = 1{,}5$, $V_{Rd,c}$
$= 7{,}72$ kN $> 7{,}69$ kN

$\beta_V = \dfrac{7{,}69}{7{,}72} = 0{,}996$

Combined tension and shear loading (interaction)

1)   Steel failure screw

$\beta_N = 0{,}102$

$\beta_V = 0{,}367$

$\beta_N{}^2 + \beta_V{}^2 = 0{,}102^2 + 0{,}367^2 = 0{,}145 < 1$ (eq. 4.52)

2)   Steel failure channel lips

$\beta_N = 0{,}186$

$\beta_V = 0{,}371$

$\beta_N{}^2 + \beta_V{}^2 = 0{,}186^2 + 0{,}371^2 = 0{,}172 < 1$ (eq. 4.52)

3)   Steel failure anchor channel (anchor 1, load position 1)

$\beta_N = 0{,}186$

$\beta_V = 0{,}447$

$\beta_N{}^2 + \beta_V{}^2 = 0{,}186^2 + 0{,}447^2 = 0{,}172 < 1$

4)   Concrete failure (concrete cone failure – concrete edge failure)

$\beta_N = 0{,}202$

$\beta_V = 0{,}996 = \dfrac{\beta_N + \beta_V}{1{,}2} = \dfrac{0{,}202 + 0{,}996}{1{,}2} = 0{,}998 < 1$ (eq. 4.53)

Verification fulfilled!

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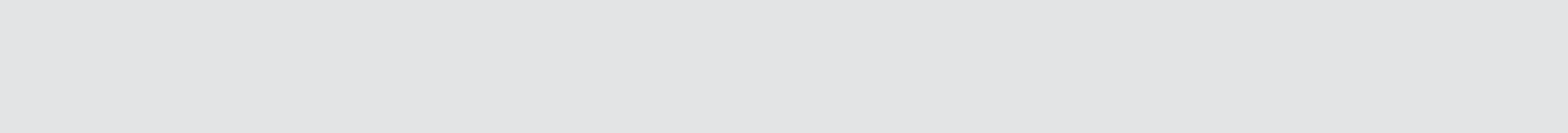
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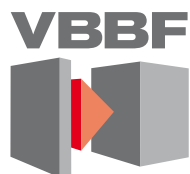MAX FRANK GMBH & CO. KG
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