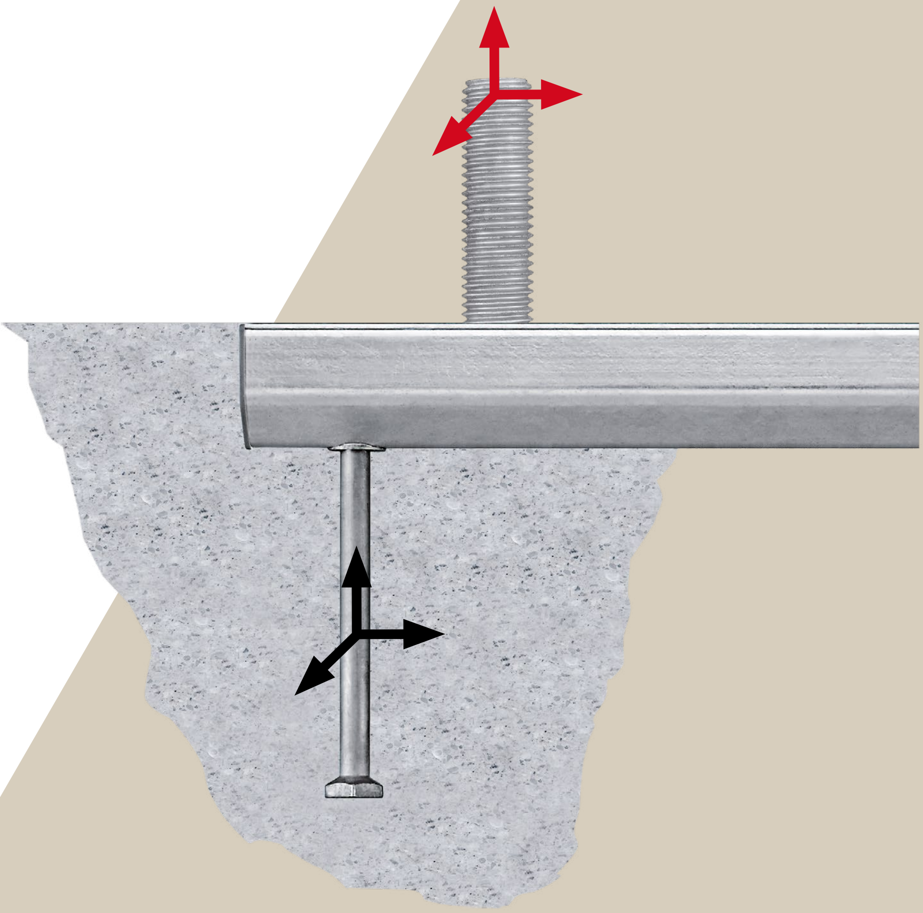
ANCHOR CHANNEL FASTENING

Design guide with examples
Version 1, September 2021



DISCLAIMER

1. The technical data presented in this design guide are based on numerous tests and evaluation criteria according to the current state-of-the-art and the relevant European regulations.
2. For anchor channels holding a European Technical Assessment (ETA), noted in the cover with the respective icon, the technical data in this design guide are based on and in accordance with the current European Technical Assessment (ETA). In addition to the ETA data, we provide Hilti test data for some products.
3. For anchor channels not holding an ETA, the technical data given in this design guide are based on numerous tests and evaluation criteria according to the current state-of-the-art and/or the relevant European regulations for the assessment of anchor channels.
4. In addition to the tests for standard service conditions (including, in some cases, seismic loads as an option), fire resistance, shock and fatigue tests may have been performed – see the reports for full details.
5. The data and values are based on the average values obtained from tests under laboratory or other controlled conditions, or is based on generally accepted methodology. It is the responsibility of the customer to use the data given in the light of conditions on-site and taking into account the intended use of the products concerned. The customer must check that listed prerequisites and criteria conform with the conditions on the jobsite. Whilst Hilti can give general guidance and advice, the nature of Hilti products means that the ultimate responsibility for selecting the right product for a particular application must lie with the customer.
6. The technical data in this design guide are provided only for the indicated test conditions. Due to variations in local base materials, on-site testing may be required to determine performance at any specific jobsite.
7. Hilti´s policy is one of continuous development. We therefore reserve the right to alter technical data and specifications, etc.
8. Construction materials and conditions vary between sites. If it is suspected that the base material has insufficient strength to achieve a suitable fastening, contact the Technical Competence Center of your local Hilti organization.
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Note
Some of the products shown in the design examples may not be available in your country. Please contact your local sales representative for more information.

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Anchor channels - Technical Design

Design examples for Hilti cast-in products

HAC anchor channels

HAC-C hot rolled anchor channels

HAC EDGE

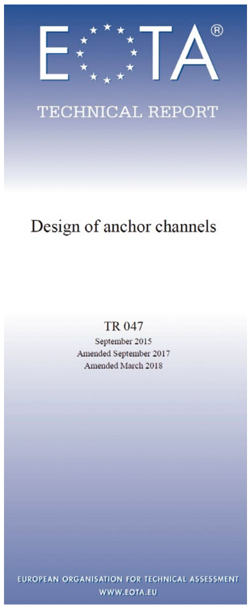
DESIGN BASICS

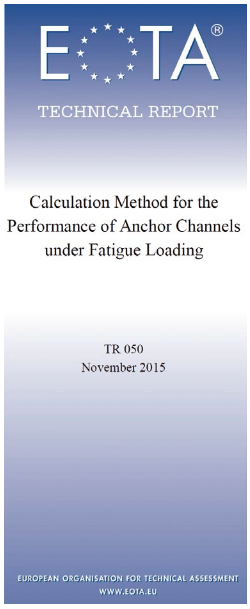
The design of anchor channels is based on the following documents:

- For static and quasi-static 2D loading in tension and shear loads acting transverse to the channel axis as well as fire exposure the anchor channels are designed in accordance with EN 1992-4 or EOTA TR 047
- For 3D static and quasi-static loading the anchor channels are designed additionally with CEN TR 17080 or EOTA TR 047-Annex B
- For fatigue loads, the anchor channels are designed in accordance with EOTA TR 050


EUROPEAN STANDARD ILNAS-EN 1992-4:2018 EN 1992-4
NORME EUROPÉENNE
EUROPÄISCHE NORM July 2018
English Version
Eurocode 2 - Design of concrete structures - Part 4: Design of fastenings for use in concrete

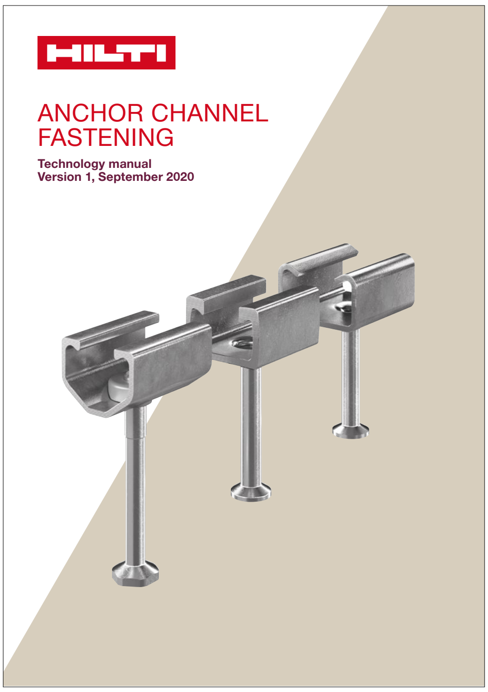

TECHNICAL REPORT CEN/TR 17080
RAPPORT TECHNIQUE
TECHNISCHER BERICHT September 2018
English Version
Design of fastenings for use in concrete - Anchor channels - Supplementary rules





TECHNICAL INFORMATION ABOUT ANCHOR CHANNELS

For more product-specific details like different types of anchor channels, applications and load resistance values please also refer to our complimentary **"Technology manual".** Please contact your local sales representative if you are interested.



DESIGN CONCEPT FOR ANCHOR CHANNELS

General

EN 1992-4 or EOTA TR 047 based design currently covers anchor channels located in cracked or uncracked normal-weight concrete which are subjected to transfer the static and quasi-static tensile loads N_{Ed} and shear loads perpendicular to channel $V_{Ed,y}$ or any combination of these loads. Additionally, CEN-TR 17080 or EOTA-TR 047 Annex B covers design of anchor channels under static 3D loading (N_{Ed}, $V_{Ed,y}$, $V_{Ed,x}$) as shown in figure 1 and 2.

Design criteria of anchor channels

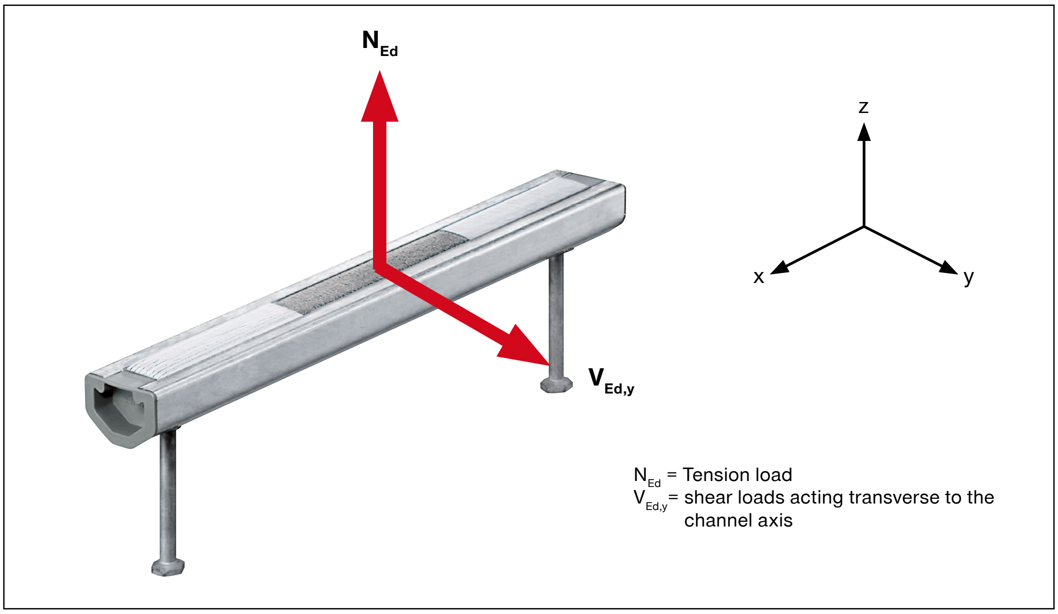


Figure 1
2D loading covered in EN 1992-4 or EOTA TR 047

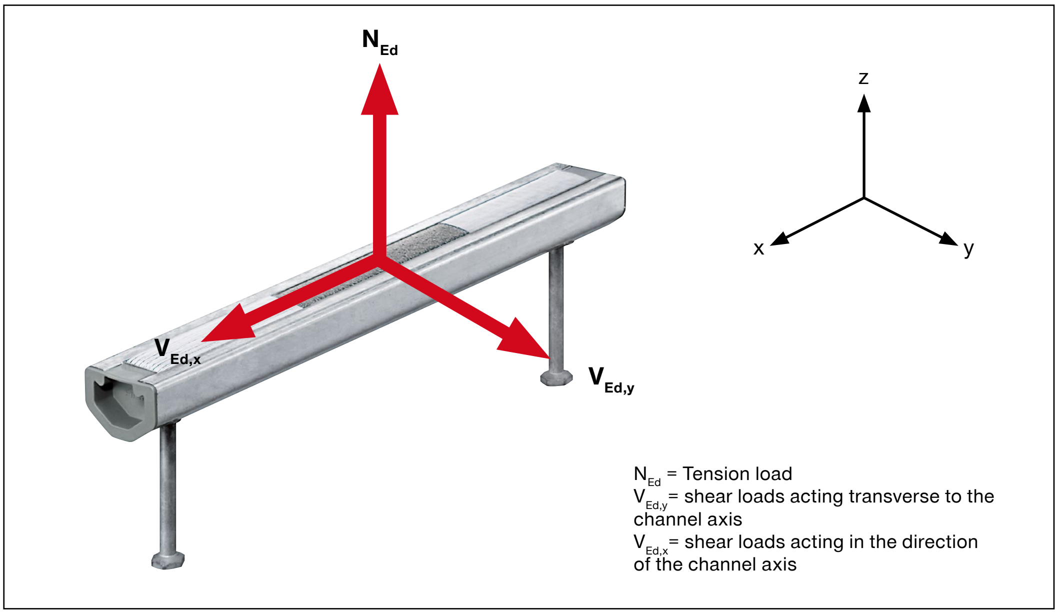


Figure 2
3D loading covered in CEN-TR 17080 or EOTA TR 047-Annex B

PARTIAL SAFETY FACTOR CONCEPT

According to the safety concept of the European Codes, the basic verification of fastening in the Ultimate Limit State (ULS) is based on a comparison of action and resistance under consideration of the respective safety factors. The design value of the action must not exceed the design value of the resistance.

The general verifications for static tension and shear are defined in the following:

$E_d \leq R_d$

The applied forces on the anchor channel shall be derived using appropriate combinations of actions on the fixture in accordance with EN 1990.

In the ultimate limit state the value of the design resistance is obtained from the characteristic resistance of the anchor channels as follows:

$R_d = R_k / \gamma_M$

Where

R_d = design resistance of anchor channel

R_k = characteristic resistance of anchor channel; values given in technology manual or the current European Technical Assessment (ETA).

γ_M = partial safety factor for material given on page 7.

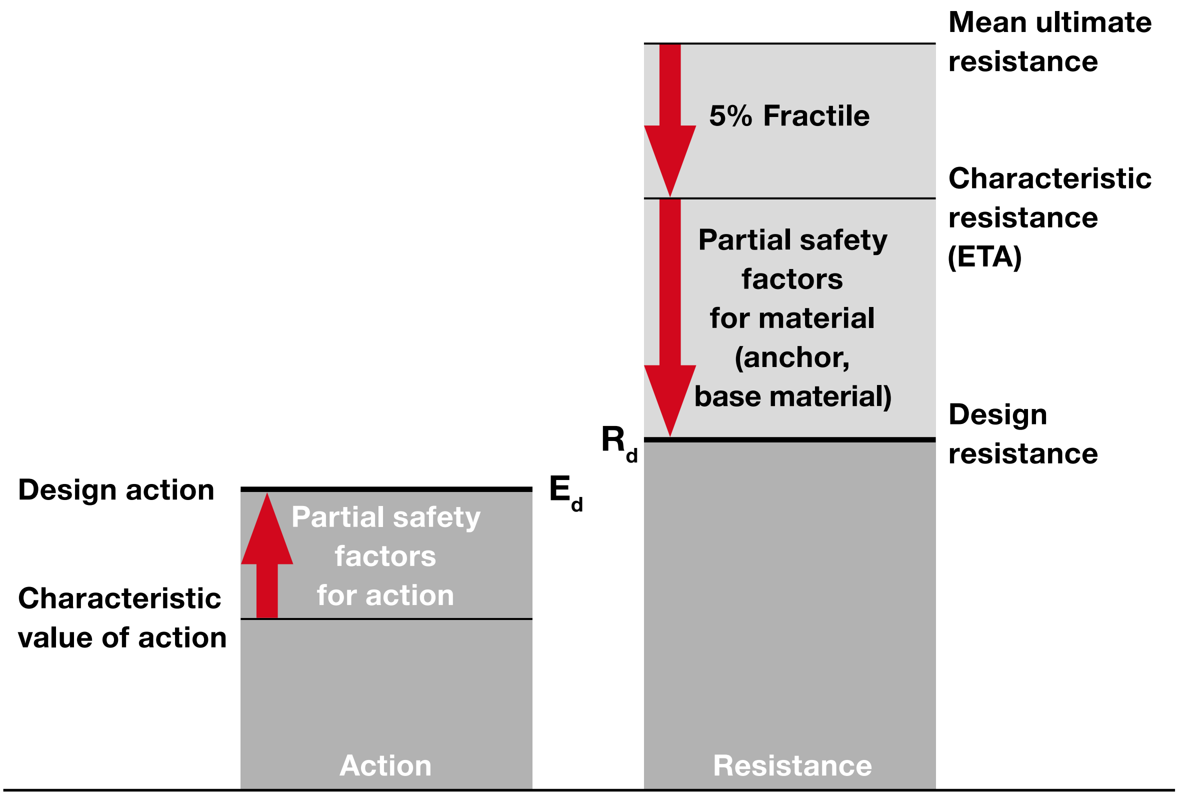


Figure 3
Partial safety factor concept

Partial safety factors for resistance

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

Note: In the absence of national regulations the recommended values of partial safety factors are given in the following table:

Partial safety factors

Failure Mode	Symbol	Factor
Steel – Tension		
Failure of anchor	γ_{Ms}	1.8
Connection b/w anchor and channel	$\gamma_{Ms,ca}$	1.8
Local failure by flexure of channel lips	$\gamma_{Ms,l}$	1.8
Bending of channel	$\gamma_{Ms,flex}$	1.15
Steel failure of supplementary reinforcement	$\gamma_{Ms,re}$	1.15
Steel failure under fire loads	$\gamma_{Ms,fi}$	1.0
Channel bolt – Tension		
Bolt grade 4.6	γ_{Ms}	2.0
Bolt grade 8.8	γ_{Ms}	1.50
Bolt grade A4-50	γ_{Ms}	2.86
Bolt grade A4-70	γ_{Ms}	1.87
Concrete – Tension		
Concrete cone failure	γ_{Mc}	1.5
Concrete blow-out failure	γ_{Mc}	1.5
Concrete pullout failure	γ_{Mc}	1.5
Concrete splitting failure	$\gamma_{M,sp}$	1.5
Steel failure of supplementary reinforcement	$\gamma_{Ms,re}$	1.15
Steel – Shear		
Failure of anchor	γ_{Ms}	1.5
Connection b/w anchor and channel	$\gamma_{Ms,ca}$	1.8
Local failure by flexure of channel lips	$\gamma_{Ms,l}$	1.8
Local failure by flexure of channel lips-installation factor	γ_{ins}	1.4
Steel failure of supplementary reinforcement	$\gamma_{Ms,re}$	1.15
Steel failure under fire loads	$\gamma_{Ms,fi}$	1.0
Channel bolt – Shear		
Bolt grade 4.6	γ_{Ms}	1.67
Bolt grade 8.8	γ_{Ms}	1.25
Bolt grade A4-50	γ_{Ms}	2.38
Bolt grade A4-70	γ_{Ms}	1.56
Concrete – Shear		
Concrete edge failure	γ_{Mc}	1.5
Concrete pry-out failure	γ_{Mc}	1.5
Steel failure of supplementary reinforcement	$\gamma_{Ms,re}$	1.15

The partial safety factors given in the table are based on EN 1992-4.

STATIC AND QUASI STATIC LOADS IN EN-1992-4, EOTA-TR 047 OR CEN-TR 17080

Determination of anchor forces under tension and shear loads acting transverse to the channel axis (N_{Ed}, $V_{Ed,y}$) as per EN 1992-4 or EOTA TR 047

The path of the load transfer is from channel bolts to the channel lips, then to anchors and from there directly into concrete. That's why besides the calculation of bolt forces the next step in the design of anchor channels is the calculation of anchor forces $N^a_{Ed,i}$. Triangular load distribution is assumed with the concept of similar triangles for the determination of anchor forces as a result of applied tension N_{Ed} and shear loads acting transverse to the channel axis $V_{Ed,y}$ as shown in figure 5. A linear superimposition of the anchor forces for all loads shall be assumed if several loads are acting on the anchor channel as shown in figure 4.

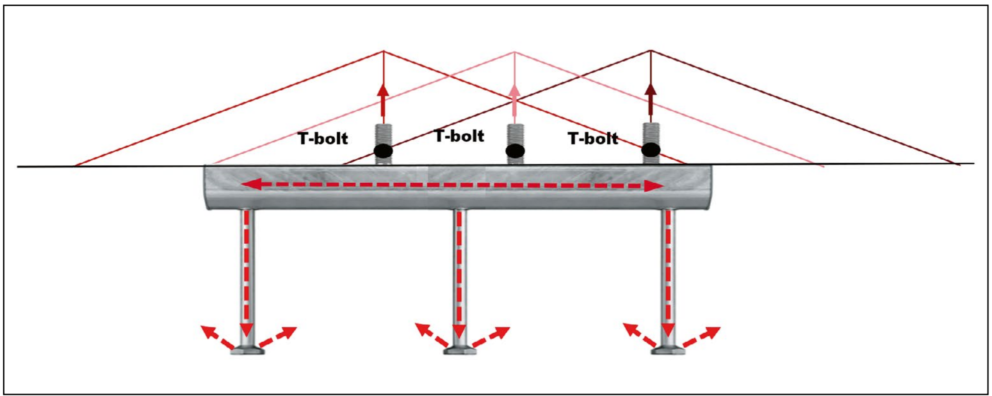


Figure 4
Superposition of anchor forces with more than one bolt per anchor channel

Anchor forces shall be determined on this basis separately for both tension and shear loads acting transverse to the channel axis.

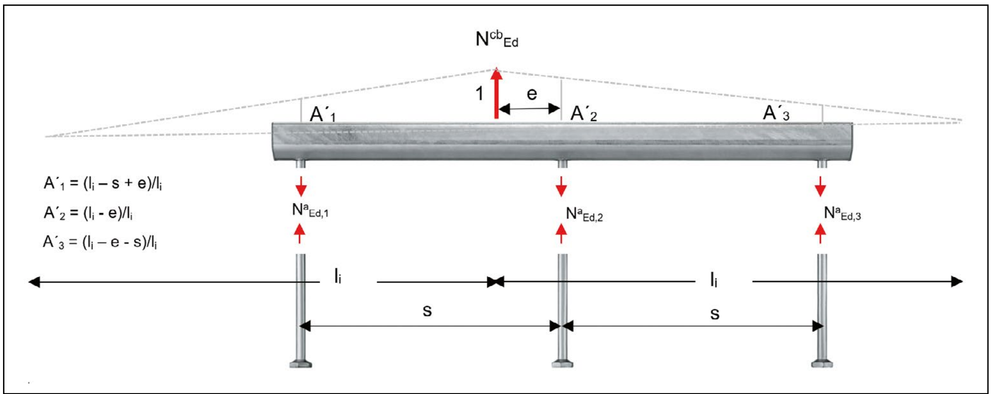


Figure 5
Redistribution of channel bolt forces N^{cb}_{Ed} into anchor forces $N^a_{Ed,i}$ with triangular load distribution model

The forces on the anchors $N^a_{Ed,i}$ are calculated with the weighted ordinate A'_i of the triangular distribution.

$$N^a_{Ed,i} = k \cdot A'_i \cdot N^{cb}_{Ed} \quad \text{and} \quad V^a_{Ed,i,y} = k \cdot A'_i \cdot V^{cb}_{Ed,y}$$

The weighting factor k is calculated with:

$$k = \frac{1}{\sum_1^n A'_i}$$

The influence length l_i of the load triangle to both sides is calculated:

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

Where I_y is moment of inertia of profile and s is anchor spacing

The design bending moment $M_{ch,Ed}$ in the channel due to tension loads can be calculated based on the assumption of a simply supported single span beam with a span length equal to anchor spacing. The characteristic values of the moment of resistance $M_{Rk,s,flex}$ are given in technology manual or the current European Technical Assessment (ETA).

Determination of anchor forces under shear loads acting in the direction of channel axis $V_{Ed,x}$ as per CEN-TR 17080 or EOTA TR 047-Annex B

The anchor forces calculations and verifications for shear in the longitudinal axis of the channel are based on EOTA TR 047 Annex B or CEN-TR 17080.

In this case, the shear load on each anchor $V^{a}_{Ed,x}$ caused by a shear load acting on the channel bolt is calculated according to the following equation which assumes a uniform load distribution on all anchors of the anchor channel with the number of anchors $n_a \leq 3$ where n_a = number of anchors as shown in figure 7.

$$V^{a}_{Ed,x} = \frac{1}{n_a} \cdot \sum V^{cb}_{Ed,x}$$

Note: The example given in figure 7; the load is equally distributed to maximum three anchors $n_a = 3$

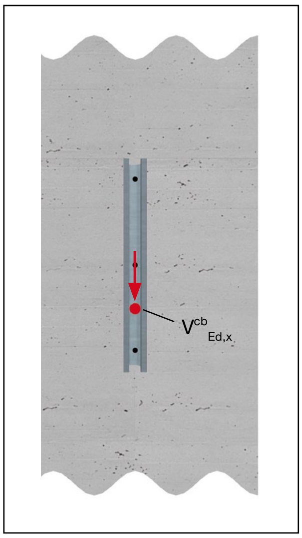


Figure 6
Acting shear load on bolt

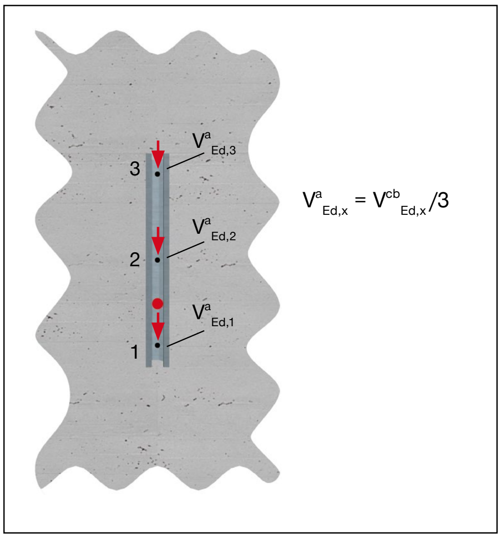


Figure 7
Equally distributed load on the anchors without edge influence

Anchor channel installed transverse to the edge

In case of steel failure and concrete pry-out failure the load distribution according to figure 7 applies.

In case of concrete edge failure or verification of supplementary reinforcement, only the anchor closest to the edge is assumed to be effective. Therefore, the sum of all the bolt forces $V^{cb}_{Ed,x}$ acting along the longitudinal axis of the channel are considered to act on the single anchor closest to the edge figure 8. This is also valid for anchor channels in narrow concrete members with $c_1 > c_{2i}$, this method is as per EOTA TR 047.

Remark: In Hilti PROFIS Anchor Channel software there are two methods to calculate anchor forces for longitudinal loads. One is explained above as per CEN TR 17080/EOTA TR 047 and the 2nd is as per Hilti method. In the Hilti method, the applied total bolt load is divided on anchors in two steps: a) applied bolt loads i.e. sum of all bolt load divided by 3 will be the load on the anchor closest to edge b) sum of all bolt loads is applied on the 3rd anchor even if number of anchors are more than 3. The critical value from a and b is taken as governing utilization for concrete verification.

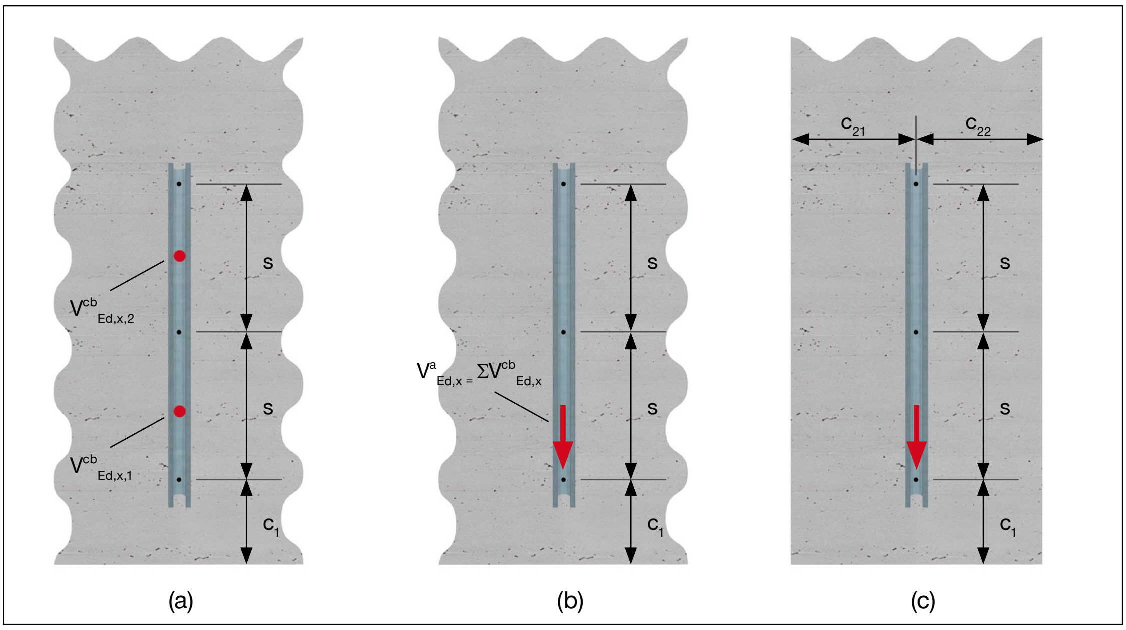


Figure 8
Calculation of anchor forces due to longitudinal shear for anchor channels situated and loaded transversely to the edge of the concrete member

a) Applied loads on bolts
b) Load considered on a single anchor closest to the edge for verification of concrete edge failure
c) Load considered on a single anchor closest to the edge for verification of concrete edge failure in a narrow concrete member

Anchor channel installed parallel to the edge

Load distribution as per figure 7, depicted also in figure 9
The sum of the applied loads on the T-bolts is equally distributed on the number of anchors of the anchor channel.

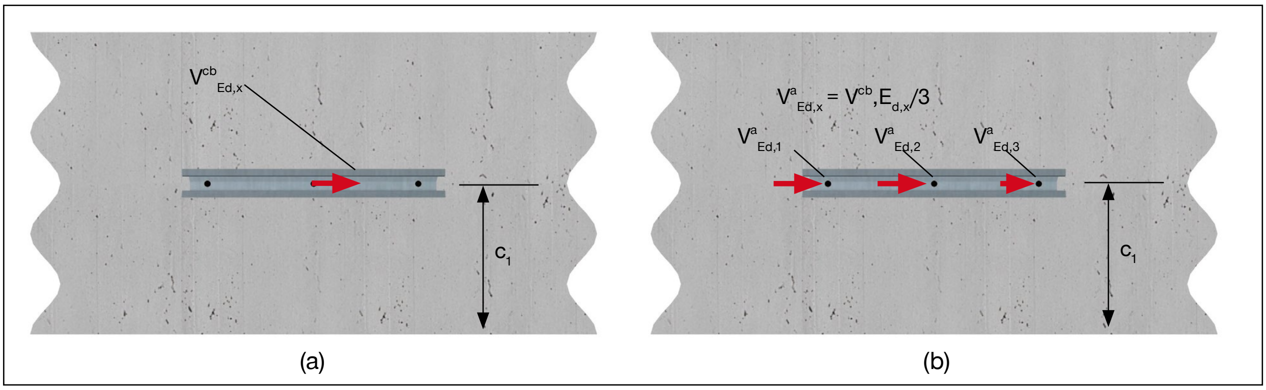


Figure 9
Calculation of anchor forces due to longitudinal shear for anchor channels situated parallel to the edge

a) Acting load on bolt
b) Distributed loads on the anchors

Overview of verifications for anchor channels

The basic equation $E_d \leq R_d$ must be fulfilled for all types of verifications. The capacities for steel failure can be taken from the current European Technical Assessment (ETA) or technology manual tables. Concrete failure capacities depend on various geometrical parameters and on concrete strength.

The design of anchor channels requires numerous verifications. A helpful tool for the design of anchor channels is the Hilti design software called PROFIS Anchor Channel that can be downloaded from Hilti webpage.

Figure 11 depicts the necessary verifications under tension, shear, and longitudinal shear. All load directions must be verified separately.

The path to transfer the load is shown in figure 10. From the fixture, loads are transferred to the channel bolts, from the channel bolts the load goes to the channel lips and from there to anchors and finally into the concrete. Based on the load path the verifications of each part of the channel and concrete are performed from the applied loads in different directions and their combined effects.

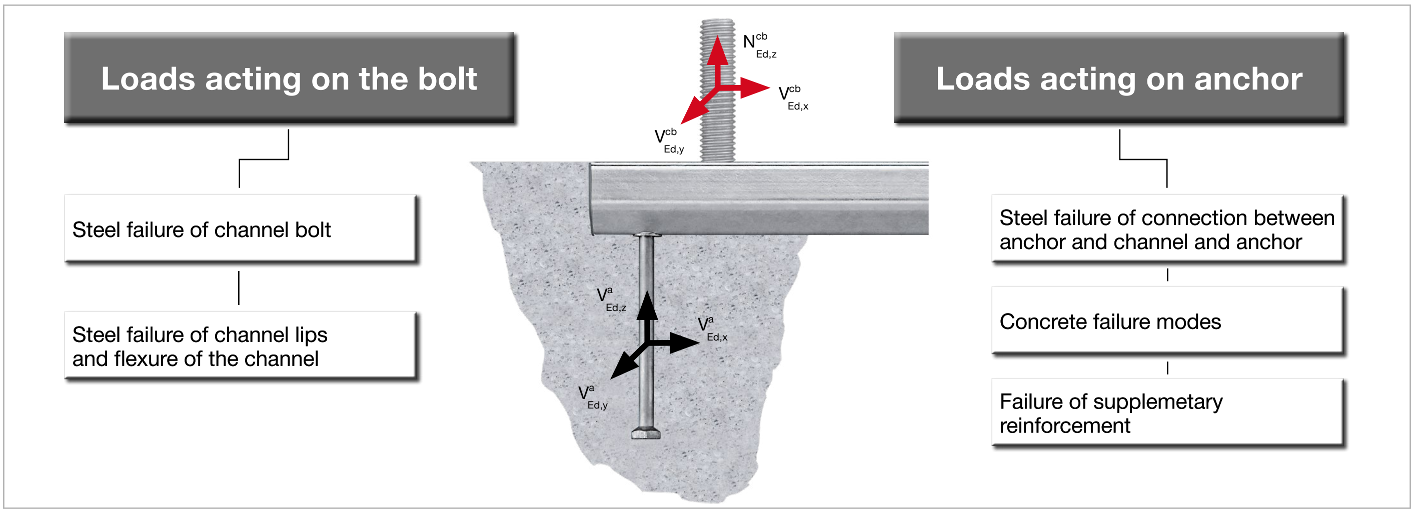


Figure 10
Load transfer from bolts to concrete and respective verifications

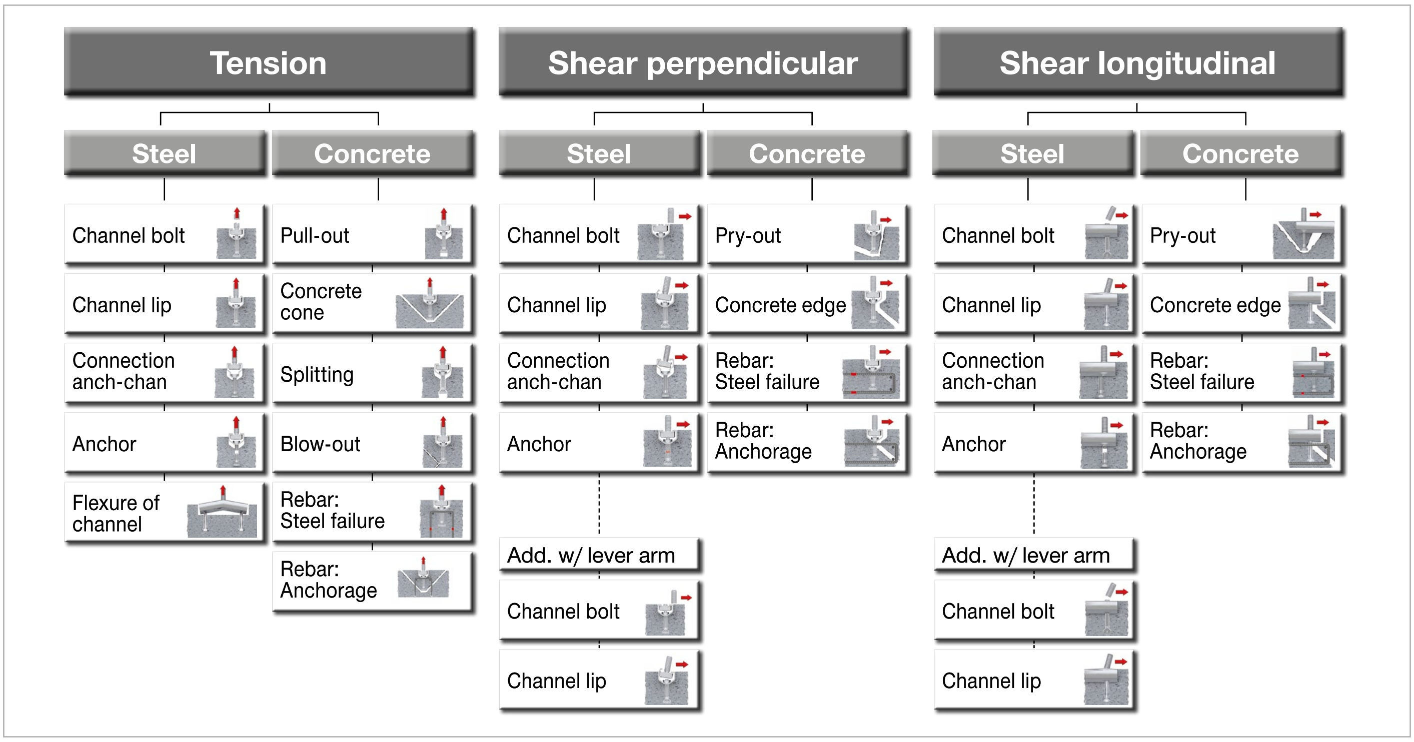


Figure 11
Required verifications under tension, perpendicular shear and longitudinal shear

VERIFICATIONS UNDER TENSION LOADS

Steel failure modes

If tension loads act on the anchor channel, the steel verifications have to be performed as shown in the table below. The characteristic strength values given in this table should be taken from the current European Technical Assessment (ETA) or technology manual. Material safety factors are taken from table on page 7.

Steel failure modes for tension				
Channel bolt failure	**Local failure of the channel lip**	**Connection between anchor and channel**	**Anchor failure**	**Flexure of channel**
				
$N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$	$N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$	$N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$	$N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$	$M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$

Steel failure of channel lips is calculated from the following equations. The spacing of the channel bolts has to be considered in the calculation. If bolts are spaced closely it reduces the channel lip capacity.

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

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \leq 1.0$$

With

$N^0_{Rk,s,l}$ = characteristic lip resistance under tension
s_{cbo} = center to center spacing between channel bolts ($s_{cbo,min}$= 5d) where d= bolt diameter
$s_{l,N}$ = characteristic spacing for channel lip failure under tension.C
Characteristic resistance values shall be taken from the current European Technical Assessment (ETA) or technology manual

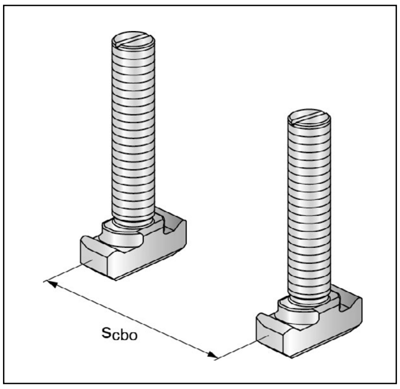
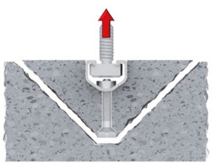
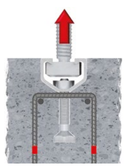
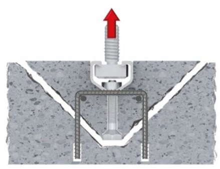


Figure 12
Bolt spacing

Concrete failure modes

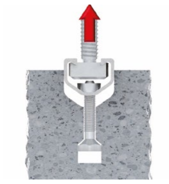
Concrete capacities are calculated according to the formulas given in this section.
The table below lists the required concrete verifications under tension loading.

Concrete failure modes for tension					
Pull-out	**Concrete cone failure**	**Concrete splitting failure**	**Concrete blow-out failure**	**Rebar steel failure**	**Rebar anchorage failure**
					
$N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mc}}$	$N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$	$N_{Rd,sp} = \frac{N_{Rk,sp}}{\gamma_{Msp}}$	$N_{Rd,cb} = \frac{N_{Rk,cb}}{\gamma_{Mc}}$	$N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Rd,a} = \frac{N_{Rk,a}}{\gamma_{Ms,re}}$

Pull-out failure

The pull-out resistance $N_{Rk,p}$ of one anchor linearly depends on the concrete compressive strength, the load-bearing area of the anchor head A_h and a constant factor k_2. This factor k_2 also takes into consideration whether concrete is cracked or uncracked.

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



With:

k_2 = 7.5 for cracked
= 10.5 for uncracked concrete

A_h = load bearing area of the anchor head given in the current European Technical Assessment (ETA) or technology manual

f_{ck} = nominal characteristic compressive cylinder strength

Note:
Anchors should always be designed for use in cracked concrete, unless a sound justification is given to the selection of uncracked concrete

Concrete cone failure

For anchor channels, $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$ must be fulfilled.

Where

h_{ch} =height of the channel, b_{ch} = width of the channel and h_{ef} = effective embedment depth as per figure 22

The characteristic resistance of one anchor of an anchor channel in case of concrete cone failure shall be calculated according to formula:

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

The different factors in the above formula are explained below:

The basic characteristic resistance of one anchor depends on the concrete compressive strength, the effective embedment depth, and a channel-dependent value:

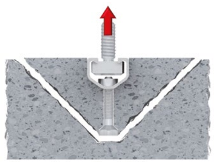
$$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5}$$

With:

k_1 depends upon concrete state i.e. cracked or uncracked. k_1 value shall be taken from current European Technical Assessment (ETA) or technology manual.

The reduction factors ψ_i are explained in the following. The influence of neighboring anchors on the concrete cone resistance is taken into account by the factor $\psi_{ch,s,N}$:

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}} \right) \cdot \frac{N_i}{N_0} \right]} \leq 1.0$$



With:

s_i = distance between the anchor under consideration and the neighboring anchors
$\leq s_{cr,N}$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3h_{ef}}{180} \right) \cdot h_{ef} \geq 3h_{ef}$$

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

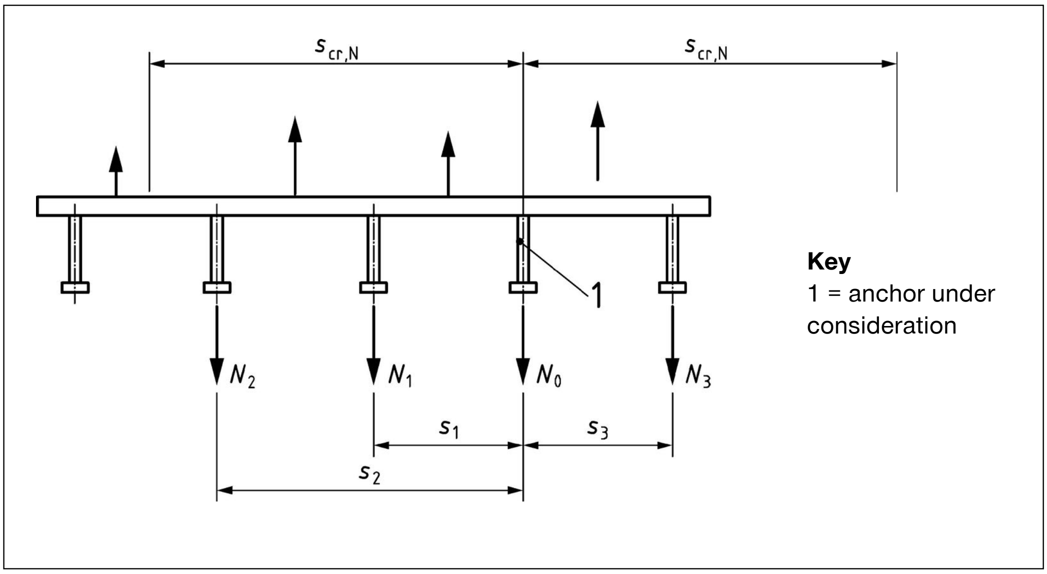


Figure 13
Critical spacing for concrete cone verifications

If the concrete cones under tension load overlap with each other due to neighboring anchors, then we should consider the reduction in the concrete cone strength. In figure 14, the concrete cones which are developed at angle are intersecting and reduction in strength due to this overlapped area $A_{overlap}$ has to be taken into account through a factor $\psi_{ch,s,N}$. If the spacing between anchors is such that these cones are not overlapping then we can take this factor as 1 as shown in figure 15.

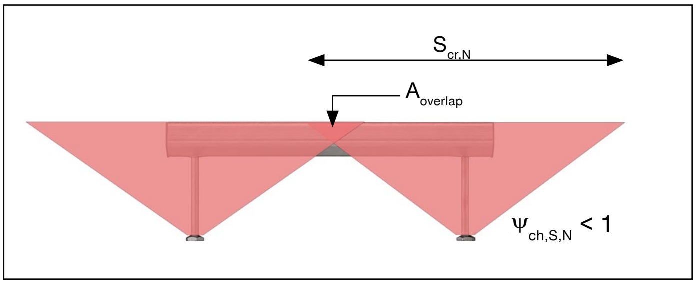


Figure 14
Due to anchor spacing concrete cone overlapping under tension loads with reduction in strength

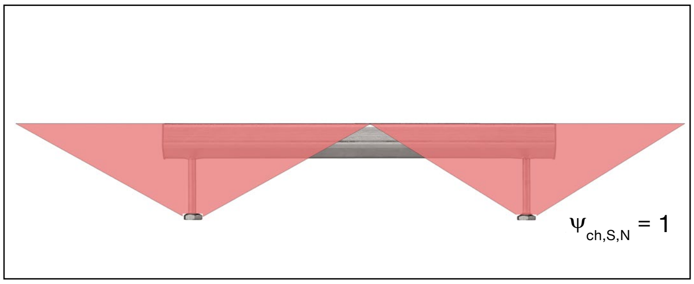


Figure 15
Due to anchor spacing concrete cones not overlapping under tension loads with no reduction strength

In case of concrete edge distance less than the characteristic edge distance $c_{cr,N}$, figure 17 the factor $\psi_{ch,e,N}$ has to be calculated. The edge distance can influence the concrete cone resistance. For narrow members with different edge distances $c_{1,1}$ or $c_{1,2}$ the minimum of these two has to be taken in the following equation:

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

With:

c_1 = edge distance of the anchor channel
$c_{cr,N}$ = critical edge distance i.e. $0.5\ s_{cr,N} \geq 1.5 \cdot h_{ef}$

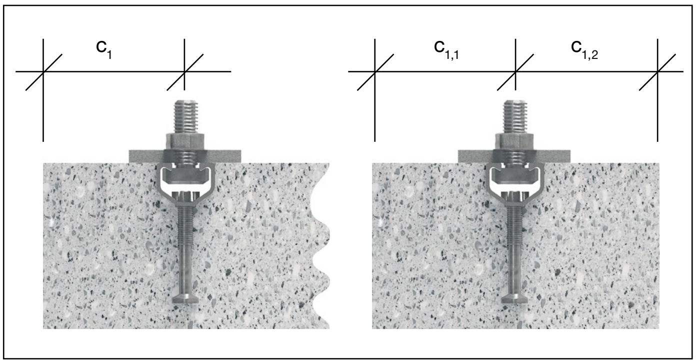


Figure 16
Anchor channel at an edge or in a narrow thin member

If the given edge distance c_1 is less than characteristic edge distance $c_{cr,N}$ the concrete cone area A_e will overlap with the edge and result in reduction at the concrete cone strength i.e. $\psi_{ch,e,N} < 1$ as shown in figure 17 otherwise if edge distance is equal or more than characteristic edge distance $c_{cr,N}$ then $\psi_{ch,e,N} = 1$ as shown in figure 18.

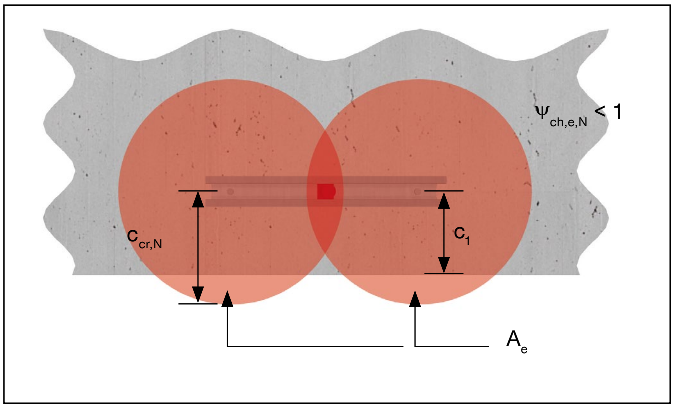


Figure 17
Due to close edge distance concrete cones, intersecting edge with reduction in strength

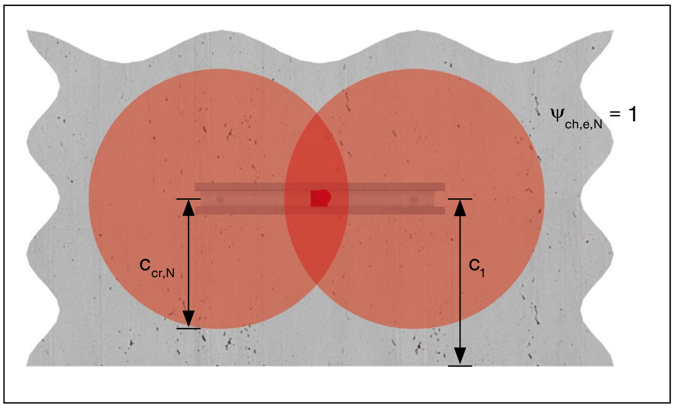


Figure 18
Due to larger edge distance, concrete cones not intersecting edge with no reduction in strength

To account for corners that are within the characteristic edge distance the factor $\psi_{ch,c,N}$ has to be applied. For an anchor of anchor channel being influenced by two corners figure 21c the factor $\psi_{ch,c,N}$ shall be calculated for $c_{2,1}$ and $c_{2,2}$ and the product of the factors shall be used in the equation to calculate the $N_{Rk,c}$

$$\psi_{ch,c,N} = \left(\frac{c_2}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

With:

c_2 = edge distance of the considered anchor
$c_{cr,N}$ = 0.5 $s_{cr,N}$

If the given edge distance c_2 is less than characteristic edge distance $c_{cr,N}$ the concrete cone area A_{co} will overlap with the edge and can result in reduction in the concrete cone strength i.e. $\psi_{ch,c,N} < 1$ as shown in figure 19 otherwise if edge distance is equal or more than $c_{cr,N}$ then $\psi_{ch,c,N} = 1$ as shown in figure 20.

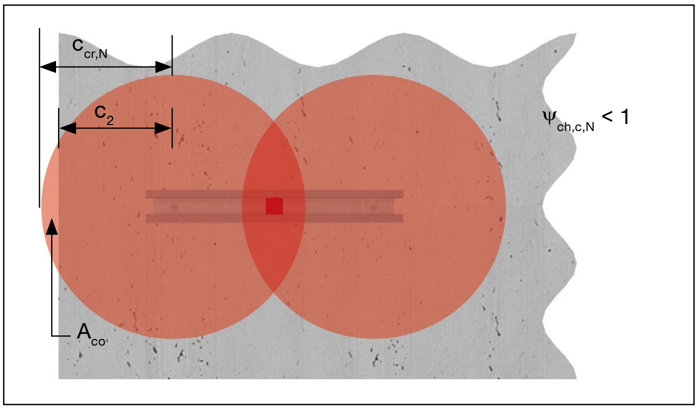


Figure 19
Due to short edge distance: concrete cones intersecting edge with reduction in strength

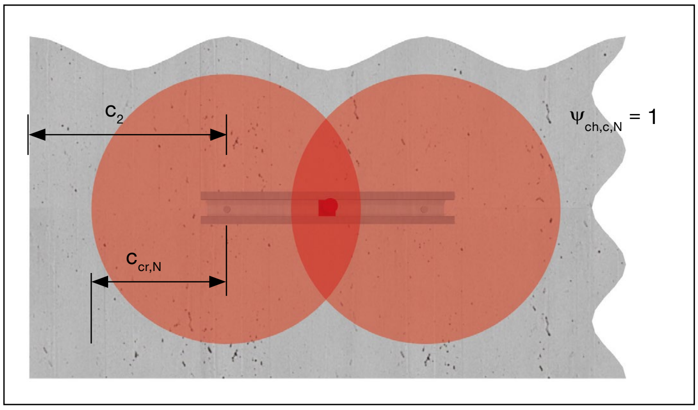


Figure 20
Due to larger edge distance: concrete cones not intersecting edge with no reduction in strength

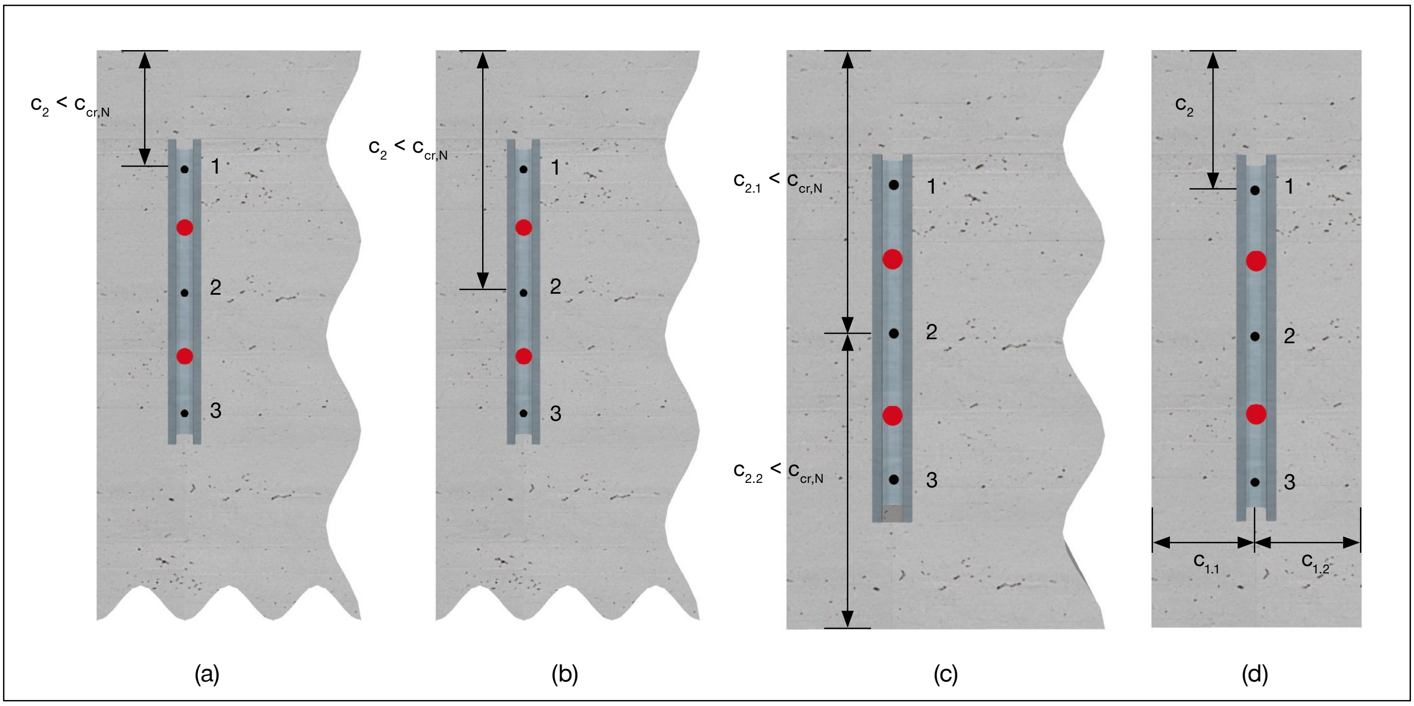


Figure 21
Definition of corner edge distance

a) Anchor 1 under consideration
b) Anchor 2 under consideration
c) Anchor 2 under consideration
d) Anchor 1 under consideration

The negative influence of dense reinforcement on the concrete cone resistance for embedment depths $h_{ef} \leq 100$ mm is reflected by the shell spalling factor $\psi_{re,N}$:

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0$$

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

a) Any diameter rebars present at spacing ≥ 150 mm
b) Rebars with a diameter of 10 mm or smaller at spacing ≥ 100 mm

Concrete splitting failure

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

Concrete splitting failure due to loading shall be considered according to the following rules

a) The characteristic edge distance in the case of splitting under load, $c_{cr,sp}$, is given in the current European Technical Assessment (ETA) or in technology manual. 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 thickness is $h \geq h_{min}$ with h_{min} corresponding to $c_{cr,sp}$

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

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

$$\sum A_{s,re} = 0.5 \cdot \frac{N^a_{Ed}}{f_{yk} / \gamma_{Ms,re}}$$

Where

N^a_{Ed} = design tensile force of the most loaded anchor under the design value of the actions

$f_{yk,re}$ = nominal yield strength of the reinforcing steel ≤ 600 MPa

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 concrete splitting failure shall be calculated according to Formula:

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

With

N^0_{RK} = min($N_{Rk,p}$;$N^0_{Rk,c}$)

$N_{Rk,p}$ as per section of pull-out resistance under tension load in the current European Technical Assessment (ETA) or in technology manual.

$N^0_{Rk,c}$, $\psi_{ch,s,N}$, $\psi_{ch,c,N}$, $\psi_{ch,e,N}$, $\psi_{re,N}$ as per page 13 however 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}

$$\psi_{h,sp} = \left(\frac{h}{h_{min}}\right)^{2/3} \leq \max\left\{1; \left(\frac{h_{ef} + c_{cr,N}}{h_{min}}\right)^{2/3}\right\} \leq 2.0$$

d) If in the current European Technical Assessment (ETA) or technology manual $c_{cr,sp}$ is given for more than one minimum member thickness h_{min}, the minimum member thickness corresponding to $c_{cr,sp}$ used in formula $N_{Rk,sp}$ shall be inserted in formula $\psi_{h,sp}$

Concrete blow-out failure

The resistance against blow-out depends on the concrete compressive strength f_{ck}, the load-bearing area of the anchor head A_h, the edge and corner distance c_1 and c_2, the mutual influence of anchors, the thickness of the concrete element, and a factor, that also takes into consideration whether concrete is cracked or not. Verification of blow-out is not needed if $c_1 > 0.5 h_{ef}$. If verification is required, the characteristic resistance of a single anchor in case of blow out is calculated as:

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

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

With

K_5 = 8.7 for cracked concrete and 12.2 for uncracked concrete

A_h = in the current European Technical Assessment (ETA) or technology manual

$\psi_{ch,s,Nb}$ is calculated analogously to $\psi_{ch,s,N}$ using $s_{cr,Nb}$ =4 c_1 instead of $s_{cr,N}$

The influence of a corner of the concrete member is considered by the factor $\psi_{ch,c,Nb}$ which is calculated as:

$$\psi_{ch,c,Nb} = \left(\frac{c_2}{c_{cr,Nb}}\right)^{0.5} \leq 1.0$$

With

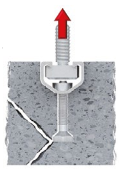
c_2 = corner distance of the anchor as figure 20 for which the resistance is calculated

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

if the anchor is influenced by two corners (figure 21c) 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 $N_{Rk,cb}$

The influence of the thickness of the concrete member for

f ≤ 2 c_1 see figure 22 is taken into account by the



$$\psi_{ch,h,Nb} = \frac{h_{ef} + f}{4c_1} \leq \frac{2c_1 + f}{4c_1} \leq 1.0$$

Where

f = distance between the anchor head and the lower surface of the concrete member figure 22.

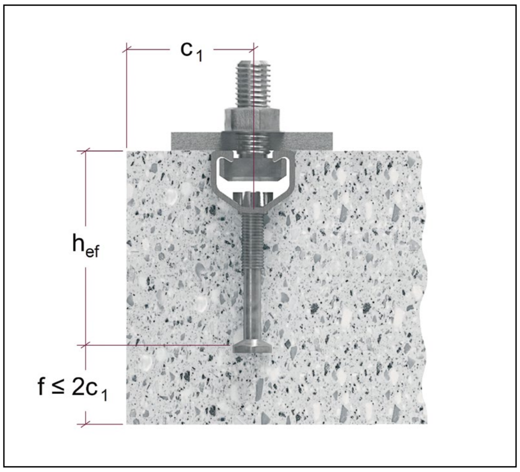


Figure 22
Anchor channel in thin slab

Supplementary reinforcement for tension loads

When the design relies on supplementary reinforcement, concrete cone failure does not need to be verified, but the supplementary reinforcement shall be designed to resist the total anchor load. It shall be anchored adequately on both sides of the potential failure planes, as shown in the figure 23.

For anchor channels located parallel to the edge of a concrete member or in a narrow concrete member, the plane of the supplementary reinforcement shall be located perpendicular to the longitudinal axis of the channel as shown in the figure 23.

We recommend using Hilti PROFIS Anchor Channel software for the design of this reinforcement to select the required diameter and anchorage length based on Eurocode 2.

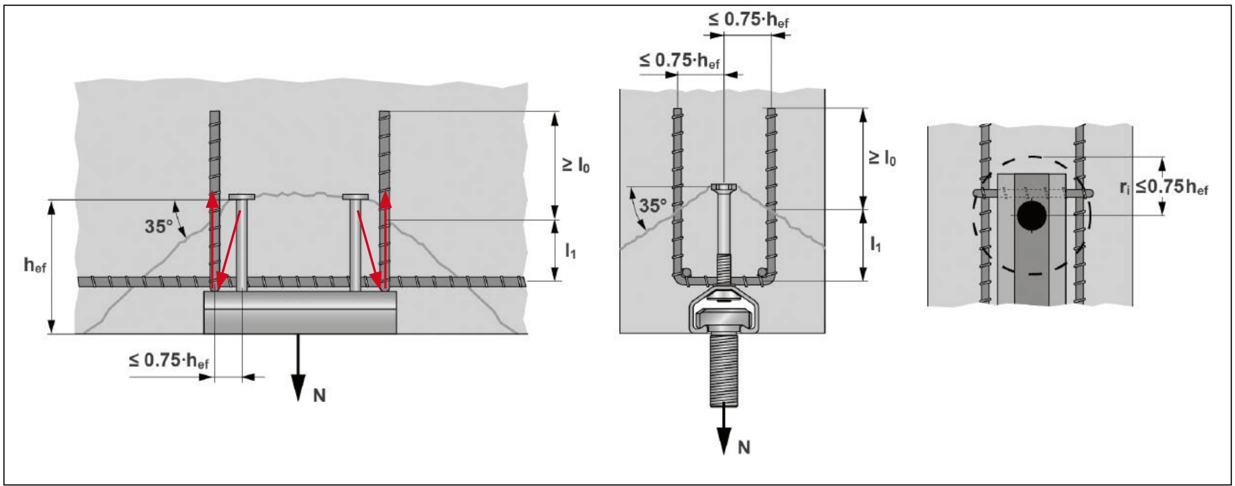


Figure 23
Detailing of supplementary reinforcement for tension loads

Note: These additional reinforcements are placed onsite as shown above and are not welded to the anchor channel. If it is not possible to arrange and place such reinforcement for any reason, Hilti can also supply factory produced anchor channels with rebars.

Anchorage failure of rebar

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

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

with

$$N^0_{Rd,a} = \frac{l_1 \cdot \pi \cdot \varphi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2}$$

with

l_1 = anchorage length in the breakout body as shown in figure 23. Only supplementary reinforcement with an anchorage length in the concrete failure cone of $l_1 \geq 4\phi$ (anchorage with bend, hooks or loops) or $l_1 \geq 10\phi$ (anchorage with straight bars) shall be assumed as effective.

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

Steel failure of rebar

The characteristic yield strength of the supplementary reinforcement is given by:

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

with

$f_{yk,re}$ ≤ 600 MPa

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

Requirement of supplementary reinforcement for tension

1. The reinforcement shall consist of ribbed reinforcing bars $f_{yk} \leq 600$ MPa with a diameter not larger than 16 mm

2. Where supplementary reinforcement has been designed for the most loaded anchor, the same reinforcement shall be provided around all other anchors

3. This additional supplementary reinforcement is placed as close to the channel profile as possible to avoid any eccentricity associated with an angle of failure cone

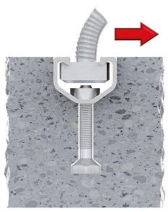
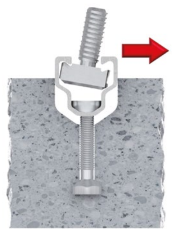
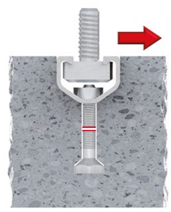
4. Preferably, supplementary reinforcement should enclose the surface reinforcement. Only reinforcement bars with a distance $\leq 0.75\ h_{ef}$ from the anchors shall be assumed effective as shown also in figure 23

5. Enough anchorage length and splice length as per EC-2 must be provided

VERIFICATION UNDER SHEAR LOADS ACTING PERPENDICULAR TO THE LONGITUDINAL AXIS OF THE CHANNEL

Steel failure modes

If shear loads act transverse to the channel axis of the channel, the steel verifications have to be performed as shown in the table below. The characteristic strength values given in this table should be taken from the current European Technical Assessment (ETA) or tables from technology manual and material safety factors are taken from the table on page 7. For the purpose of a simple model for the verification, it is assumed that the entire shear load is transferred into the concrete member via the anchors.

Steel failure modes under shear loads perpendicular to the channel axis				
Channel bolt failure w/o lever arm	**Channel bolt failure with lever arm**	**Channel lip w/o lever arm**	**Connection between anchor and channel**	**Anchor**
				
$V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	$V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V_{Rd,s,l} = \frac{V_{Rk,s,l,y}}{\gamma_{Ms,l}}$	$V_{Rd,s,c,y} = \frac{V_{Rk,s,c,y}}{\gamma_{Ms,ca}}$	$V_{Rd,s,a,y} = \frac{V_{Rk,s,a,y}}{\gamma_{Ms}}$

Steel failure (Shear force without lever arm)

Characteristic resistance of channel lips is based on the basic lip strength $V^0_{R,k,s,l,}$ and bolt spacing factor, because spacing of the channel bolts has to be considered in the calculation. When bolts are spaced closely it might reduce the channel lip capacity.

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

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

With

$V^0_{Rk,s,l}$ = characteristic lip resistance under shear

s_{cbo} = center to center spacing between channel bolts ($s_{cbo,min}$= 5d) where d= bolt diameter

$s_{l,v}$ = characteristic spacing for channel lip failure under shear

Characteristic resistance values shall be taken from the current European Technical Assessment (ETA) or technology manual.

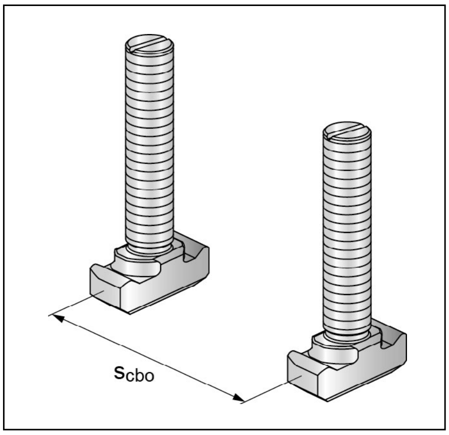


Figure 24
Bolt spacing

Steel failure (Shear loads with lever arm)

The characteristic resistance of a channel bolt $V_{Rk,s,M}$ with stand-off installation is calculated:

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

with

l_a = stand-off distance i.e. distance between shear load and concrete surface see figure 25

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
= 2.0, if full restraint is assumed, valid only if the fixture cannot rotate)

The value α_M can be chosen with any value between 1 and 2 depending on the constraint conditions. In case conditions are not clear α_M should be chosen with α_M=1.0.

$$M_{Rk,s} = M^0_{Rk,s}\left(1 - \frac{N^{cb}_{Ed}}{N_{Rd,s}}\right)$$

Where

$M^0_{Rk,s}$ = Characteristic bending resistance of the channel bolt

N^{cb}_{Ed} = applied tension load on the bolt

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

Where

$N_{Rk,s}$ is the characteristic bolt resistance

Characteristic resistance values shall be taken from the current European Technical Assessment (ETA) or technology manual

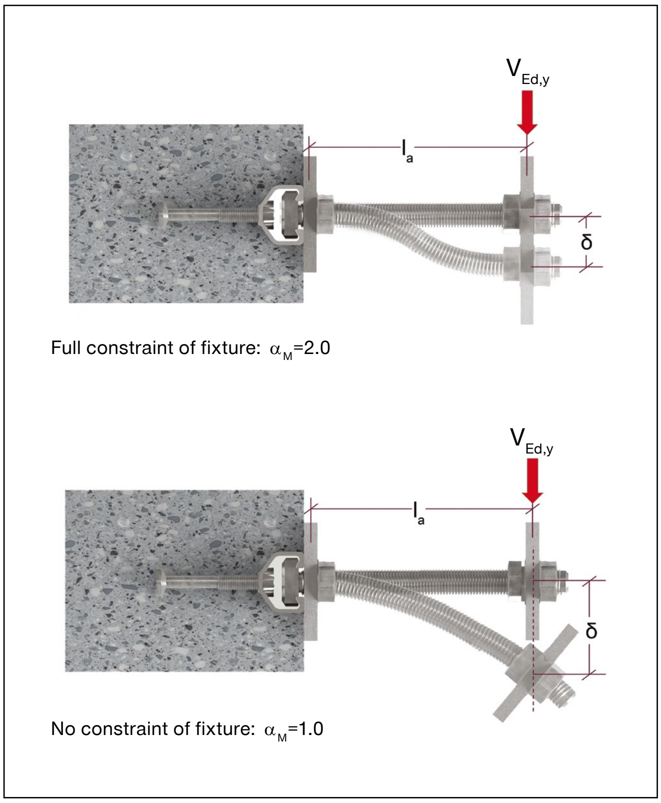
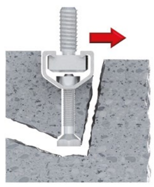
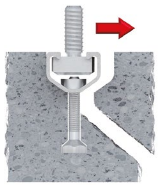
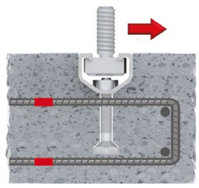
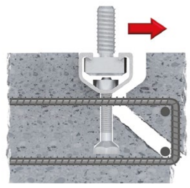


Figure 25
Principle cases of constraint level

Table of contents
Design of anchor channels
HAC Design Examples
HAC-C(-P) Design Examples
HAC EDGE Design Examples

Concrete failure modes

Concrete capacities are calculated according to the formulas given in this section.
The table below lists the required concrete verifications under shear loading.

Concrete failure modes under shear loads perpendicular to the channel axis			
Pry-out	**Concrete edge failure**	**Steel failure of supplementary reinforcement**	**Anchorage failure of supplementary reinforcement**
			
$V_{Rd,cp,y} = \frac{V_{Rk,cp}}{\gamma_{Mc}}$	$V_{Rd,c,y} = \frac{V_{Rk,c}}{\gamma_{Mc}}$	$N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Rd,a} = \sum_{i=1}^{n_{re}} \frac{l_1 \cdot \pi \cdot \varphi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2}$

Concrete pry-out failure

In pry-out failure mode, concrete break-out occurs at the back of the channel when loaded in shear. As the concrete failure mode looks quite similar to the concrete cone that occurs under tensile loads, the resistance of pry-out is based on the resistance of concrete cone break-out under tensile load multiplied by the factor k_8 :

$$V_{Rd,cp,y} = k_8 \cdot N_{Rk,c}$$

Where
k_8 factor for pry-out resistance
$N_{Rk,c}$ according to page 13

For anchor channels with supplementary reinforcement the pry-out resistance is calculated with the reduction factor 0.75:

$$V_{Rd,cp,y} = 0.75 \cdot k_8 \cdot N_{Rk,c}$$

All relevant factors shall be taken from the current European Technical Assessment (ETA) or technology manual

Concrete edge failure

Failure of concrete edge needs to be verified when the anchor channel is installed parallel to an edge of the concrete member and shear loads are applied perpendicular to the longitudinal axis of the channel. The resistance of one anchor is calculated with basic resistance of concrete $N^0_{Rk,c}$, and other influencing factors:

$$V_{Rk,c,y} = V^0_{Rk,c} \cdot \psi_{ch,s,V} \cdot \psi_{ch,c,V} \cdot \psi_{ch,h,V} \cdot \psi_{ch,90^\circ,V} \cdot \psi_{re,V}$$

The basic resistance of one anchor that is not influenced by neighboring anchors or concrete edges is calculated with:

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

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

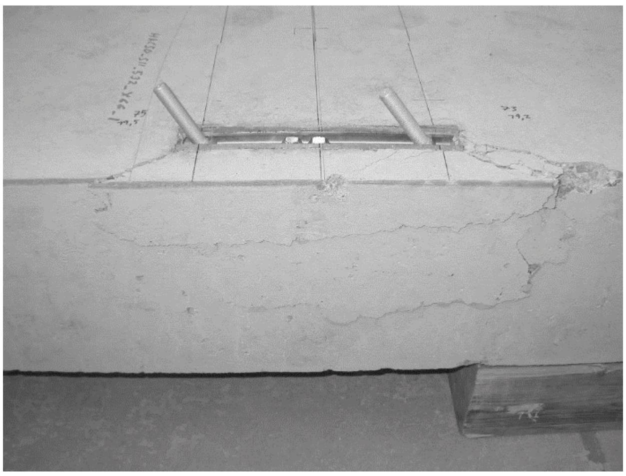


Figure 26
Typical crack pattern under shear load

The reduction ψ - factors are explained in the following. The influence of neighboring anchors on the concrete edge resistance is taken into account by the factor $\psi_{ch,s,V}$:

$$\psi_{ch,s,V} = \frac{1}{1+\sum_{i=1}^{n_{ch,V}}\left[\left(1-\frac{s_i}{s_{cr,V}}\right)^{1.5}\cdot\frac{V_i}{V_0}\right]} \leq 1.0$$

With:

s_i = distance between the anchors under consideration and the neighboring anchors $\leq s_{cr,V}$

$s_{cr,V}$ = 4 c_1 + 2 b_{ch} where conditions $h_{ch}/h_{ef} \leq 0.4$ and $b_{ch}/h_{ef} \leq 0.7$ are fulfilled

$s_{cr,V}$ = to be taken from the current European Technical Assessment (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 condition above:

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

If the concrete cones under shear loads overlap with each other due to neighboring anchors, then we must cosider the reduction in the concrete edge strength. In figure 27, the concrete cones are intersecting and reduction in strength due to this overlapped area $A_{overlap}$ has to be taken into account through a factor $\psi_{ch,s,V}$. If the spacing between anchors is such that these cones are not overlapping, then we can take this factor as 1.

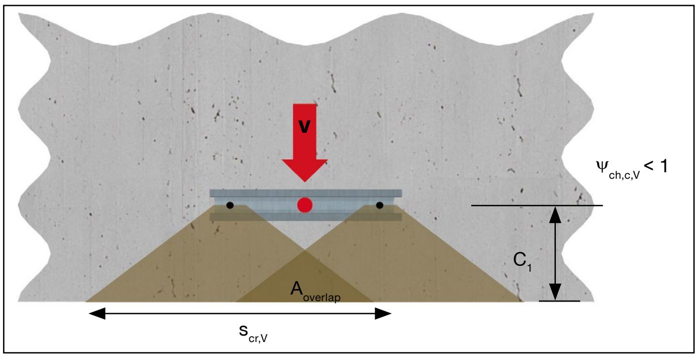


Figure 27
Due to anchor spacing concrete cone overlapping under shear loads with reduction in strength

The influence of a corner on the characteristic edge resistance is taken into account by the factor $\psi_{ch,c,V}$. As area, $A_{overlap}$ of the cone is going out of the edge this reduces the strength of the concrete.

$$\psi_{ch,c,V} = \left(\frac{c_2}{c_{cr,V}}\right)^{0.5} \leq 1.0$$

With

$c_{cr,v}$ = 0.5 $s_{cr,V}$

c_2 = figure 29

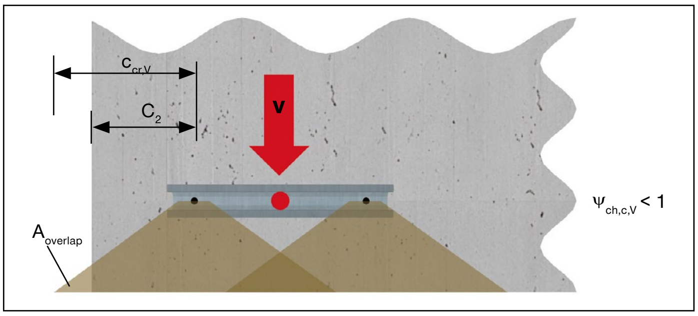


Figure 28
Due to corner edge distance concrete cones, interesting edge with reduction in strength

If the corner edge distance c_2 is $\geq c_{cr,V}$ then $\psi_{ch,c,V}$ can be taken as 1 with no reduction in strength as shown in figure 29

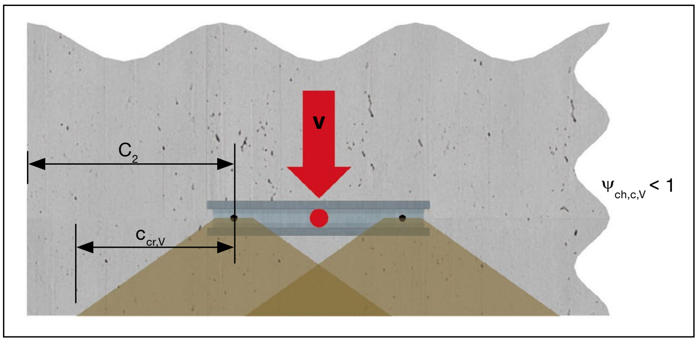


Figure 29
Due to corner edge distance concrete cones, not intersecting edge with no reduction in strength

The component member thickness also plays a vital role in the calculation of concrete edge strength. The factor $\psi_{ch,h,V}$ takes into account the member thickness:

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0.5} \leq 1.0$$

With

$h_{cr,V}$ is critical height which is calculated based on concrete edge c_1 and channel height h_{ch}

$$h_{cr,V} = 2c_1 + 2h_{ch}$$

$h_{cr,V}$ to be taken from the current European Technical Assessment (ETA) if $h_{ch}/h_{ef} > 0.4$ and/or $b_{ch}/h_{ef} > 0.7$.

If $h_{cr,V}$ > member thickness h then it means we do not have concrete in the area A_{hv} so, in this case, $\psi_{ch,h,V} < 1$. If member thickness $h \geq h_{cr,V}$ then $\psi_{ch,h,V} = 1$ as shown in figure 30.

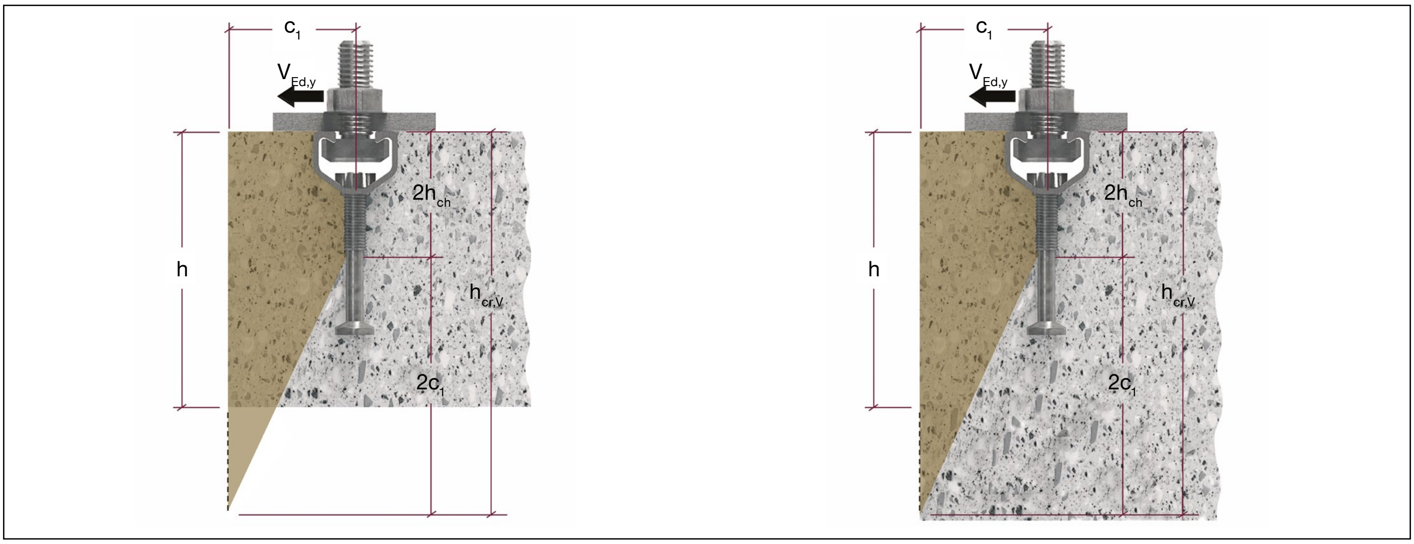
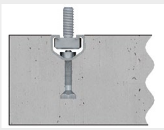
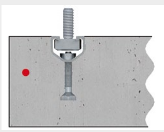
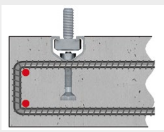


Figure 30
Influence of member thickness on the concrete edge strength

The factor $\psi_{re,V}$ takes into account the effect of reinforcement in the concrete member.

The following $\psi_{re,V}$ values should be taken into account based on the existing reinforcement:

$\psi_{re,V}$	Reinforcement	EOTA TR047 ($\psi_{re,V}$) March 2018	EN 1992-4:2018	Hilti recommendation
1.0	No reinforcement 	-	-	-
1.2	Straight edge reinforcement 	$d_s \geq 12$ mm	N/A	$d_s \geq 12$ mm
1.4	Straight edge reinforcement + stirrups 	Straight edge reinforcement: $d_s \geq 12$ mm Stirrups or wire mesh: d_s is not specified, spacing a=min(100 mm; $2c_1$) (c_1 edge distance)	Straight edge reinforcement: d_s is not specified Stirrups or wire mesh: d_s is not specified spacing a=min(100 mm; $2c_1$) (c_1 edge distance)	Straight edge reinforcement**: $d_s \geq 12$ mm Stirrups**: $d_s \geq 8$ mm spacing 200 mm maximum refer to figure 34

reinforcement is effective only if $c_1 \geq 100$ mm

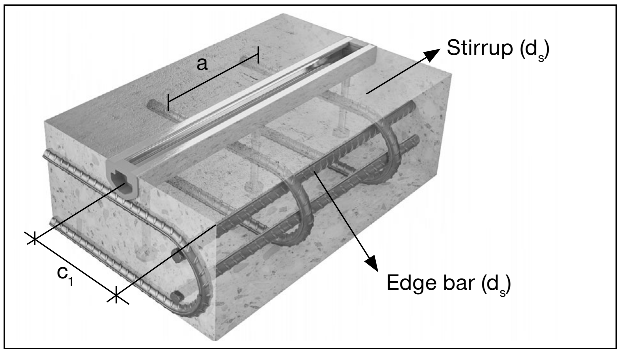
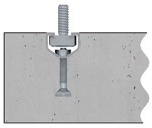
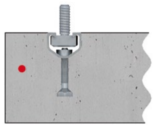
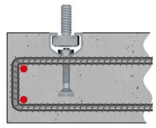
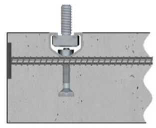


Figure 31
Component with edge bars and stirrups

Capacity	$V_{Rd.c}$	$1.2 \cdot V_{Rd.c}$	$1.4 \cdot V_{Rd.c}$	$\sim 5\ V_{Rd.c}$
Required reinforcement	-	Straight edge rebar	Straight edge rebar + stirrups	-
Design of the reinforcement	-	Not required	Not required	Verification of the rebar of the HAC-EDGE product is considered in the PROFIS software analysis.

Recommendations regarding the reinforcement detailing in the concrete member (Hilti method)

Edge reinforcement ($\psi_{re.V}$=1.2):

The diameter of the edge rebars must be ≥ 12 mm.
The length of the edge rebar must be:
$l_{min} = l_{channel} + 4c_1 + 2l_o$ as shown in the figure 32

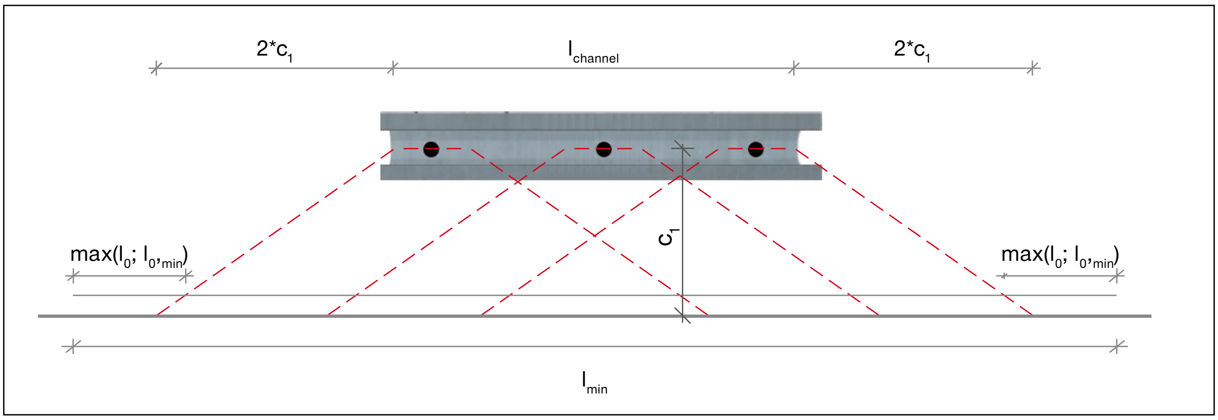


Figure 32
Required length of the edge bar

Position of the longitudinal bar

It is recommended to place the edge bar in the shaded area shown in the figure 33

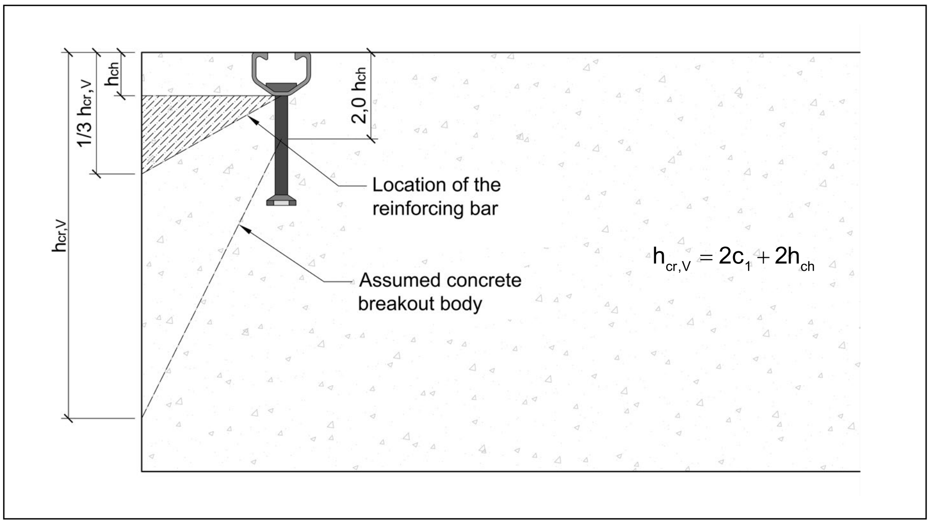


Figure 33
Effective area for the placement of edge bar

Edge reinforcement and stirrups ($\psi_{re.V}$=1.4):

The diameter of the edge rebars must be ≥ 12 mm and stirrup diameter ≥ 8 mm with maximum stirrup spacing of 200 mm.

Stirrups must be placed on both sides of the channel up to spacing of $2c_1$ as shown in the figure 34.

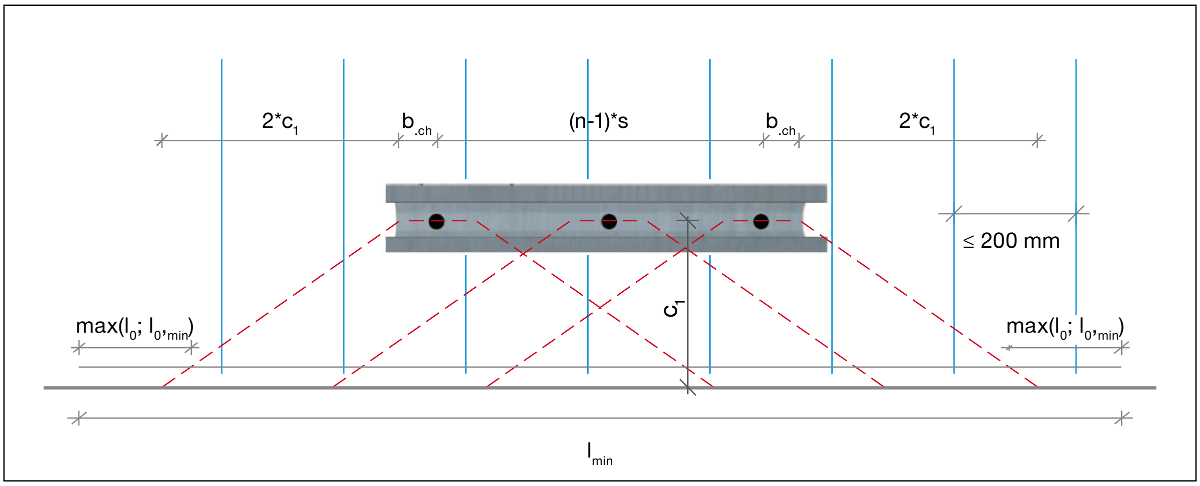


Figure 34
Detailing of reinforcement as per Hilti Method

In case of edge reinforcement where concrete is assumed cracked a factor $\psi_{re,V}$ > 1 shall only be used if the height of the channel is h_{ch} ≤ 40 mm.

If the required capacity with this reinforcement is not achieved then please refer to our HAC-Edge solution which offers up to ~5 times higher concrete edge capacity.

The factor $\psi_{ch,90°,V}$ considers the influence of shear loads acting parallel to the edge.

$\psi_{ch,90°,V} = 2.5$

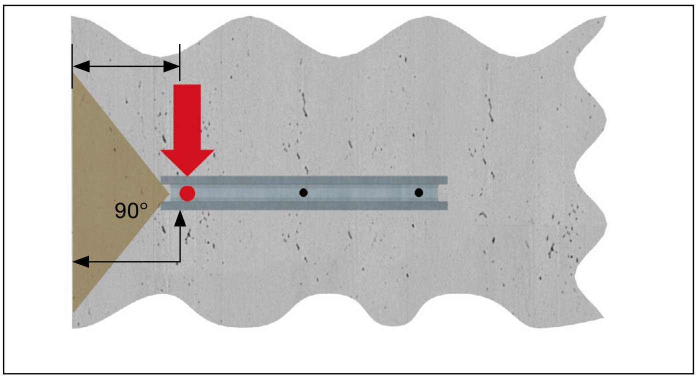


Figure 35
Anchor channel with shear load parallel to edge c_2

VERIFICATION UNDER SHEAR LOADS ACTING IN THE DIRECTION OF THE CHANNEL AXIS

Steel failure modes

If shear loads act on the longitudinal axis of the channel, steel verifications must be performed. The characteristic resistance values in the table below should be taken from the current European Technical Assessment (ETA) or technology manual.

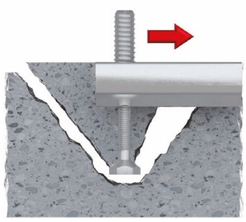
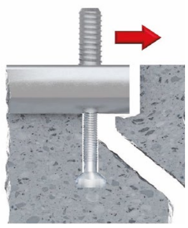
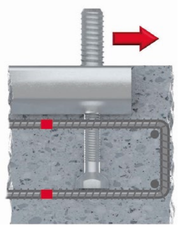
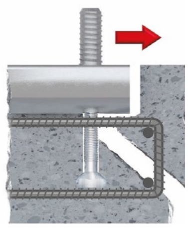
Steel verification of the bolt with lever arm for shear loads acting in the direction of the channel axis is currently not permitted by the code. Please contact your local team for an engineering solution.

Steel failure modes under shear acting in direction of channel axis				
Channel bolt failure w/o lever arm	Channel bolt failure with lever arm	Channel lip w/o lever arm	Connection between anchor and channel	Anchor
				
$V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$	$V_{Rd,s,M} = \frac{V_{Rk,s,M}}{\gamma_{Ms}}$	$V_{Rd,s,l,x} = \frac{V_{Rk,s,l,x}}{\gamma_{Ms,l} \cdot \gamma_{inst}}$	$V_{Rd,s,c,x} = \frac{V_{Rk,s,c,x}}{\gamma_{Ms,ca}}$	$V_{Rd,s,a,x} = \frac{V_{Rk,s,a,x}}{\gamma_{Ms}}$

Concrete failure modes

Concrete capacities calculated according to the the formulas given in this section.

The following table lists the required concrete verifications under shear loading.

Concrete failure modes under shear loads parallel to the channel axis			
Pry-out	Concrete edge failure	Steel failure of supplementary reinforcement	Anchorage failure of supplementary reinforcement
			
$V_{Rd,cp,x} = \frac{V_{Rk,cp,x}}{\gamma_{Mc}}$	$V_{Rd,c,x} = \frac{V_{Rk,c,x}}{\gamma_{Mc}}$	$N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms,re}}$	$N_{Rd,a} = \sum_{i=1}^{n_{re}} \frac{l_1 \cdot \pi \cdot \varphi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2}$

Pry-out failure

In pry-out failure mode, concrete break-out occurs at the back of the channel when loaded in shear. As the concrete failure mode looks like the concrete cone that occurs under tensile loads, the characteristic resistances based on the resistance of concrete cone break-out under tensile load are multiplied by the factor k_8 as per equation:

$$V_{Rd,cp,x} = k_8 \cdot N_{Rk,c}$$

Where

k_8 factor for pry-out resistance

For anchor channels with supplementary reinforcement the pry-out resistance is calculated as:

$$V_{Rd,cp,x} = 0.75 \cdot k_8 \cdot N_{Rk,c}$$

All relevant factors shall be taken from the current European Technical Assessment (ETA) or technology manual

Concrete edge failure

Anchor channel installed transverse to the edge

The characteristic resistance of the anchor channel loaded towards the edge is calculated according to the following equations:

$$V_{Rk,c,x} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{re,V}$$

Where

$$V^0_{Rk,c} = k_9 \cdot d_a^{\alpha} \cdot h_{ef}^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{1.5}$$

With

K_9 = 1.7 for cracked concrete
= 2.4 for uncracked concrete

$$\alpha = 0.1 \cdot \left(\frac{h_{ef}}{c_1}\right)^{0.5} \qquad \beta = 0.1 \cdot \left(\frac{d_a}{c_1}\right)^{0.2}$$

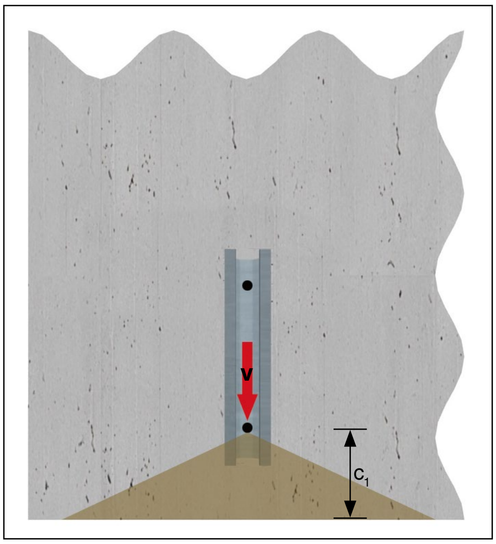


Figure 36
Concrete edge verification under longitudinal shear

The value of h_{ef} is given in the relevant European Technical Assessment with $h_{ef} \leq 12d_a$

For round anchors, d_a is given in the relevant European Technical Assessment.

The ratio of $A_{c,V}/A^0_{c,v}$ 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.

$A^0_{c,V}$ = reference projected area.
= 4.5. c_1^2

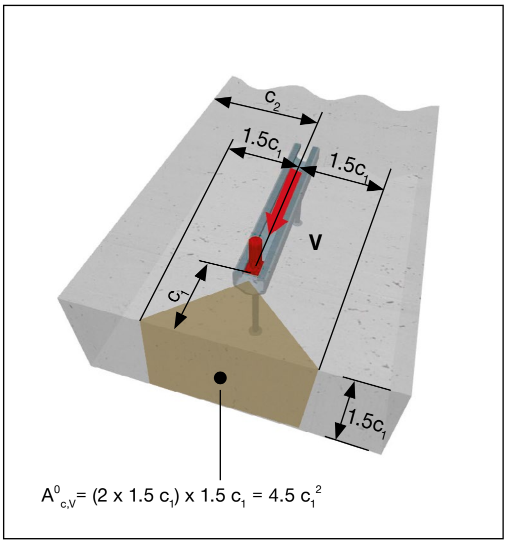


Figure 37

$A_{c,V}$ = the area for idealized concrete breakout body, limited by the overlapping concrete cones of adjacent anchors ($s \leq 3_{c1}$) as well as by edges parallel to the assumed loading direction ($c_2 \leq 1.5c_1$) and by member thickness ($h \leq 1.5c_1$)

$A_{c,V}$ = h . ($1.5c_1$ + $1.5c_1$) if c_2 is less than $1.5c_1$ then take c_2

h = $1.5c_1$ if h< $1.5c_1$ then take h

The factor ratio $\psi_{s,V}$ takes into account 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 narrow concrete members, the smaller value of these edge distances shall be used for c_2 in the following equation:

$$\psi_{s,V} = 0.7 + 0.3 \cdot \frac{c_2}{1.5c_1} \leq 1.0$$

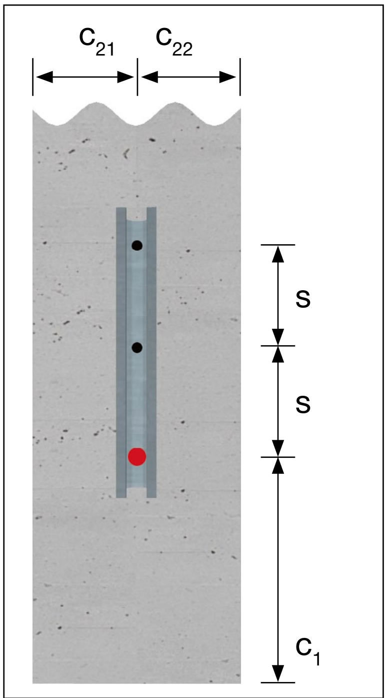


Figure 38
Edge distances in concrete narrow member

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 $A_{c,v}/A_{c0,V}$

$$\psi_{h,V} = \left(\frac{1.5 \cdot c_1}{h}\right)^{0.5} \geq 1.0$$

Where h = component thickness

$\psi_{re,V}$ according to section of transverse shear loads

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 the front anchor and the edge shall be used as per figure 38.

For anchor channels in narrow thin member with $c_{2,max} \leq 1.5c_1$ and h $\leq 1.5c_1$ the calculation according to equation page 28 $V_{Rk,c,x}$ leads to conservative results. More accurate results are obtained if c_1 is replaced by

$$c_1' = \max\left\{\frac{c_{2,max}}{1.5}; \frac{h}{1.5}\right\} \geq 1.0$$

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

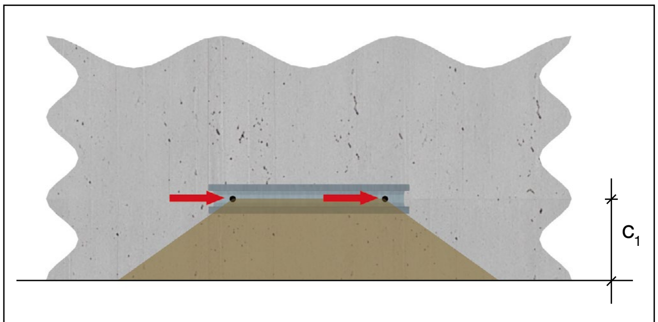


Figure 39
Anchor channel loaded longitudinal axis of the channel

Anchor channels installed parallel to the edge

The characteristic resistance $V_{Rk,c}$ of the most unfavorable anchor for concrete edge failure shall be calculated according to the following equation:

$$V_{Rk,c,x} = 2 \cdot V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{re,V} / n_a$$

$V^0_{Rk,c}$, $\psi_{s,V}$, $\psi_{h,V}$, $\psi_{re,V}$, $A_{c,V}$, $A^0_{c,V}$, see section for anchor channel installed transverse to edge page 28.

SUPPLEMENTARY REINFORCEMENT FOR SHEAR LOADS

Shear loads acting transverse to the channel axis

In case the concrete edge resistance is not sufficient, reinforcement can be added. The entire shear load must be taken up by the reinforcement and the concrete edge verification is not needed. Verifications for supplementary reinforcement include the proof of the rebar steel resistance and sufficient rebar anchorage length as per Eurocode 2. We recommend using Hilti PROFIS Anchor Channel software for dimensioning of the required diameter of the reinforcement and anchorage length.

Tensile force in the reinforcement caused by shear load V_{Ed} due to eccentricity e_s (V_{Ed} and $N_{Ed,re}$ are not in the same action line) has to be taken into account.

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

V_{Ed} = Max. applied bolt load

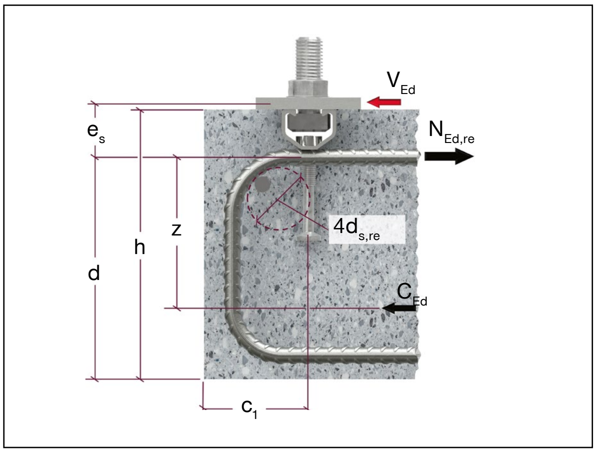


Figure 40
Calculation of forces in the supplementary reinforcement

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

$$e_s = l + \frac{t}{2} + \max(c, h_{ch}) + \frac{d_{s,re}}{2}$$

l	= stand-off distance as per figure 25
t	= thickness of the fixture
c	= concrete cover
h_{ch}	= channel height
$d_{s,re}$	= rebar diameter
z	= 0.85d

$$d = h - \max(c, h_{ch}) - \frac{d_{s,re}}{2} \leq \min(2h_{ef}, 2c_1)$$

Where

h	= member thickness
c	= concrete cover
h_{ch}	= channel height
$d_{s,re}$	= rebar diameter
c_1	= edge distance
h_{ef}	= effective channel height

The loads from the anchor are transferred to the rebars via a strut-and-tie model.

Steel strength of the supplementary reinforcement

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

$$N_{Rk,re} = n_{re} \cdot A_{s,re} \cdot f_{yk,re}$$

Where

n_{re}	= number of bars of supplementary reinforcement effective for one anchor
$f_{yk,re}$	≤ 600 MPa
$A_{s,re}$	= area of the bar used

Anchorage failure of supplementary reinforcement

$$N_{Rd,a} = \sum_{i=1}^{n_{re}} \frac{l_1 \cdot \pi \cdot d_{s,re} \cdot f_{bd}}{\alpha_1 \cdot \alpha_2} \leq N_{Rd,re}$$

Where

l_1	= anchorage length in the breakout body. l_1 has to be larger than the minimum anchorage length
f_{bd}	= design bond strength calculated according to EN 1992-1-1

α_1 and α_2 influencing factor as per EN 1992-1-1

Required verifications:

$N_{Ed,re} \leq N_{Rd,re}$
$N_{Ed,re} \leq N_{Rd,a}$

Detailing of supplementary reinforcement for shear loads acting transverse to channel axis based on EOTA TR047/EN-1992-4

The supplementary reinforcement shall be in the form of a surface reinforcement as shown in figure 41.

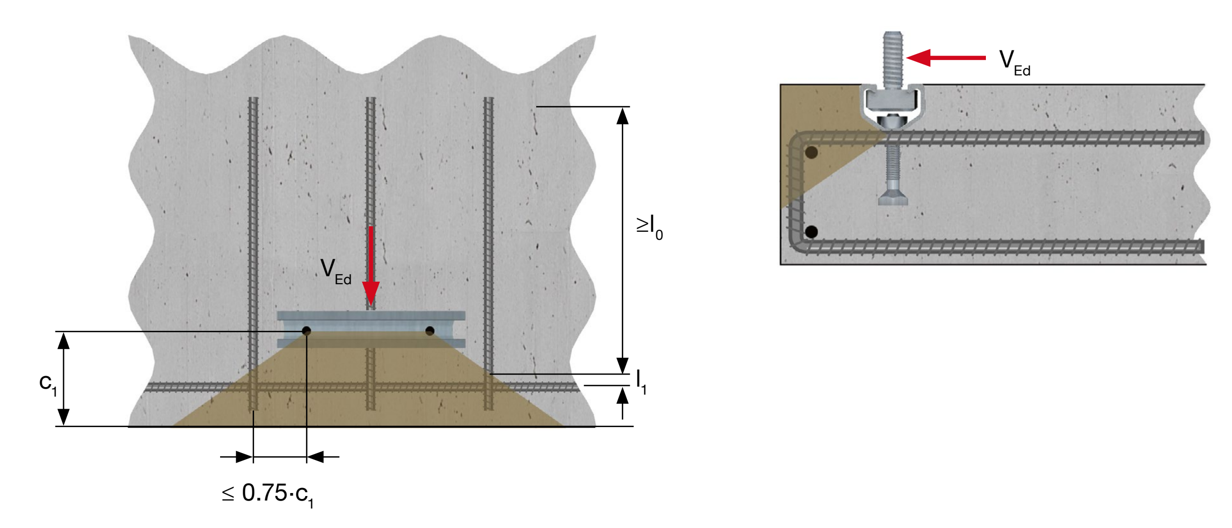


Figure 41
Supplementary reinforcement to take up shear forces perpendicular

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 41 then the bars shall only be assumed effective if the following requirements are fulfilled:

a) Supplementary reinforcement calculated for most loaded anchor under shear shall be placed around each anchor considered effective for concrete edge failure

b) The supplementary reinforcement should consist of ribbed bars with $f_{yk} \leq 600$ MPa and the diameter of the bar is not larger than 16 mm. The bending diameter should comply with EN-1992-1-1

c) Bars are within a distance of $0.75.c_1$ from the anchor

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

Min l_1	= 10 x diameter of the bar	straight bars or without welded transverse bars
	= 4 x diameter of the bar	bars with hook, bend or loop

e) The breakout body assumed should be the same as that for calculating the edge resistance for the concrete edge failure

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 45° may be assumed

Detailing of supplementary reinforcement for shear loads acting in direction of channel axis based on EOTA TR047/EN-1992-4

Anchor channel arranged perpendicular to the edge

To design the stirrup for longitudinal load it is assumed that all the load applied on the channel bolts is transferred to the anchor closest to the edge as shown in figure 42.

Only stirrups with a distance $\leq 0.75c_1$ from the anchor shall be assumed as effective. The characteristic resistance of steel shall be calculated as per equations given on page 30.

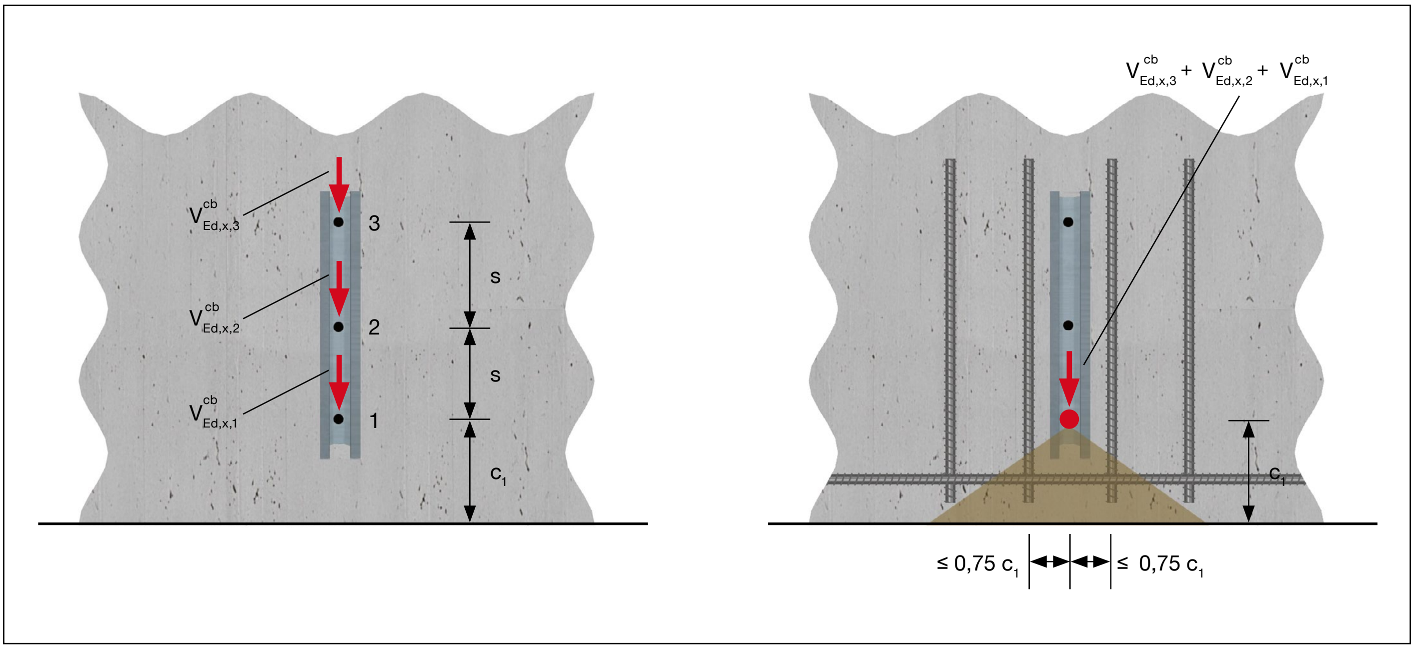


Figure 42
Anchor channel loaded longitudinal to shear axis

Anchor channel arranged parallel to the edge

When the design shear force acts parallel to the edge as per figure 43, 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 the edge.

The characteristic resistance of steel shall be calculated as equation on page 30 with anchorage and splice length as per Eurocode 2.

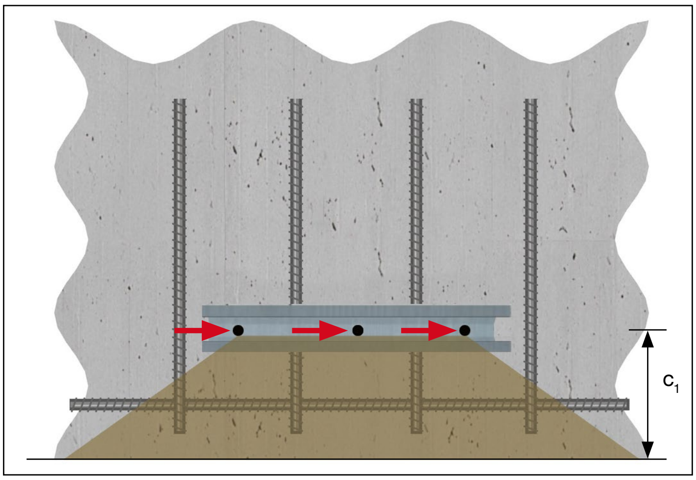


Figure 43
Anchor channel with shear load in the longitudinal direction of the channel

Supplementary reinforcement for shear loads acting in the direction of channel axis

Based on Hilti method:

Hair Pin

If the concrete edge capacity is not sufficient when load is acting in the direction of the channel axis ($V_{Ed,x}$) then reinforcement to control the edge breakout failure can be designed. The placement of the reinforcement is shown in figure 44. This method is also implemented in the Hilti software when you select “Hilti Design Method” under tab “loads”

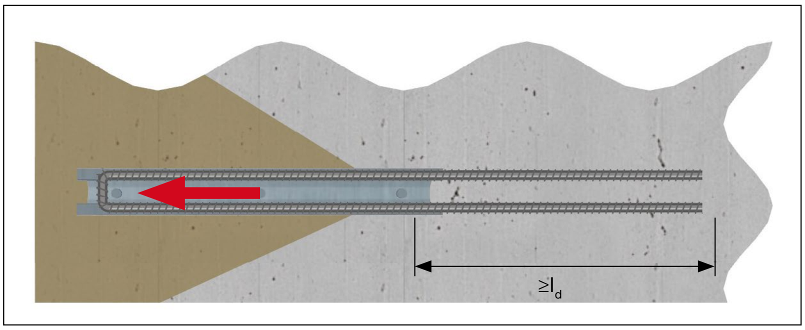


Figure 44
The anchorage lengths and steel strength according to EN 1992 1-1

COMBINED TENSION AND SHEAR LOADS

In the first step, all single verifications for steel and concrete failure modes are carried out separately as explained in the above sections for the most unfavorable anchor or position of the bolt in the anchor channel. In this section, the combined effects of tension, shear perpendicular and shear longitudinal must be considered.

ANCHOR CHANNELS WITHOUT SUPPLEMENTARY REINFORCEMENT

Steel failure of channel bolts

The following equation shall be satisfied for shear without stand-off.

$$\left(\frac{N^{cb}_{Ed}}{N_{Rd,s}}\right)^2 + \left(\frac{V^{cb}_{Ed}}{V_{Rd,s}}\right)^2 \leq 1.0$$

Where

$$V^{cb}_{Ed} = \sqrt{\left[\left(V^{cb}_{Ed,x}\right)^2 + \left(V^{cb}_{Ed,y}\right)^2\right]}$$

is the resultant applied load due to x and y direction

The respective bolt steel resistance $N_{Rd,s}$ & $V_{Rd,s}$ values from current European Technical Assessment (ETA) or from technology manual.

Steel failure of channel lips and flexural failure of channel

The following equation shall be satisfied:

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

with

k_{13} = 2.0 if $V_{Rd,s,l} \leq N_{Rd,s,l}$
= to be taken from the current European Technical Assessment (ETA) if $V_{Rd,s,l} > N_{Rd,s,l}$,
= 1.0 as a conservative assumption

Note: The basic interaction concept is shown in figure 45

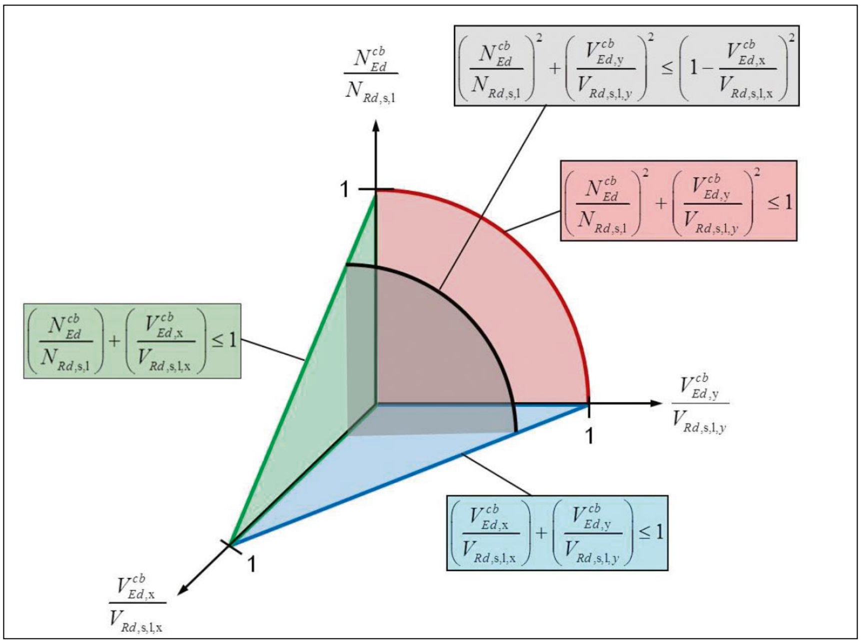


Figure 45
Interaction concept of anchor channels (figure source EOTA TR 047)

Steel failure of anchor and connection between anchor and channel

The verification shall be satisfied:

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

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 current European Technical Assessment (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

In this verification, the exponent k_{14} can be chosen according to the ratio of the shear and tensile resistance of the anchor or anchor-channel connection.

Hilti method based on external investigation

Steel failure of channel lips and flexural failure of channel

The following verification shall be satisfied:

$$\mathrm{Max}\left(\frac{N^{cb}_{Ed}}{N_{Rd,s,l}};\frac{M_{ch,Ed}}{M_{Rk,s,flex}}\right)^{k_{13}}+\left(\frac{V^{cb}_{Ed,y}}{V_{Rd,s,l,y}}\right)^{k_{13}}+\left(\frac{V^{cb}_{Ed,x}}{V_{Rd,s,l,x}}\right)^{2}$$

With

k_{13} = 2.0 if $V_{Rd,s,l}$ ≤ $N_{Rd,s,l}$
= to be taken from the current European Technical Assessment (ETA) if $V_{Rd,s,l}$ > $N_{Rd,s,l}$,
= 1.0 as a conservative assumption

Steel failure of anchor and connection between anchor and channel

The following verification shall be satisfied:

$$\mathrm{Max}\left(\frac{N^a_{Ed}}{N_{Rd,s,a}};\frac{N^a_{Ed}}{N_{Rd,s,c}}\right)^{k_{14}}+\max\left(\frac{V^a_{Ed,y}}{V_{Rd,s,a,y}};\frac{V^a_{Ed,y}}{V_{Rd,s,c,y}}\right)^{k_{14}}+\left(\max\left(\frac{V^a_{Ed,x}}{V_{Rd,s,a,x}};\frac{V^a_{Ed,x}}{V_{Rd,s,c,x}}\right)\right)^{2}$$

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 current European Technical Assessment (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

In this verification, the exponent k_{14} can be chosen according to the ratio of the shear and tensile resistance of the anchor or anchor-channel connection.

Concrete failure modes

The following interaction equation shall be satisfied:

$$\left(\frac{N^a_{Ed}}{N_{Rd}}\right)^{1.5}+\left(\frac{V^a_{Ed,x}}{V_{Rd,x}}\right)^{1.5}+\left(\frac{V^a_{Ed,y}}{V_{Rd,y}}\right)^{1.5}\leq 1.0$$

alternatively,

$$\left(\frac{N^a_{Ed}}{N_{Rd}}\right)^{1.0}+\left(\frac{V^a_{Ed,y}}{V_{Rd,y}}\right)^{1.0}\leq 1.2$$

The largest value $\frac{N^a_{Ed}}{N_{Rd}}$ for the relevant tension failure modes (concrete cone, pull-out, splitting, and blow-out failure) and $\frac{V^a_{Ed,x}}{V_{Rd,x}}$ as well as $\frac{V^a_{Ed,y}}{V_{Rd,y}}$ for the relevant failure modes under shear loading (concrete edge failure, pry-out failure) shall be taken in equation (44).

Anchor channels with supplementary reinforcement

The verifications for steel failure of the channel bolt and the anchor channel shall be done according to the above equations. The verification of concrete failure modes is explained in the following.

Supplementary reinforcement to take up tension loads and shear loads in x-direction and y-direction

The interaction equation for concrete failure mode 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 the shear loads (minimum value for bond and yielding)

Supplementary reinforcement to take up tension loads or shear loads in x-direction and y-direction

The following interaction equation shall be fulfilled

$$\left(\frac{N^a_{Ed}}{N_{Rd}}\right)^{1.0} + \left(\frac{V^a_{Ed,x}}{V_{Rd,x}}\right)^{1.0} + \left(\frac{V^a_{Ed,y}}{V_{Rd,y}}\right)^{1.0} \leq 1.0$$

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 for the supplementary reinforcement to take up shear loads (minimum value for bond and yielding) where applicable.

FATIGUE LOADS

The design of anchor channels under fatigue loads is depicted in EOTA Technical report TR050. This technical report provides a design method for anchor channels only under tensile fatigue loading in combination with or without static and quasi-static loads. The qualification of anchor channels under fatigue loads is based on European Assessment Document EAD. No static or quasi-static shear or fatigue shear load may be applied in combination with a fatigue tensile load.

Applied fatigue loads on anchor channels

In general, all types of actions occurring during the period of intended use of an anchor channel shall be taken into account for the design. Typically, harmonic and/or periodic actions figure 46 and figure 47 including different (peak-to-peak) amplitudes and algebraic signs are considered in the context of fatigue loading. Harmonic and periodic actions can consist of:

- Oscillations touching zero
- Oscillations with the same algebraic sign
- Oscillations with a changing algebraic sign-alternating sign

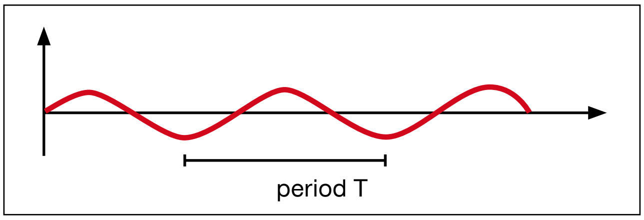


Figure 46
Oscillations with an alternating sign

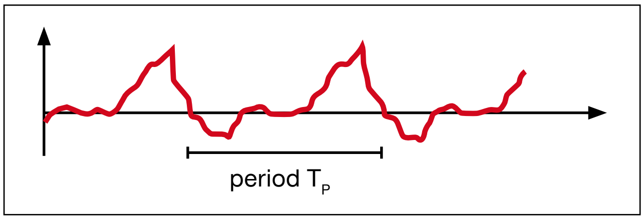


Figure 47
Periodic actions considered as harmonic load

All types of loads acting during the entire life of anchor channels shall be considered during the design process.

Cyclic loads may consist of a single constant or different amplitudes. When different amplitudes need to be taken into account, the sequence of loading may be converted into a collective action of one load level with an equivalent grade of damage by using Miner's rule. An example of a such resulting collective action, or a single constant amplitude load cycle is given in figure 48. For the overall fatigue design process, the knowledge of the S-N curve or, at a minimum, the fatigue limit resistance, is required and the design methods I and or II as mentioned in the following sections can be used.

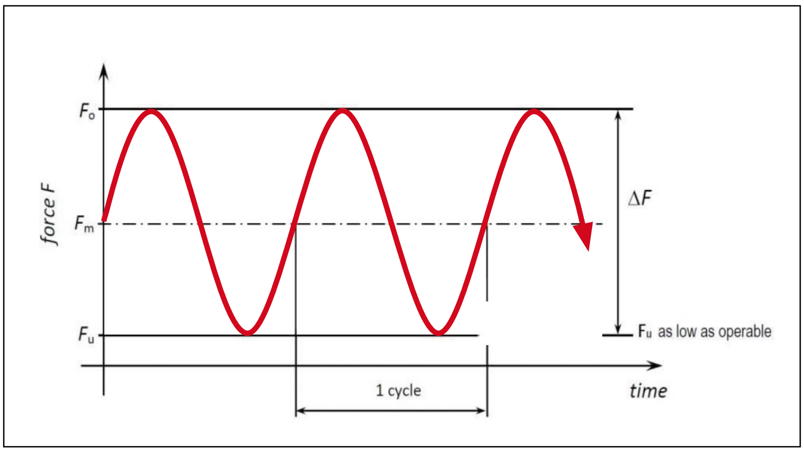


Figure 48
Definition of load cycle (F_0= maximum (upper) cyclic load; F_u= minimum (lower) cyclic load: F_m= mean load, ΔF= cyclic load

LOAD DISTRIBUTION ON ANCHORS UNDER STATIC AND FATIGUE TENSION LOADS

This section only covers static and cyclic tension loads perpendicular to concrete surface. Load combinations including static and cyclic shear loads acting alone or in combination with any type of tension load are not covered in this section.

As shown in figure 51 the equivalent static action $N_{Ed,eq}$ and the equivalent fatigue action $\Delta N_{Ed,eq}$ are calculated using linear superposition. This is applicable for single loads or multiple loads acting simultaneously on the anchor channel. For the sake of simplicity, the equivalent static action $N_{Ed,eq}$ and the equivalent fatigue action $\Delta N_{Ed,eq}$ are assumed to be acting at the same location

The range of influence of a single static tension load shall be taken into account according to the figure 49:

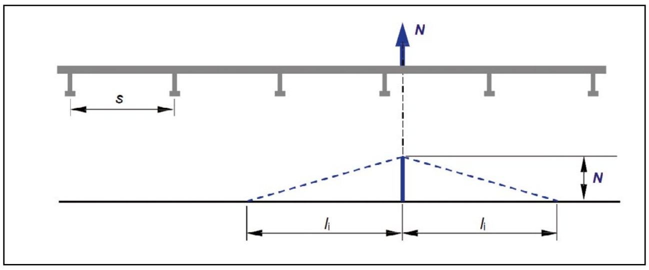


Figure 49
Load distribution from bolt to anchor with static load applied on channel bolt

The range of influence of a cyclic tension load is assumed to be different and is shown in the figure 50:

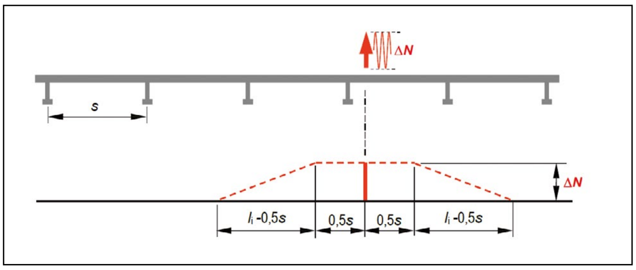


Figure 50
Load distribution from bolt to anchor with fatigue load applied on channel bolt

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

Similarly effect of combination of static and fatigue loads is shown in the figure 45

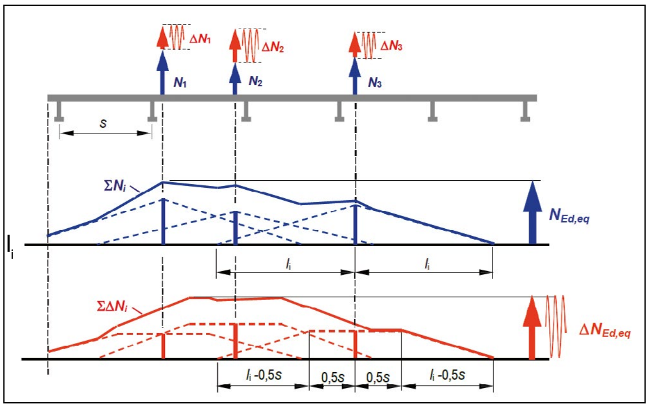


Figure 51
Load distribution from bolt to anchor with static and fatigue load applied on channel bolts

DESIGN OF ANCHOR CHANNELS UNDER FATIGUE LOADS

The partial safety concept is used for the design of anchor channels under fatigue loads. Fatigue loads are marked with Δ.

The design fatigue load under tensile loads is determined as follows:

$$\Delta E_d \leq \Delta R_d$$

ΔE_d: Fatigue design action
ΔR_d: Fatigue design resistance

$$\Delta E_d = \gamma_{fat} \cdot \Delta E_k$$

γ_{fat}: Partial safety factor for cyclic load

The following partial safety factors for actions are recommended in the absence of other national regulations:

a) **Action:** If there is a collective load with a different level of actions and maximum value of actions ΔN_{max} is assumed for the design the recommended partial safety factor is:

$$\gamma_{F,fat} = 1.0$$

b) **Action:** If the effective (actual) collective action is converted by using Miner's rule to a collective of one level with an equivalent level of damage, then recommended partial safety factor is:

$$\gamma_{F,fat} = 1.2$$

c) **Action:** If the effective (actual) collective action is a collective of one load level, the recommended partial safety factor is:

$$\gamma_{F,fat} = 1.2$$

The recommended value $\gamma_{F,fat}$ = 1.2 in case of no precise information.

Now the following partial safety factors for resistance are recommended for anchor channels under fatigue loads:

The values of the partial factors for anchor channels under fatigue loading for use in country may be found in its national annexes of EN 1992-4. For the determination of the design value of the fatigue limit resistance it is recommended to take the partial safety factor for material as $\gamma_{M,fat}$ = 1.35 for all failure modes.

d) For the transition range from static to fatigue resistance the partial safety factors are calculated as follows:

$$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_M - \gamma_{M,fat}) \cdot (\tau N_{Rk,n} - \Delta N_{Rk,\infty})/(N_{Rk} - \Delta N_{Rk,\infty})$$

e) **Resistance:** For the determination of design value of the fatigue resistance the characteristic values obtained from the tests shall be divided with a partial safety factor $\gamma_{M,fat}$ i.e.

$$\Delta N_{Rd} = \frac{\Delta N_{Rk}}{\gamma_{fat}}$$

For the transition range from static to fatigue resistance, the characteristic values obtained from the tests shall be divided with a partial safety factor $\gamma_{M,fat,n}$ i.e.

$$\Delta N_{Rd,s,0,n} = \frac{\Delta N_{Rk,0,n}}{\gamma_{fat,n}}$$

In the absence of other national regulations the following safety factors γ_M and $\gamma_{M,fat}$ are recommended for design method I according to EOTA TR 050 and ETA-11/0006:

γ_M = 1,8 (steel)

γ_M = 1,5 (concrete)

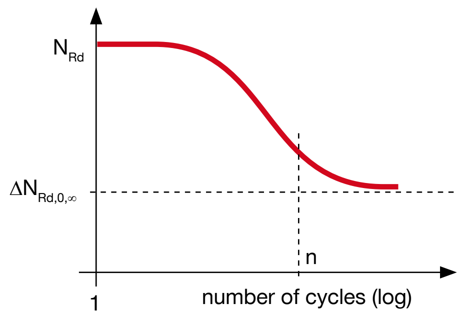
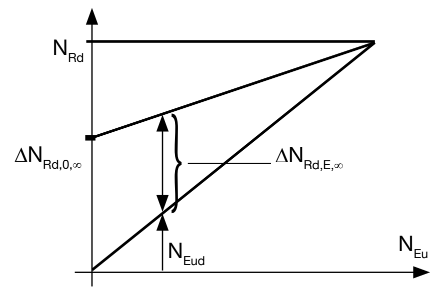
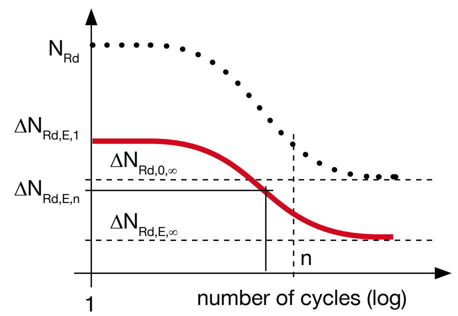
$\gamma_{M,fat}$ = 1,35

In the absence of other national regulations the following safety factor $\gamma_{M,fat}$ is recommended for design method II according to EOTA TR 050 and ETA-11/0006:

$\gamma_{M,fat}$ = 1,35

Each failure mode i.e. steel failure, concrete cone failure and pull-out shall be verified separately.

The design of anchor channels with fatigue influence should be designed with the concept provided in the following table.

Step		Result	Comment
1	S-N curves for design fatigue resistances developed with zero or low minimum cyclic load		S-N curves can be determined for each failure mode. At a minimum, the value of the fatigue limit resistance, $\Delta N_{Rd,0,oo}$ shall be determined
2	Goodman-diagram developed for selected nr. of load cycles, n		The Goodman diagram allows to establish the fatigue resistance $\Delta N_{Rd,E,n}$ in relation to the lower cyclic load, N_{Eud} for given number of load cycles, n
3	Converted S-N curves under pulsating stress (N_{Eud} > 0)		The conversion of the S-N curves developed with zero or low minimum (lower) cyclic load (see step 1) into S-N curves including different (N_{Eud} > 0) lower cyclic load is achieved by means of the Goodman diagram (see step 2) for given number(s) of load cycles, n
4	Design verifications: - Steel failure, Pull-out failure and concrete cone failure		

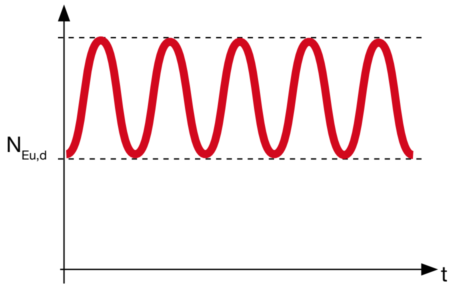
DESIGN METHOD I (COMPLETE/EXACT METHOD)

The exact design methodology usually delivers better results but requires more detailed knowledge of the applied loads. The following three cases are distinguished:

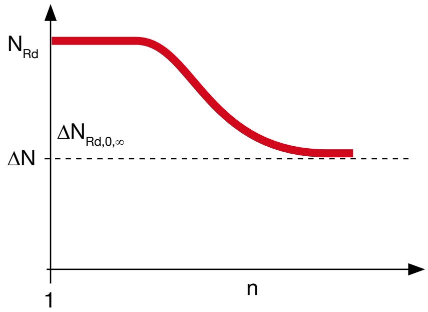
Case-1:

The design value of the lower cyclic load N_{Eud} is known.

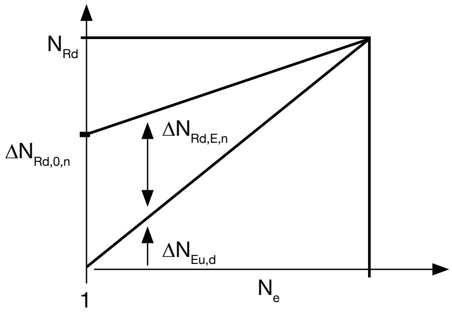
Cycling loading



S-N curve



Goodman diagram



$\Delta N_{Rd;E;n} = \Delta N_{Rd;E;\infty}$

Where

$\Delta_{NRd,E,n}$ = design value of fatigue resistance under combined influence of static and fatigue loads at n load cycles

$\Delta_{NRd,E,\infty}$ = design value of fatigue resistance under combined influence of static and fatigue loads at $n > 10^6$ load cycles

The fatigue resistance used in the design verification is determined using Goodman diagram assuming an infinite number of cycles $n = \infty$, as the load cycles are not known and the appropriate value of the lower cyclic load N_{Eud} in accordance with the following equation:

$$\Delta N_{Rd;E;\infty} = \Delta N_{Rd;0;\infty} \cdot \left(1 - \frac{N_{Eud}}{N_{Rd}}\right)$$

Where

$N_{Ed} = N_{Eud}$ is the applied static load

N_{Rd} design value of static resistance i.e. steel resistance or concrete pull out or concrete cone resistance

$\Delta_{NRd;0;\infty}$ design value of the fatigue resistance without static preload and $n > 10^6$ load cycles. Values should be taken from the current European Technical Assessment (ETA) or technology manual.

where the fatigue effect ΔN_{Ed} is determined as the difference between the upper and the lower cyclic load

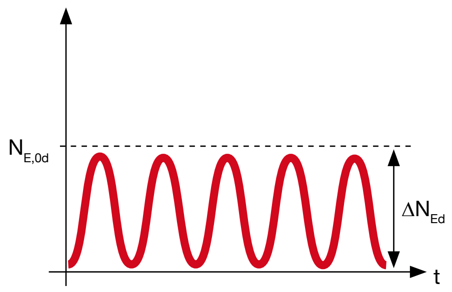
$\Delta N_{Ed} = N_{Eod} - N_{Eud}$

Only the design value of the fatigue-relevant load is taken into account.

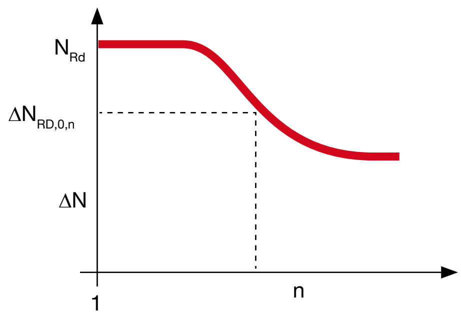
Case-2:

The maximum number of loading cycles n during the entire life is known.

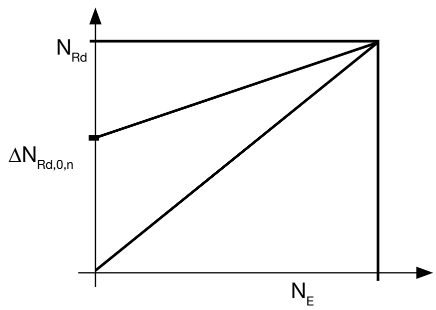
Cycling loading



S-N curve



Goodman diagram



$\Delta N_{Rd;E;n} = \Delta N_{Rd;0;n}$

Where

$\Delta_{NRd,E,n}$ = design value of fatigue resistance under combined influence of static and fatigue loads at n load cycles

$\Delta_{NRd,0,n}$ = design value of fatigue resistance without static preload and given n load cycles as per table xxx (table with fatigue resistance)

The fatigue resistance used in the design verification is taken from S-N curve for the given number of load cycles n and

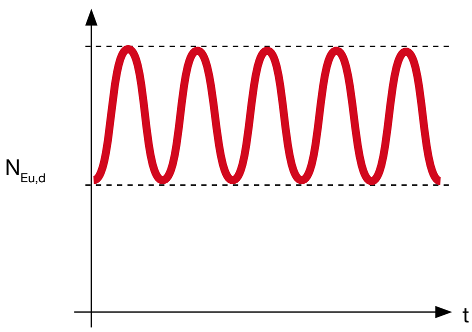
$\Delta N_{Ed} = \Delta N_{Eod}$

Only the design value of the fatigue-relevant load is taken into account.

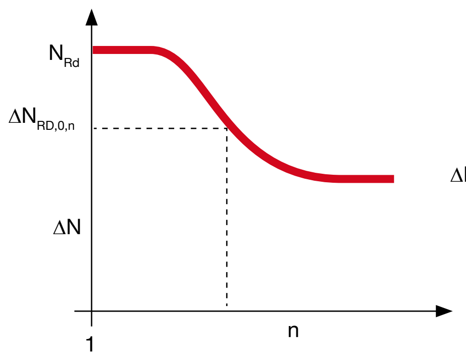
Case-3:

The design value of the lower cyclic load N_{Eud} is available and the maximum number of loading cycles n during the entire life is known.

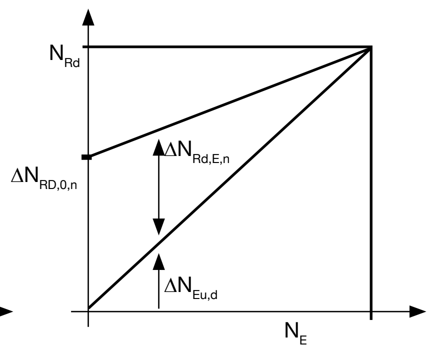
Cycling loading



S-N curve



Goodman diagram



$\Delta N_{Rd;E;n}$

Where

The fatigue resistance used in the design verification is determined using Goodman diagram for the given number of load cycles n and the appropriate value of the lower load N_{Eud} in accordance with equation below:

$$\Delta N_{Rd;E;n} = \Delta N_{Rd;0;n} \cdot \left(1 - \frac{N_{Eud}}{N_{Rd}}\right)$$

$\Delta N_{Ed} = N_{Eod} - N_{Eud}$

Only the design value of the fatigue-relevant load is taken into account.

Required verifications for design:

Design case 1:	
Steel failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;s;E;\infty}} \leq 1.0$
Pullout	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;p;E;\infty}} \leq 1.0$
Concrete cone failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;c;E;\infty}} \leq 1.0$

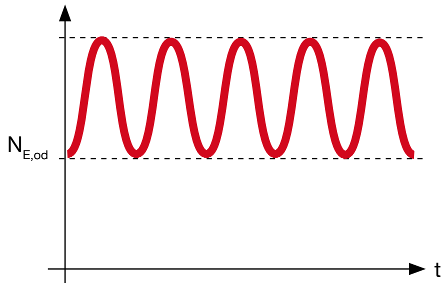
Design case 2:	
Steel failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;s;0;n}} \leq 1.0$
Pullout	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;p;0;n}} \leq 1.0$
Concrete cone failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;c;0;n}} \leq 1.0$

Design case 3:	
Steel failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;s;E;n}} \leq 1.0$
Pullout	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;p;E;n}} \leq 1.0$
Concrete cone failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;c;E;n}} \leq 1.0$

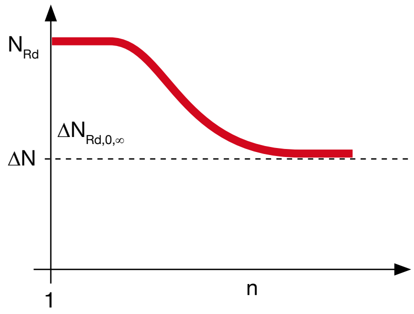
DESIGN METHOD II (SIMPLIFIED METHOD)

Precise allocation of the design value of the lower cyclic load N_{Eud} is not possible and an upper limit to the number of load cycles n over the working life of the anchor channel cannot be predicted.

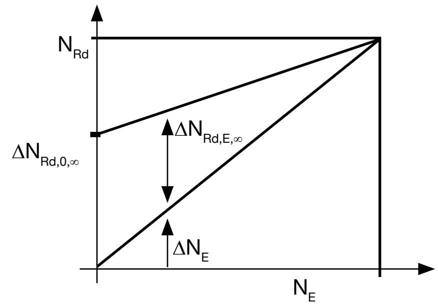
Cycling loading



S-N curve



Goodman diagram



Therefore, the following values shall be used for design:

$\Delta N_{Rd;E;n} = \Delta N_{Rd;0;\infty}$

The fatigue resistance used in the design verification is the design value of fatigue limit resistance with $N_{Eud} = 0$ and

$\Delta N_{Ed} = N_{Eod}$

All acting loads are assumed to be fatigue-relevant

Steel failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;s;0;\infty}} \leq 1.0$
Pullout	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;p;0;\infty}} \leq 1.0$
Concrete cone failure	$\frac{\Delta N_{Ed}}{\Delta N_{Rd;c;0;\infty}} \leq 1.0$

Summary: Anchor channels design under fatigue loading EOTA TR 050

Cases	n cycles	$N_{E.ud}$	Design method	Fatigue relevant load	Fatigue resistance	Required verifications
1	✗	✓	I.	ΔN_{Ed}	$\Delta N_{Rd.E.n} = \Delta N_{Rd.E.\infty}$	$\Delta N_{Ed} / \Delta N_{Rd.s.E.\infty} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.p.E.\infty} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.c.E.\infty} \leq 1.0$
2	✓	✗	I.	All acting loads	$\Delta N_{Rd.E.n} = \Delta N_{Rd.0.n}$	$\Delta N_{Ed} / \Delta N_{Rd.s.0.n} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.p.0.n} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.c.0.n} \leq 1.0$
3	✓	✓	I.	ΔN_{Ed}	$\Delta N_{Rd.E.n}$	$\Delta N_{Ed} / \Delta N_{Rd.s.E.n} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.p.E.n} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.c.E.n} \leq 1.0$
4	✗	✗	II.	All acting loads	$\Delta N_{Rd.E.n} = \Delta N_{Rd.0.\infty}$	$\Delta N_{Ed} / \Delta N_{Rd.s.0.\infty} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.p.0.\infty} \leq 1.0$ $\Delta N_{Ed} / \Delta N_{Rd.c.0.\infty} \leq 1.0$

FIRE LOADS

The verification of anchor channels under fire exposure shall include all the failure modes i.e. steel and concrete. The relevant requirements of EN 1992-1-2 e.g. partial factors and load combinations shall be observed. The characteristic resistances under fire exposure should be taken from the current European Technical Assessment (ETA) or from this document in the respective sections

The fire resistance is classified according to EN 13501-2 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 given in EN 1992-4. 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 shall be prevented by appropriate measures taken into account in the design.

Partial factors

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

NOTE
The recommended value is $\gamma_{M,fi}$ = 1,0 for steel failure and concrete related failure modes under shear loading. For concrete related failure modes under tension $\gamma_{M,fi}$ = 1,0 x γ_{inst}

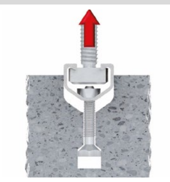
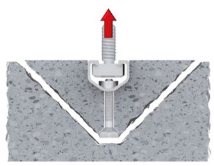
Actions

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

STEEL FAILURE MODES UNDER FIRE LOADS

VERIFICATIONS UNDER TENSION LOADS

Steel failure modes			
Steel failure of bolt	**Local flexure of channel lips**	**Connection between anchor and channel**	**Steel failure of anchor**
			
$N_{Rd,s,fi} = \frac{N_{Rk,s,fi}}{\gamma_{M,fi}}$	$N_{Rd,s,l,fi} = \frac{N_{Rk,s,l,fi} \cdot \psi_{l,N}}{\gamma_{M,fi}}$	$N_{Rd,s,c,fi} = \frac{N_{Rk,s,c,fi}}{\gamma_{M,fi}}$	$N_{Rd,s,a,fi} = \frac{N_{Rk,s,a,fi}}{\gamma_{M,fi}}$

Concrete failure modes	
Pull-out	**Concrete cone failure**
	
$N_{Rk,p,fi}$ = 0.25 x $N_{Rk,p}$ for fire exposure up to 90 minutes $N_{Rk,p,fi}$ = 0.20 x $N_{Rk,p}$ for fire exposure 90 - 120 minutes	$N^0_{Rk,c,fi} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$ for fire exposure up to 90 minutes $N^0_{Rk,c,fi} = 0.8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$ for fire exposure 90 - 120 minutes

CONCRETE FAILURE MODES UNDER FIRE LOADS

Pull-out failure

The characteristic resistance of anchor channels installed in concrete classes C20/25 to C50/60 may be obtained from equations:

$N_{Rk,p,fi}$ = 0.25 x $N_{Rk,p}$ for fire exposure up to 90 minutes

$N_{Rk,p,fi}$ = 0.20 x $N_{Rk,p}$ for fire exposure between 90 minutes and 120 minutes

where

$N_{Rk,p}$ is the characteristic resistance for pull-out failure given in the current European Technical Assessment (ETA) in cracked concrete C20/25 under ambient temperature

Hence final equations are:

for fire exposure up to 90 minutes

$$N_{Rd,p,fi} = \left(\frac{5 \cdot k_2 \cdot A_h}{\gamma_{Mc,fi}}\right)$$

for fire exposure between 90 and 120 minutes

$$N_{Rd,p,fi} = \left(\frac{4 \cdot k_2 \cdot A_h}{\gamma_{Mc,fi}}\right)$$

k_2 and A_h values from the current European Technical Assessment (ETA)

Concrete cone failure

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

Which is same equation as given on page 13 for concrete cone failure.

The characteristic resistance of an anchor of anchor channels $N^0_{Rk,c,fi}$ not influenced by neighboring anchors or concrete edges installed in concrete strength classes C20/25 to C50/60 may be obtained according to equations:

for fire exposure up to 90 minutes

$$N^0_{Rk,c,fi} = \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$$

for fire exposure between 90 and 120 minutes

$$N^0_{Rk,c,fi} = 0.8 \cdot \frac{h_{ef}}{200} \cdot N^0_{Rk,c} \leq N^0_{Rk,c}$$

$N^0_{Rk,c}$ = is the characteristic resistance of a single anchor in cracked concrete C20/25 under ambient temperature

$$N^0_{Rk,c} = 4.472 \cdot k_1 \cdot h_{ef}^{1.5}$$

The characteristic spacing $s_{cr,N}$ and edge distance $c_{cr,N}$ should be taken as follows:

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 \cdot h_{ef}}{180}\right) \cdot h_{ef} \geq 4 \cdot h_{ef}$$

$c_{cr,N}$ = 0.5 x $s_{cr,N}$

Hence final equations are:

for fire exposure up to 90 minutes

$$N_{Rd,c,fi} = \frac{h_{ef} \cdot 0.0223 \cdot k_1 \cdot h_{ef}^{1.5} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N}}{\gamma_{Mc,fi}}$$

for fire exposure between 90 minutes and 120 minutes

$$N_{Rd,c,fi} = \frac{h_{ef} \cdot 0.0178 \cdot k_1 \cdot h_{ef}^{1.5} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N}}{\gamma_{Mc,fi}}$$

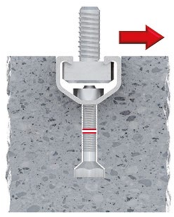
Concrete splitting failure

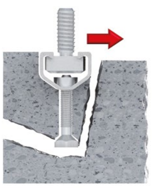
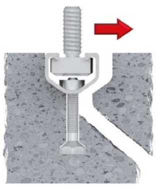
The assessment of concrete splitting failure due to fire exposure is not required because the splitting forces are assumed to be taken up by the reinforcement.

Concrete blow-out failure

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

VERIFICATIONS UNDER SHEAR LOADS

Steel failure modes			
Steel failure of bolt	**Local flexure of channel lips**	**Connection between anchor and channel**	**Steel failure of anchor**
			
$V_{Rd,s,fi} = \frac{V_{Rk,s,fi}}{\gamma_{M,fi}}$	$V_{Rd,s,l,fi} = \frac{V_{Rk,s,l,fi} \cdot \psi_V}{\gamma_{M,fi}}$	$V_{Rd,s,c,fi} = \frac{V_{Rk,s,c,fi}}{\gamma_{M,fi}}$	$V_{Rd,s,a,fi} = \frac{V_{Rk,s,a,fi}}{\gamma_{M,fi}}$

Concrete failure modes	
Pry-out failure	**Concrete edge failure**
	
$V_{Rk,cp,fi} = k_8 \cdot N_{Rk,c,fi}$ for fire exposure up to 90 minutes $V_{Rk,cp,fi} = k_8 \cdot N_{Rk,c,fi}$ for fire exposure 90 - 120 minutes	$V^0_{Rk,c,fi} = 0.25 \text{ x } V^0_{Rk,c}$ for fire exposure up to 90 minutes $V^0_{Rk,c,fi} = 0.20 \text{ x } V^0_{Rk,c}$ for fire exposure 90 - 120 minutes

CONCRETE FAILURE MODES

Pry-out failure

The characteristic resistance in case of anchor channels installed in concrete classes C20/25 to C50/60 should be obtained using equations:

for fire exposure up to 90 minutes

$$V_{Rk,cp,fi} = k_8 \cdot N_{Rk,c,fi}$$

for fire exposure between 90 minutes and 120 minutes

$$V_{Rk,cp,fi} = k_8 \cdot N_{Rk,c,fi}$$

k_8 taken from the current European Technical Assessment (ETA) or technology manual

Hence the final equations are:

for fire exposure up to 90 minutes

$$V_{Rd,cp,fi} = k_8 \cdot \left(\frac{h_{ef} \cdot 0.0223 \cdot k_1 \cdot h_{ef}^{1.5} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N}}{\gamma_{Mc,fi}} \right)$$

for fire exposure between 90 minutes and 120 minutes

$$V_{Rd,cp,fi} = k_8 \cdot \left(\frac{h_{ef} \cdot 0.0178 \cdot k_1 \cdot h_{ef}^{1.5} \cdot \psi_{ch,s,N} \cdot \psi_{ch,e,N} \cdot \psi_{ch,c,N} \cdot \psi_{re,N}}{\gamma_{Mc,fi}} \right)$$

Concrete edge failure

The characteristic resistance of an anchor of an anchor channel installed in concrete classes C20/25 to C50/60 should be obtained using equations on page 22 with the following modifications:

for fire exposure up to 90 minutes

$V^0_{Rk,c,fi} = 0.25 \times V^0_{Rk,c}$

for fire exposure between 90 minutes and 120 minutes

$V^0_{Rk,c,fi} = 0.20 \times V^0_{Rk,c}$

Where

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

$$V^0_{Rk,c} = 4.472 \cdot k_{12} \cdot c_1^{4/3}$$

Hence the final equations are:

for fire exposure up to 90 minutes

$$V_{Rd,c,fi} = \left(\frac{1.118 \cdot k_{12} \cdot c_1^{4/3} \cdot \psi_{ch,s,V} \cdot \psi_{ch,c,V} \cdot \psi_{ch,h,V} \cdot \psi_{ch,90^\circ,V} \cdot \psi_{re,V}}{\gamma_{Mc,fi}} \right)$$

for fire exposure between 90 minutes and 120 minutes

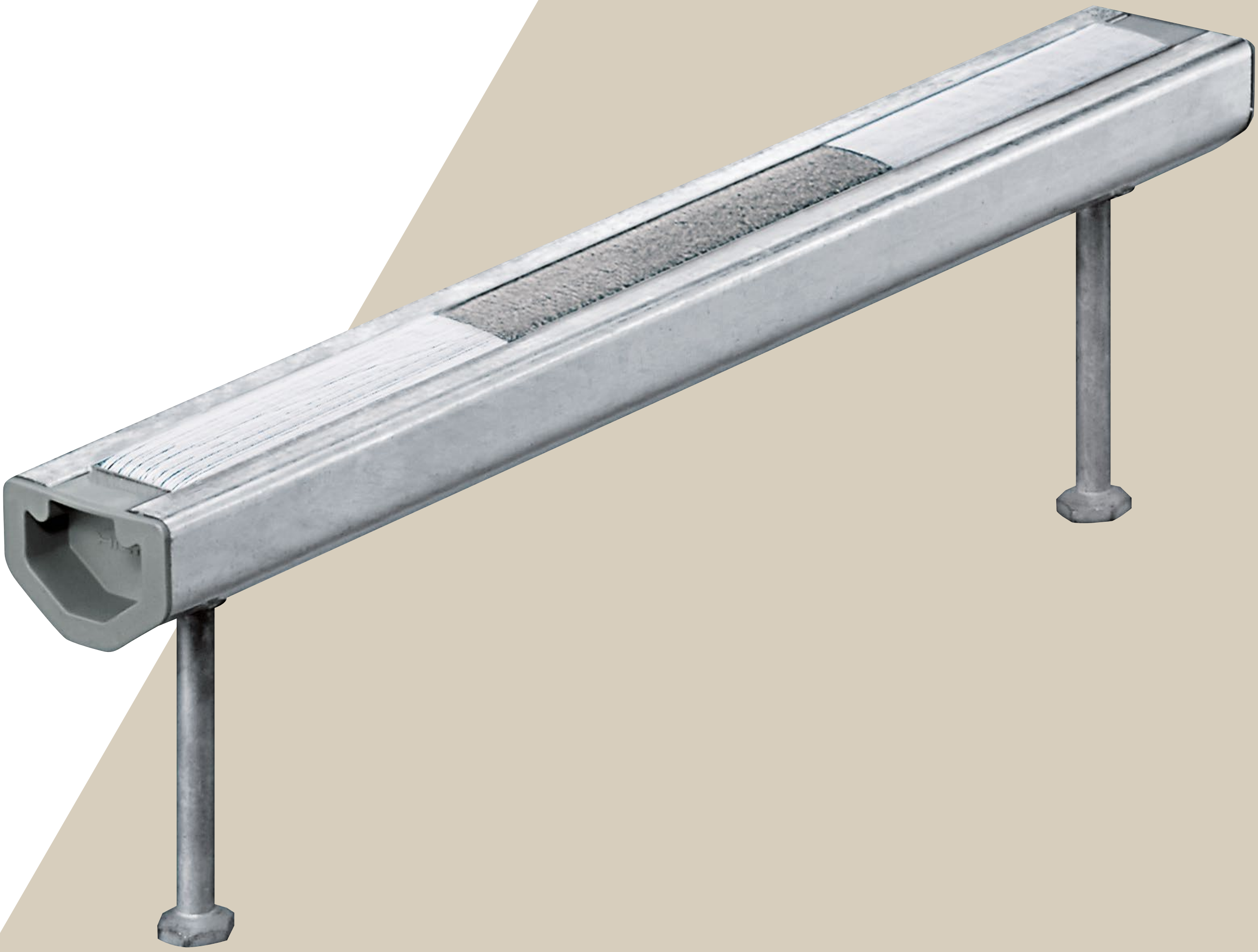
$$V_{Rd,c,fi} = \left(\frac{0.89 \cdot k_{12} \cdot c_1^{4/3} \cdot \psi_{ch,s,V} \cdot \psi_{ch,c,V} \cdot \psi_{ch,h,V} \cdot \psi_{ch,90^\circ,V} \cdot \psi_{re,V}}{\gamma_{Mc,fi}} \right)$$

Combined tension and shear loads under fire

Interaction of tension and shear loads as per page 33 but the design actions and design resistances used in these verifications shall correspond to fire exposure.

HAC ANCHOR CHANNELS

Design examples



DESIGN EXAMPLE 1

Design of standard HAC anchor channel with 3D loading

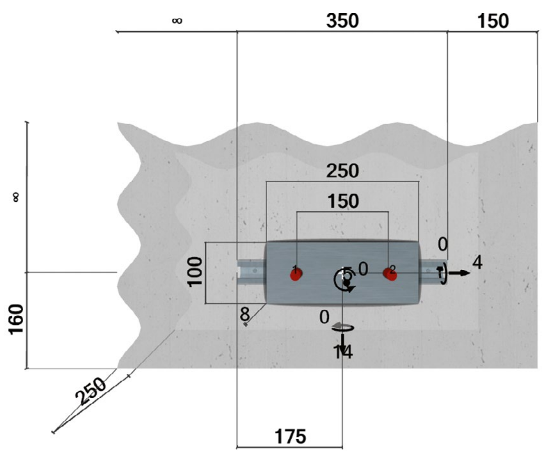
INPUT DATA

Base Material:

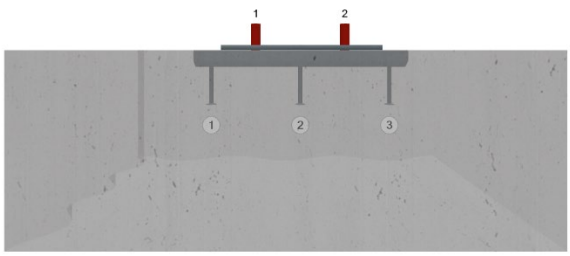
Concrete C30/37, Normal weight concrete
Concrete condition: cracked
Member thickness h = 250 mm
Edge distance c_1 = 160 mm, c_2 =150 mm
Existing reinforcement widely spaced

Design basics:

Standard: Hilti design method based on EN 1992-4.
Longitudinal shear as per EOTA TR047
Annex B/CEN-TR 17080
European Technical Assessment: ETA-11/0006



Top view



Side view

Applied loads:

Tension load N_{Ed} = 5 kN
Shear load $V_{Ed,y}$ = 14 kN
Shear load $V_{Ed,x}$ = 4 kN

Applied loads are on the center of the bracket

Solution

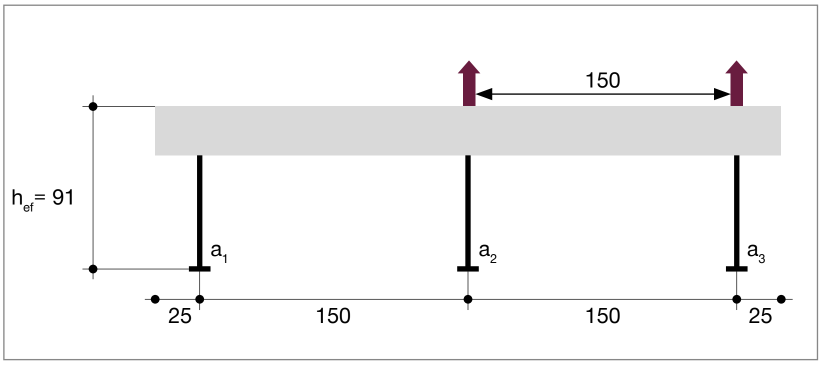
Selected product:
Anchor channel : HAC-40 91/350 F
Channel bolt : HBC-C-N 8.8F, M16 x 50 mm (notching bolt)

DESIGN STEPS

1.Calculation of bolt forces

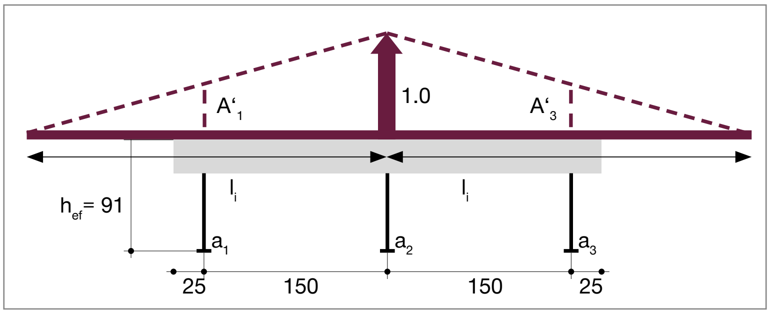
Bolt	N^{cb}_{Ed} [kN]	$V^{cb}_{Ed,y}$ [kN]	$V^{cb}_{Ed,x}$ [kN]
1	2.5	7.0	2.0
2	2.5	7.0	2.0

2. Calculation of anchor forces

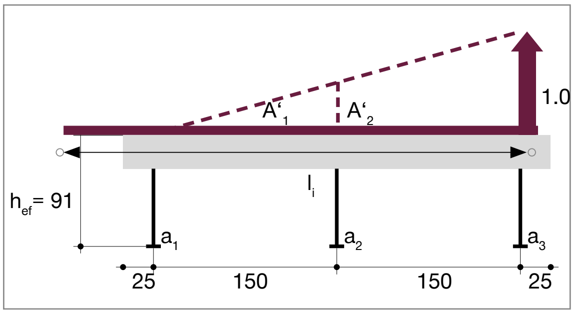


Critical load position on anchor channel

Influence length:
$l_i = 13 \times I_y^{0.05} \times s^{0.5}$
$l_i = 13 \times 21463^{0.05} \times 150^{0.5}$
$l_i = 262$ mm



Anchor load due to bolt 1



Anchor load due to bolt 2

Anchor forces tension N and perpendicular shear V_y

	Anchor a_1	Anchor a_2	Anchor a_3
Load 1 distance from anchor [mm]	150	0	150
$A'_i = (l_i - s)/l_i$	(262 - 150)/262 = 0.43	(262 - 150)/262 = 0.43	(262 - 0)/262 =1.0
$k = \frac{1}{\sum A'_i}$		k = 1/ (1+ 0.43) = 0.70	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,1}$	0.70 x 0 x 2.5 = **0 kN**	0.70 x 0.43 x 2.5 = **0.75 kN**	0.70 x 1.0 x 2.5 = **1.75 kN**
Load 2 distance from anchor [mm]	300	150	0
$A'_i = (l_i - s)/l_i$	(262 - 300)/262 = 0	(262 - 0)/262 = 1.0	(262 - 150)/262 = 0.43
$k = \frac{1}{\sum A'_i}$		k = 1/ (0.43 + 1.0 + 0.43) = 0.54	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,2}$	0.54 x 0.43 x 2.5 = **0.58 kN**	0.54 x 1.0 x 2.5 = **1.35 kN**	0.54 x 0.43 x 2.5 = **0.58 kN**
Sum of anchor loads N^a_{Ed}	**0 + 0.58 = 0.58 kN**	**0.75 + 1.35 = 2.1 kN**	**1.75 + 0.58 = 2.33 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,1}$	0.70 x 0 x 7.0 = **0 kN**	0.70 x 0.43 x 7.0 = **2.09 kN**	0.70 x 1.0 x 7.0 = **4.90 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,2}$	0.54 x 0.43 x 7.0 = **1.62 kN**	0.54 x 1.0 x 7.0 = **3.78 kN**	0.54 x 0.43 x 7.0 = **1.62 kN**
Sum of anchor loads V^a_{Ed}	**0 + 1.62 = 1.62 kN**	**2.09 + 3.78 = 5.87 kN**	**4.90 + 1.62 = 6.52 kN**

Anchor forces longitudinal shear V_x (EOTA TR 047 Annex B)

Applied load on anchor channel in x-direction [kN]	Anchor a_1	Anchor a_2	Anchor a_3
4	1.33	1.33	1.33

3. Verifications

Tension loading summary

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Anchor	2.33	18.39	13	Ok
Connection anchor-channel	2.33	13.89	17	Ok
Channel lip	2.5	13.89	18	Ok
Channel bolt	2.5	83.73	3	Ok
Flexure channel	N/A	N/A	N/A	N/A
Pull-out	2.33	31.33	8	Ok
Concrete cone	2.33	14.74	16	Ok

3.1 Steel failure (EN 1992-4 section 7.4.1.3)

3.1.1 Anchor (Anchor a_3)

$$N^{a}_{Ed} \leq N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$$

$N^{a}_{Ed} = 2.33$ kN $\quad N_{Rk,s,a} = 33.1$ kN $\quad \gamma_{Ms} = 1.8 \quad N_{Rd,s,a} = 18.39$ kN

$$\beta_{N,s,a} = \frac{2.33}{18.39} = 13\%$$

3.1.2 Connection between anchor and channel (Anchor a_3)

$$N^{a}_{Ed} \leq N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$$

$N^{a}_{Ed} = 2.33$ kN $\quad N_{Rk,s,c} = 25$ kN $\quad \gamma_{Ms,ca} = 1.8 \quad N_{Rd,s,c} = 13.89$ kN

$$\beta_{N,s,c} = \frac{2.33}{13.89} = 17\%$$

3.1.3 Local flexure of channel lip (bolt 1)

$$N^{cb}_{Ed} \le N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}} \qquad N_{Rk,s,l} = N^0_{Rk,s,l} \times \psi_{l,N}$$

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \le 1.0$$

s_{cbo} = 150 mm (given bolt spacing)

$\psi_{l,N}$ = 82 mm

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{150}{82}\right) = 1.0$$

N^{cb}_{Ed} = 2.50 kN	$N^0_{Rk,s,l}$ =25 kN
$N_{Rk,s,l}$ =25 kN	$\gamma_{Ms,l}$ = 1.8
$N_{Rd,s,l}$=13.89 kN	

$$\beta_{N,s,l} = \frac{2.5}{13.89} = 18\%$$

3.1.4 Channel bolt (bolt 1)

$$N^{cb}_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$$

N^{cb}_{Ed} = 2.50 kN	$N_{Rk,s,}$=125.6 kN
γ_{Ms} = 1.5	$N_{Rd,s,}$=83.73 kN

$$\beta_{N,s} = \frac{2.5}{83.733} = 3\%$$

3.2 Concrete failure

3.2.1 Pull-out failure (Anchor a_3) (EN 1992-4 section 7.4.1.4)

$$N^a_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$$

$$N_{Rk,p} = k_2 \times A_h \times f_{ck}$$

A_h = 209 mm2	k_2 = 7.5
f_{ck} = 30 MPa	N^a_{Ed} = 2.33 kN
$N_{Rk,p}$ = 47 kN	γ_{Mp}= 1.5
$N_{Rd,p}$ = 31.33 kN	

$$\beta_{N,p} = \frac{2.33}{31.33} = 8\%$$

3.2.2 Concrete cone failure (Anchor a_3)

(EN 1992-4 section 7.4.1.5)

$$N^a_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$

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

$$N^0_{Rk,c} = k_1 \times \sqrt{f_{ck}} \times h_{ef}^{1.5}$$

$$N^0_{Rk,c} = 8.0 \times \sqrt{30} \times 91^{1.5} = 38.04 \text{ kN}$$

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}}\right) \cdot \frac{N_i}{N_0}\right]} \le 1.0$$

$$\psi_{ch,s,N} = \frac{1}{1 + \left(1 - \frac{150}{390}\right)^{1.5} \cdot \frac{2.1}{2.33} + \left(1 - \frac{300}{390}\right)^{1.5} \cdot \frac{0.58}{2.33}} = 0.68$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 h_{ef}}{180}\right) \cdot h_{ef} \ge 3 h_{ef}$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 \times 91}{180}\right) \cdot 91 = 390\text{mm}$$

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \le 1.0$$

$c_{cr,N}$ = critical edge distance i.e. 0.5 $s_{cr,N}$ ≥ 1.5h_{ef}

$c_{cr,N}$ = 0.5 x 390 = 195 mm ≥ 136.5 mm

$$\psi_{ch,e,N} = \left(\frac{160}{195}\right)^{0.5} = 0.90$$

$$\psi_{ch,c,N,1} = \left(\frac{c_{2,1}}{c_{cr,N}}\right)^{0.5} \le 1.0$$

$$\psi_{ch,c,N,1} = \left(\frac{175}{195}\right)^{0.5} = 0.96$$

$$\psi_{ch,c,N,2} = \left(\frac{c_{2,2}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{2,2} \text{ given)}$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \le 1.0$$

$$N_{Rk,c} = 38.04 \times 0.68 \times 0.90 \times 0.96 \times 1.0 = 22.35\text{kN}$$

k_1 = 8.0	f_{ck} = 30 MPa
h_{ef} = 91 mm	$N^0_{Rk,c}$= 38.04 kN
s= 150 mm	$s_{cr,N}$ = 390 mm
$\psi_{ch,s,N}$ = 0.68	c_1 = 160 mm
$c_{cr,N}$ = 195 mm	$\psi_{ch,e,N}$ = 0.90
c_2 = 175 mm	$\psi_{ch,e,N,1}$ = 0.96
$\psi_{ch,e,N,2}$ = 1.0	$\psi_{re,N}$ = 1.0
N^a_{Ed} = 2.33 kN	$N_{Rk,c}$ = 22.35 kN
γ_{Mc}= 1.5	$N_{Rd,p}$ = 14.90 kN

$$\beta_{N,c} = \frac{2.33}{14.9} = 16\%$$

Shear loading summary

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Channel bolt w/o lever arm	7.28	50.24	15	Ok
Flexure channel lip w/o lever arm perpendicular	7.00	13.89	51	Ok
Flexure channel lip w/o lever arm longitudinal	2.00	7.82	26	Ok
Anchor perpendicular	6.52	13.89	47	Ok
Anchor longitudinal	1.33	12.27	11	Ok
Connection anchor-channel perp.	6.52	13.89	47	N/A
Connection anchor-channel long.	1.33	6.94	20	Ok
Concrete pry out perpendicular	6.52	29.50	22	Ok
Concrete pry out longitudinal	1.33	23.28	6	Ok
Concrete edge perpendicular	6.52	7.70	85	Ok
Concrete edge longitudinal	4.00	14.37	28	Ok

3.3 Steel failure (EN 1992-4 section 7.4.2.3, longitudinal shear as per EOTA TR 047 Annex B section B6.2.2.2)

3.3.1 Channel bolt

$$V^{cb}_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$

$$V^{cb}_{Ed} = \sqrt{\left[\left(V^{cb}_{Ed,x}\right)^2 + \left(V^{cb}_{Ed,y}\right)^2\right]}$$

$$V^{cb}_{Ed} = \sqrt{(2)^2 + (7)^2} = 7.28 \text{ kN}$$

$V^{cb}_{Ed,y}$ = 7.0 kN $\quad$ $V^{cb}_{Ed,x}$ = 2.0 kN

$V_{Rk,s,}$ = 62.8 kN $\quad$ γ_{Ms} = 1.25

$V_{Rd,s,}$ = 50.24 kN

$$\beta_{V,s} = \frac{7.28}{50.24} = 15\%$$

3.3.2 Local flexure of channel lips- shear perpendicular w/o lever arm (EN 1992-4 section 7.4.2.3)

$$V^{cb}_{Ed,y} \leq V_{Rd,s,l,y} = \frac{V_{Rk,s,l,y}}{\gamma_{Ms,l}}$$

$$V_{Rk,s,l,y} = V^{0}_{Rk,s,l,y} \times \psi_{l,v}$$

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

s_{cbo} = 150 mm (bolt spacing) $\quad$ $s_{l,v}$ = 82 mm

$$\psi_{l,v} = 0.5\left(1 + \frac{150}{82}\right) = 1.0$$

$V_{cbEd,y}$ = 7.0 kN $\quad$ $V^{0}_{Rk,s,l,y}$ = 34.9 kN

$V_{Rk,s,l,y}$ = 34.9 kN $\quad$ $\gamma_{Ms,l,y}$ = 1.8

$V_{Rd,s,l,y}$ = 13.89 kN

(taken same as $N_{Rd,s,l}$ for quadratic interaction)

$$\beta_{V,s,l,y} = \frac{7.0}{13.89} = 51\%$$

3.3.3 Local flexure of channel lips- shear longitudinal w/o lever arm (Longitudinal shear as per EOTA TR 047 Annex B, section B 6.2.2.2.4)

$$V^{cb}_{Ed,x} \leq V_{Rd,s,l,x} = \frac{V_{Rk,s,l,x}}{\gamma_{Ms,l,x}}$$

$$V_{Rk,s,l,x} = V^{0}_{Rk,s,l,x} \times \psi_{l,v}$$

$\psi_{l,v}$ = 1.0 $\quad$ $\gamma_{Ms,l,x}$= 1.4x1.8 = 2.52

$V^{cb}_{Ed,x}$ = 2.0 kN $\quad$ $V^{0}_{Rk,s,l,x}$ = 19.7 kN

$V_{Rk,s,l,x}$ = 19.7 kN $\quad$ $\gamma_{Ms,l}$ = 1.8

γ_{ins} = 1.4 $\quad$ $V_{Rd,s,l,x}$ = 7.82 kN

$$\beta_{V,s,l,x} = \frac{2.0}{7.82} = 26\%$$

3.3.4 Anchor-shear perpendicular (Anchor a_3) (EN 1992-4 section 7.4.2.3)

$$V^a{}_{Ed,y} \le V_{Rd,s,a,y} = \frac{V_{Rk,s,a,y}}{\gamma_{Ms}}$$

$V^a{}_{Ed,y}$ = 6.52 kN $\quad$ $V_{Rk,s,a,y}$ = 33.1 kN

γ_{Ms} = 1.5 $\quad$ $V_{Rd,s,a,y}$ =13.89 kN

(same as tension capacity for quadratic interaction)

$$\beta_{V,s,a,y} = \frac{6.52}{13.89} = 47\%$$

3.3.5 Anchor-shear longitudinal (Anchor a_3) (Longitudinal shear as per EOTA TR 047 Annex B, section B 6.2.2.2.2)

$$V^a{}_{Ed,x} \le V_{Rd,s,a,x} = \frac{V_{Rk,s,a,x}}{\gamma_{Ms}}$$

$V^a{}_{Ed,x}$ = 1.33 kN $\quad$ $V_{Rk,s,a,x}$ = 18.4 kN

γ_{Ms} = 1.5 $\quad$ $V_{Rd,s,a,x}$ = 12.27 kN

$$\beta_{V,s,a,x} = \frac{1.33}{12.27} = 11\%$$

3.3.6 Connection between anchor and channel - shear perpendicular (Anchor a1) (EN 1992-4 section 7.4.2.3)

$$V^a{}_{Ed,y} \le V_{Rd,s,c,y} = \frac{V_{Rk,s,c,y}}{\gamma_{Ms}}$$

$V^a{}_{Ed,y}$ = 6.52 kN $\quad$ $V_{Rk,s,c,y}$ = 39.6 kN

$\gamma_{Ms,ca}$ = 1.8 $\quad$ $V_{Rd,s,c,y}$ = 13.89 kN

(same as tension capacity for quadratic interaction)

$$\beta_{V,s,c,y} = \frac{6.52}{13.89} = 47\%$$

3.3.7 Connection between anchor and channel - shear longitudinal (Anchor a_3) (Longitudinal shear as per EOTA TR 047 Annex B, section B 6.2.2.2.3)

$$V^a{}_{Ed,x} \le V_{Rd,s,c,x} = \frac{V_{Rk,s,c,x}}{\gamma_{Ms,ca}}$$

$V^a{}_{Ed,y}$ = 1.33 kN $\quad$ $V_{Rk,s,c,x}$ = 12.50 kN

$\gamma_{Ms,ca}$ = 1.8 $\quad$ $V_{Rd,s,c,x}$ = 6.94 kN

$$\beta_{V,s,c,x} = \frac{1.33}{6.94} = 20\%$$

3.4 Concrete failure

3.4.1 Concrete pry-out failure – shear perpendicular (Anchor a3) (EN 1992-4 section 7.4.2.4)

$$V^a{}_{Ed,y} \le V_{Rd,cp,y} = \frac{V_{Rk,cp,y}}{\gamma_{Mc}}$$

$$V_{Rk,cp,y} = k_8 \times N_{Rk,c}$$

$N_{Rk,c}$ taken from section 3.2.2

$N_{Rk,c}$ = 22.35 kN

$$V_{Rk,cp,y} = 2 \times 22.35 = 44.7\text{kN}$$

K_8 = 2.0 $\quad$ $V^a{}_{Ed,y}$ = 6.52 kN

$N_{Rk,c}$ = 22.35 kN $\quad$ $V_{Rk,cp,y}$ = 44.7 kN

γ_{Mc} = 1.5 $\quad$ $V_{Rd,cp,y}$ = 29.80 kN

$$\beta_{V,cp,y} = \frac{6.52}{29.8} = 22\%$$

3.4.2 Concrete pry-out failure – shear longitudinal (Anchor a_2) (Longitudinal shear as per EOTA TR 047 Annex B, section B 6.2.2.3)

$$V^a{}_{Ed,x} \le V_{Rd,cp,x} = \frac{V_{Rk,cp,x}}{\gamma_{Mc}}$$

$$V_{Rk,cp,x} = k_8 \times N_{Rk,c}$$

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

$$N^0{}_{Rk,c} = k_1 \times \sqrt{f_{ck}} \times h_{ef}{}^{1.5}$$

$$N^0{}_{Rk,c} = 8.0 \times \sqrt{30} \times 91^{1.5} = 38.04 \text{ kN}$$

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}}\right) \cdot \frac{N_i}{N_0}\right]} \le 1.0$$

$$\psi_{ch,s,N} = \frac{1}{1 + \left(1 - \frac{150}{390}\right)^{1.5} \cdot \frac{1.33}{3.33} + \left(1 - \frac{150}{390}\right)^{1.5} \cdot \frac{1.33}{1.33}} = 0.51$$

Remark: Need to check for which anchor this factor is critical in this case anchor 2 gives a critical result as compared to anchor 3 although anchor 3 is closer to edge

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3h_{ef}}{180}\right) \cdot h_{ef} \ge 3h_{ef}$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 \cdot 91}{180}\right) \cdot 91 = 390\text{mm}$$

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \le 1.0$$

$c_{cr,N}$ = critical edge distance i.e. 0.5 $s_{cr,N} \ge 1.5h_{ef}$

$c_{cr,N}$ = 0.5 x 390 = 195 mm ≥ 136.5 mm

$$\psi_{ch,e,N} = \left(\frac{325}{195}\right)^{0.5} = 1.0$$

$$\psi_{ch,c,N,1} = \left(\frac{c_{2,1}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (as now } c_{2,1} \text{ given)}$$

$$\psi_{ch,c,N,2} = \left(\frac{c_{2,2}}{c_{cr,N}}\right)^{0.5} \le 1.0$$

$$\psi_{ch,c,N,2} = \left(\frac{160}{195}\right)^{0.5} = 0.90$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \le 1.0$$

$$N_{Rk,c} = 38.04 \times 0.51 \times \cdot 1.0 \times 0.90 \times 1.0 = 17.46 \text{ kN}$$

$$V_{Rk,cp,x} = 2 \times 17.46 = 34.92 \text{kN}$$

k_1 = 8.0	f_{ck} = 30 MPa
h_{ef} = 91 mm	$N^0_{Rk,c}$ = 38.04 kN
s= 150 mm	$s_{cr,N}$ = 390 mm
$\psi_{ch,s,N}$ = 0.51	c_1 = 325 mm
$c_{cr,N}$ = 195 mm	$\psi_{ch,e,N}$ = 1.0
c_2 = 160 mm	$\psi_{ch,e,N,1}$ = 1.0
$\psi_{ch,e,N,2}$ = 0.90	$\psi_{re,N}$ = 1.0
$V^a_{Ed,x}$ = 1.33 kN	k_8 = 2.0
$N_{Rk,c}$ = 17.46 kN	γ_{Mc}= 1.5
$V_{Rk,cp,x}$ = 34.92 kN	$V_{Rd,cp,x}$ = 23.28 kN

$$\beta_{V,cp,x} = \frac{1.33}{23.28} = 6\%$$

3.4.3 Concrete edge failure – shear perpendicular (Anchor a3) (EN 1992-4 section 7.4.2.5)

$$V^a_{Ed,y} \le V_{Rd,c,y} = \frac{V_{Rk,c,y}}{\gamma_{Mc}}$$

$$V_{Rk,c,y} = V^0_{Rk,c} \times \psi_{ch,s,V} \times \psi_{ch,c,V,1} \times \psi_{ch,c,V,2} \times \psi_{ch,h,V} \times \psi_{ch,90^\circ,V} \times \psi_{re,V}$$

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

$$V^0_{Rk,c} = 7.5 \times \sqrt{30} \times 160^{4/3} = 35.68 \text{ kN}$$

$$\psi_{ch,s,V} = \frac{1}{1 + \sum_{i=1}^{n_{ch,V}} \left[\left(1 - \frac{s_i}{s_{cr,V}}\right)^{1.5} \cdot \frac{V_i}{V_0}\right]} \le 1.0$$

$$\psi_{ch,s,V} = \frac{1}{1 + \left(1 - \frac{150}{722}\right)^{1.5} \cdot \frac{5.87}{6.52} + \left(1 - \frac{300}{722}\right)^{1.5} \cdot \frac{1.62}{6.52}} = 0.57$$

$s_{cr,V}$ = 4 c_1 + 2 b_{ch}

$s_{cr,V}$ = 4 x160 + 2 x 41 =722 mm

$c_{cr,v}$ = 0.5 $s_{cr,V}$

$c_{cr,v}$ = 0.5 x 722 =361 mm

$$\psi_{ch,c,V} = \left(\frac{c_{2,1}}{c_{cr,V}}\right)^{0.5} \le 1.0$$

$$\psi_{ch,c,V,1} = \left(\frac{175}{361}\right)^{0.5} = 0.70$$

$$\psi_{ch,c,V,2} = \left(\frac{c_{2,2}}{c_{cr,V}}\right)^{0.5} = 1.0 \text{ (no c2,2 given)}$$

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0.5} \le 1.0$$

$$h_{cr,V} = 2c_1 + 2h_{ch}$$

$$h_{cr,V} = 2 \times 160 + 2 \times 28 = 376 \text{ mm}$$

$$\psi_{ch,h,V} = \left(\frac{250}{360}\right)^{0.5} = 0.81$$

$$V_{Rk,c,y} = 35.68 \times 0.57 \times 0.70 \times 1.0 \times 0.81 \times 1.0 \times 1.0 = 11.53 \text{ kN}$$

k_{12} = 7.5	f_{ck} = 30 MPa
c_1 = 160 mm	c_2 = 175 mm
$V^0_{Rk,c}$= 35.68 kN	s = 150 mm
$s_{cR,V}$ = 722 mm	$\psi_{ch,s,V}$ = 0.57
$c_{cr,V}$ = 361 mm	$\psi_{ch,c,V,1}$ = 0.70
$\psi_{ch,c,V,2}$ = 1.0	h = 250 mm
$h_{vr,V}$ = 276 mm	$\psi_{ch,h,V}$ = 0.81
$\psi_{ch,90°,V}$ = 1.0	$\psi_{re,V}$ = 1.0
$V^a_{Ed,y}$ = 6.52 kN	$V_{Rk,c,y}$ = 11.53 kN
γ_{Mc}= 1.5	$V_{Rd,c,y}$ = 7.70 kN

$$\beta_{V,c,y} = \frac{6.52}{7.70} = 85\%$$

3.4.4 Concrete edge failure – shear longitudinal direction x+ (Anchor a_3) (Longitudinal shear as per EOTA TR 047 Annex B, section B 6.2.2.4)

$$V^a_{Ed,x} \le V_{Rd,c,x} = \frac{V_{Rk,c,x}}{\gamma_{Mc}}$$

$$V_{Rk,c,x} = V^0_{Rk,c} \times \frac{A_{c,V}}{A^0_{c,V}} \times \psi_{s,V} \times \psi_{h,V} \times \psi_{re,V}$$

$$V^0_{Rk,c} = k_9 \times d_a^{\alpha} \times h_{ef}^{\beta} \times \sqrt{f_{ck}} \times c_1^{1.5}$$

$A_{c,V}$ = h(1.5c_1 + 1.5c_1), if c_2 is less than 1.5c_1 then take c_2

h = 1.5c_1 if h < 1.5c_1 then take h

h=1.5 x 175 = 262.5 mm > 250 mm (slab thickness) = 250 mm

$A_{c,V}$ = 250(1.5 x 175 + 160) = 105625 mm^2

$A^0_{c,V}$ = 4.5 x 1752 =137813 mm^2

$$\alpha = 0.1 \cdot \left(\frac{h_{ef}}{c_1}\right)^{0.5}$$

$$\alpha = 0.1 \cdot \left(\frac{86}{175}\right)^{0.5} = 0.07$$

$$\beta = 0.1 \cdot \left(\frac{d_a}{c_1}\right)^{0.2}$$

$$\beta = 0.1 \cdot \left(\frac{7.2}{175}\right)^{0.2} = 0.053$$

$$V^0_{Rk,c} = 1.7 \times 7.2^{0.07} \times 86^{0.053} \times \sqrt{30} \times 175^{1.5} = 31.34 \text{ kN}$$

$$\psi_{s,V} = 0.7 + 0.3 \cdot \frac{c_2}{1.5c_1} \leq 1.0$$

$$\psi_{s,V} = 0.7 + 0.3 \cdot \frac{160}{1.5 \cdot 175} = 0.88$$

$$\psi_{h,V} = \left(\frac{1.5 \cdot c_1}{h}\right)^{0.5} \geq 1.0$$

$$\psi_{h,V} = \left(\frac{1.5 \cdot 175}{250}\right)^{0.5} = 1.02$$

$$V_{Rk,c,x} = 31.34 \times \frac{105625}{137813} \times 0.88 \times 1.02 \times 1.0 = 21.56\text{kN}$$

K_9 = 1.7	d_a = 7.2 mm
h_{ef}= 86 mm (≤ 12da)	f_{ck} = 30 MPa
α = 0.07	β = 0.07
c_1 = 175 mm	c_2 = 160 mm
$V^0_{Rk,c}$= 31.34 kN	$A_{c,V}$ = 105625 mm^2
$A^0_{c,V}$ = 137813 mm^2	$\psi_{s,V}$ = 0.88
h = 250 mm	$\psi_{h,V}$ = 1.02
$\psi_{re,V}$ = 1.0	$V^a_{Ed,x}$ = 4.0 kN
$V_{Rk,c,x}$ = 21.56 kN	γ_{Mc} = 1.5
$V_{Rd,c,x}$ = 14.37 kN	

$$\beta_{V,c,x} = \frac{4.0}{14.37} = 28\%$$

3.5 Combined tension and shear loads (EN 1992-4 section 8.3.3, longitudinal shear as per EOTA TR047 Annex B Section B.6.3)

3.5.1 Channel bolt (bolt 1)

$$\beta_{N+V,s} = \left(\beta_{N,s}\right)^2 + \left(\beta_{V,s}\right)^2 \leq 1.0$$

$$\beta_{N+V,s} = \left(0.03\right)^2 + \left(0.15\right)^2 = 0.03$$

Utilization = 3%

3.5.2 Point of load application – channel lip (bolt 1)

$$\beta_{N+V,la,c} = \left(\beta_{N,s,l}\right)^{k_{13}} + \left(\beta_{V,s,l,y}\right)^{k_{13}} \leq \left(1 - \beta_{V,s,l,x}\right)^{k_{13}}$$

k_{13} = 2.0 if $V_{Rd,s,l}$ ≤ $N_{Rd,s,l}$

$$\beta_{N+V,la,c} = \left(0.18\right)^2 + \left(0.51\right)^2 \leq \left(1 - 0.26\right)^2$$

$$\beta_{N+V,la,c} = 0.29 \leq 0.55$$

Utilization= 53%

3.5.3 Anchor and connection between anchor and channel (anchor a_3)

$$\beta_{N+V,ac} = \max\left(\beta_{N,s,a};\beta_{N,s,c}\right)^{k_{14}} + \max\left(\beta_{V,s,a,y};\beta_{V,s,c,y}\right)^{k_{14}} \leq \left(1 - \max\left(\beta_{V,s,a,x};\beta_{V,s,c,x}\right)\right)^{k_{14}}$$

k_{14} = 2.0 if max ($V_{Rd,s,a}$;$V_{Rd,s,c}$) ≤ min ($N_{Rd,s,a}$, $N_{Rd,s,c}$)

$$\beta_{N+V,ac} = \max\left(0.13;0.17\right)^2 + \max\left(0.47;0.47\right)^2 \leq \left(1 - \max\left(0.11;0.20\right)\right)^2$$

$$\beta_{N+V,ac} = \left(0.17\right)^2 + \left(0.47\right)^2 \leq \left(1 - \left(0.20\right)\right)^2 = 0.25 \leq 0.64$$

Utilization= 39%

3.5.4 Concrete (anchor a_3)

$$\beta_{N+V,c} = \left(\beta_{N,c}\right)^{1.5} + \left(\beta_{V,c,x}\right)^{1.5} + \left(\beta_{V,c,y}\right)^{1.5} \leq 1.0$$

$$\beta_{N+V,c} = \left(0.16\right)^{1.5} + \left(0.85\right)^{1.5} + \left(0.28\right)^{1.5} = 0.99$$

Utilization= 99%

Design ok! (Maximum utilization: 99%)

DESIGN EXAMPLE 2

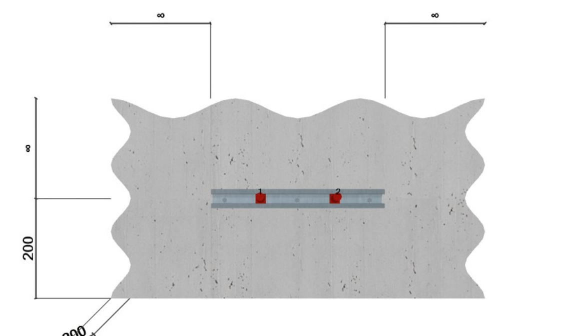
Design of standard HAC anchor channel with tension fatigue loading

INPUT DATA

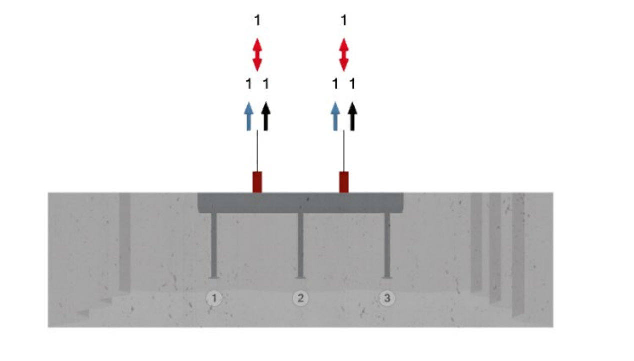
Base Material:

Concrete C35/45, Normal weight concrete
Concrete condition: cracked
Member thickness h = 200 mm
Edge distance c_1 = 200 mm, no corner influence

Bolt spacing 150 mm
Selected anchor channel HAC-60 148/350 F
Load cycle > 2 million
Existing reinforcement widely spaced



Top view



Side view

Design basics:

Standard: Hilti design method based on
EOTA TR047/EN 1992-4 & EOTA TR050

European Technical Assessment: ETA 11/0006

Applied loads per bolts:

Tension:
Static permanent characteristic load $N_{Ek,g}$ = 1 kN per bolt
Static variable characteristic load $N_{Ek,q}$ = 1 kN per bolt
Fatigue characteristic load ΔN_{Ek} = 1 kN per bolt

Shear:
Shear load = 0 kN

DESIGN STEPS

1.Calculation of bolt forces

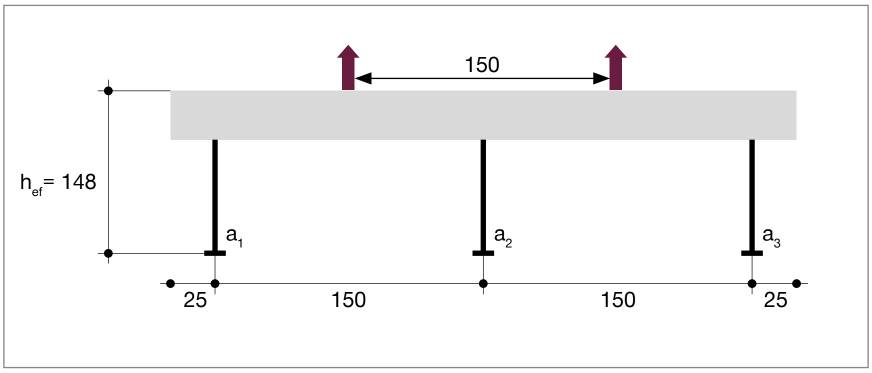
Static loads:
Load case 1 = 1.35 x (permanent load) + 1.5 x (variable load)
N^{cb}_{Ed} = 1.35 x 1 kN + 1.5 x 1 kN = 2.85 kN

Bolt	N^{cb}_{Ed} [kN]	V^{cb}_{Ed} [kN]
1	2.85	-
2	2.85	-

Fatigue loads:
Load case 1 = 1.2 x Fatigue characteristic load
N^{cb}_{Ed} = 1.2 x 1 = 1.2 kN

Bolt	ΔN^{cb}_{Ed} [kN]	ΔV^{cb}_{Ed} [kN]
1	1.2	-
2	1.2	-

2. Calculation of anchor forces under static loads (permanent & variable)



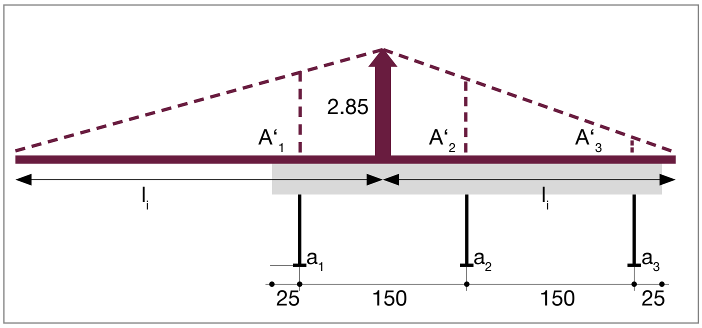
Critical load position on anchor channel

Influence length:

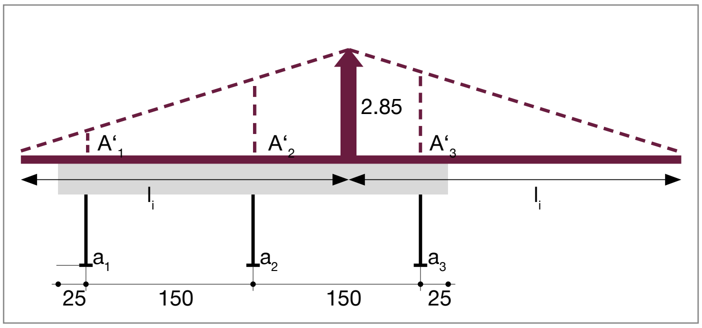
l_i = 13 x $I_y^{0.05}$ x $s^{0.5}$

l_i = 13 x $57930^{0.05}$ x$150^{0.5}$

l_i = 276 mm



Anchor load due to bolt 1 static load



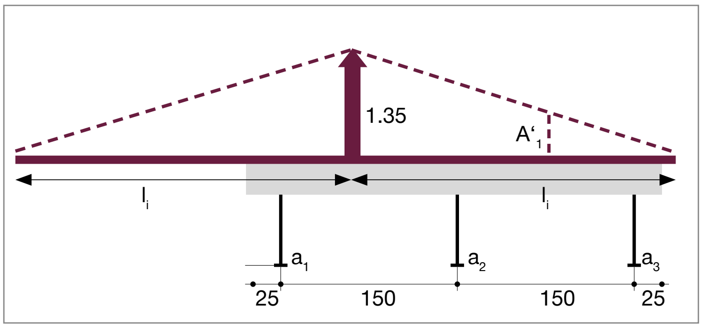
Anchor load due to bolt 2 static load

Anchor forces tension N

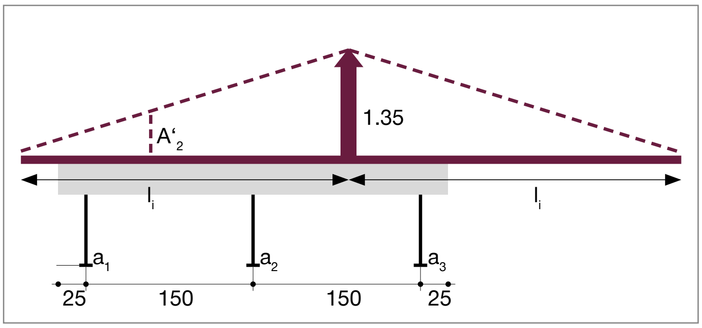
	Anchor a_1	Anchor a_2	Anchor a_3
Load 1 distance from anchor [mm]	75	75	225
$A'_i = (l_i - s)/l_i$	(276 - 75)/276 = 0.73	(276 - 75)/276 = 0.73	(276 - 225)/276 =0.18
$k = \frac{1}{\sum A'_i}$		k = 1/ (0.73 + 0.73 + 0.18) = 0.61	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,1}$	0.61 x 0.73 x 2.85 = **1.27 kN**	0.61 x 0.73 x 2.85 = **1.27 kN**	0.61 x 0.184 x 2.85 = **0.32 kN**
Load 2 distance from anchor [mm]	225	75	75
$A'_i = (l_i - s)/l_i$	(276 - 225)/276 =0.18	(276 - 75)/276 = 0.73	(276 - 75)/276 = 0.73
$k = \frac{1}{\sum A'_i}$		k = 1/ (0.18 + 0.73 + 0.73) = 0.61	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,2}$	0.61 x 0.18 x 2.85 = **0.32 kN**	0.61 x 0.73 x 2.85 = **1.27 kN**	0.61 x 0.73 x 2.85 = **1.27 kN**
Sum of anchor loads N^a_{Ed}	**1.27 + 0.32 = 1.59 kN**	**1.27 + 1.27 = 2.54 kN**	**0.32 + 1.27 = 1.59 kN**

3. Equivalent static and fatigue design action calculation

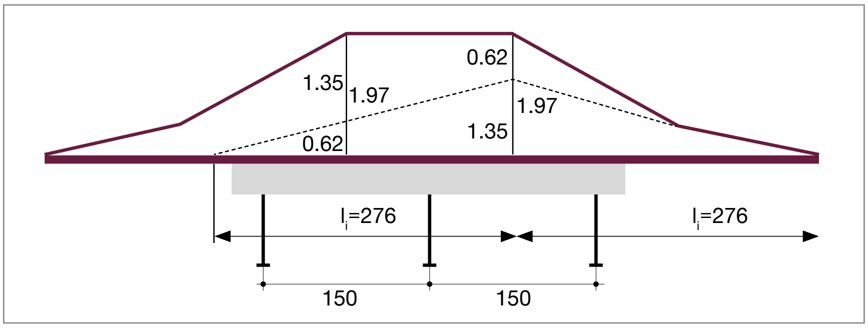
Permanent static load: Equivalent static design action calculation:



Applied static load bolt 1



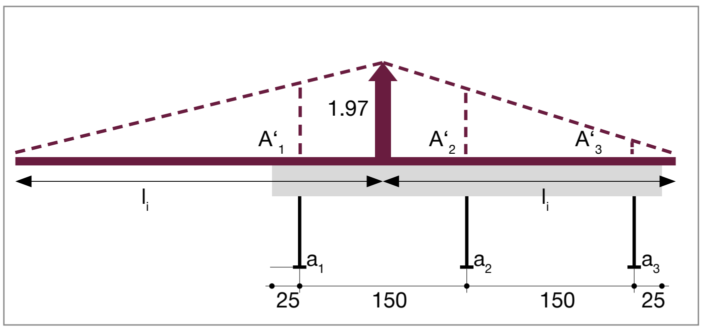
Applied static load bolt 2



Calculation of equivalent static design action

	Load 1	Load 2
Applied load [kN]	1.35	1.35
A'_1, A'_2	(1.35/276) x (276-150) = 0.62	(1.35/276) x (276-150) = 0.62
Equivalent substitution force $N_{Ed,eq}$ [kN]	0.62 + 1.35 = 1.97	1.35 + 0.62 = 1.97

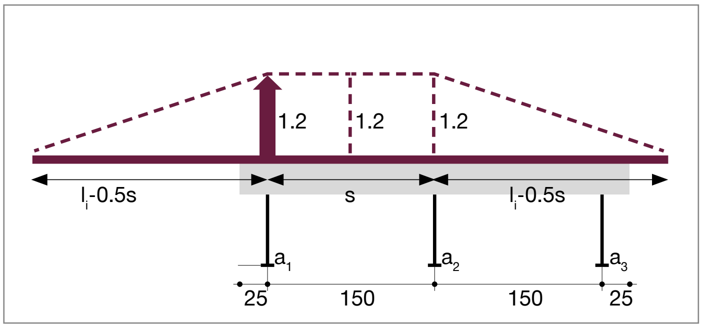
Resulting anchor forces under equivalent static design action $N_{Ed,eq}$



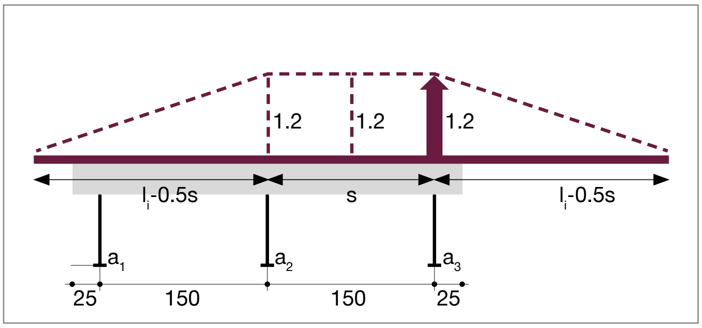
Applied equivalent substitution force

	Anchor a_1	Anchor a_2	Anchor a_3
Load 1 distance from anchor [mm]	75	75	225
$A'_i = (l_i - s)/l_i$	(276 - 75)/276 = 0.73	(276 - 75)/276 = 0.73	(276 - 225)/276 =0.18
$k = \frac{1}{\sum A'_i}$		k = 1/ (0.73 + 0.73 + 0.184) = 0.61	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,1}$	0.61 x 0.73 x 1.97 = **0.87 kN**	0.61 x 0.73 x 1.97 = **0.87 kN**	0.61 x 0.18 x 1.97 = **0.22 kN**

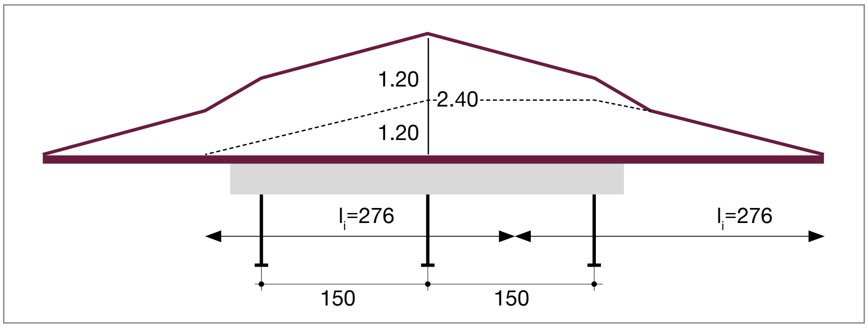
Fatigue load: Equivalent design fatigue cyclic load



Applied fatigue load bolt 1



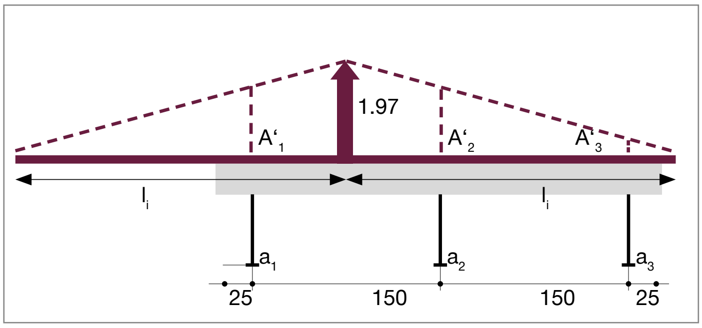
Applied fatigue load bolt 1



Calculation of equivalent design fatigue cyclic load

	Load 1	Load 2
Applied load [kN]	1.2	1.2
A'_I, A'_2	1.2	1.2
Equivalent design fatigue force $\Delta N_{Ed,eq}$ [kN]	2.4	2.4

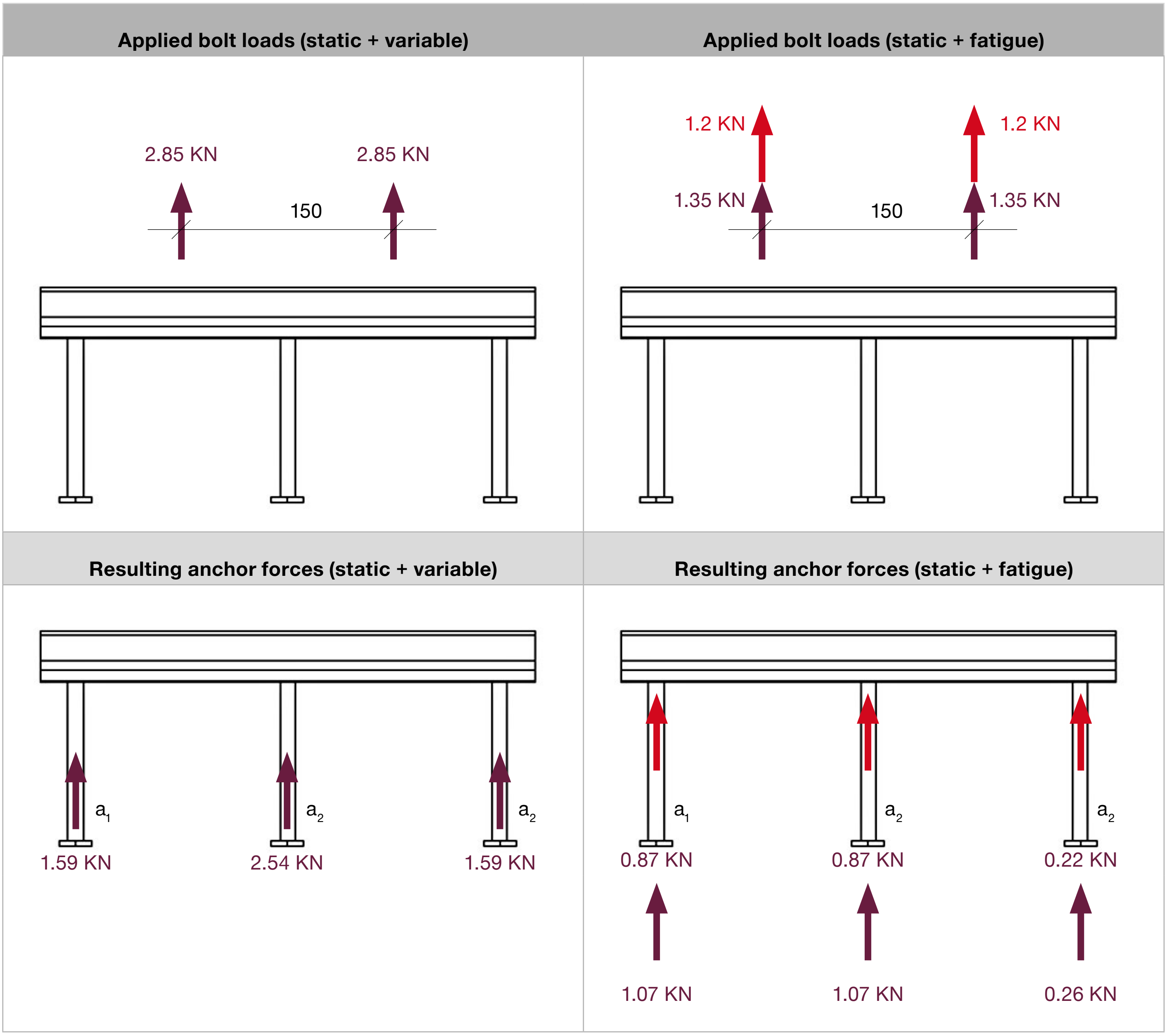
Resulting forces under equivalent design fatigue cyclic load $\Delta N_{Ed,eq}$



Applied equivalent substitution force

	Anchor a_1	Anchor a_2	Anchor a_3
Load 1 distance from anchor [mm]	75	75	225
$A'_I = (l_i - s)/l_i$	(276 - 75)/276 = 0.73	(276 - 75)/276 = 0.73	(276 - 225)/276 =0.18
$k = \frac{1}{\sum A'_i}$	k = 1/ (0.73 + 0.73 + 0.184) = 0.61		
$\Delta N^a_{Ed} = k \times A'_I \times N^{Ed}_{cb,1}$	0.61 x 0.73 x 2.4 = **1.07 kN**	0.61 x 0.73 x 2.4 = **1.07 kN**	0.61 x 0.18 x 2.4 = **0.26 kN**

Summary of applied loads ansd anchor forces



4. Verifications

Tension loading summary

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Anchor	2.54	29.17	9	Ok
Connection anchor-channel	2.54	27.83	9	Ok
Channel lip	2.85	27.83	10	Ok
Channel bolt	2.85	83.73	4	Ok
Flexure channel	0.11	1.90	6	Ok
Pull-out	2.54	45.15	6	Ok
Concrete cone	2.54	30.63	9	Ok
Steel failure -fatigue	2.40	2.41	100	Ok
Concrete pull out-fatigue	1.07	27.47	4	Ok
Concrete cone-fatigue	1.07	18.57	6	Ok

4.1 Steel failure (EN 1992-4 section 7.4.1.3)

4.1.1 Anchor (Anchor a$_2$)

$$N^{a}_{Ed} \le N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$$

N^{a}_{Ed} = 2.54 kN $N_{Rk,s,a}$ = 52.5 kN

γ_{Ms} = 1.8 $N_{Rd,s,a}$ = 29.17 kN

$$\beta_{N,s,a} = \frac{2.54}{29.17} = 9\%$$

4.1.2 Connection between anchor and channel (Anchor a$_2$)

$$N^{a}_{Ed} \le N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$$

N_{aEd} = 2.54 kN $N^{Rk,s,c}$ = 50.1 kN

$\gamma_{Ms,ca}$= 1.8 $N_{Rd,s,c}$= 27.83 kN

$$\beta_{N,s,a} = \frac{2.54}{27.83} = 9\%$$

4.1.3 Local flexure of channel lip (bolt 1)

$$N^{cb}_{Ed} \le N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$$

$$N_{Rk,s,l} = N^{0}_{Rk,s,l} \times \psi_{l,N}$$

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \le 1.0$$

s_{cbo} = 150 mm (given bolt spacing)

$\psi_{l,N}$ = 87 mm

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{150}{87}\right) = 1.0$$

N^{cb}_{Ed} = 2.85 kN $N^{0}_{Rk,s,l}$ = 50.1 kN

$N_{Rk,s,l}$ = 50.1 kN $\gamma_{Ms,l}$ = 1.8

$N_{Rd,s,l}$= 27.83 kN

$$\beta_{N,s,a} = \frac{2.85}{27.83} = 10\%$$

4.1.4 Channel bolt (bolt 1)

$$N^{cb}_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$$

N^{cb}_{Ed} = 2.85 kN $N_{Rk,s,}$= 125.6 kN

γ_{Ms} = 1.5 $N_{Rd,s,}$= 83.73 kN

$$\beta_{N,s,a} = \frac{2.85}{83.73} = 4\%$$

4.1.5 Flexure of channel (assume a beam with two loads to calculate the bending moment)

$$M_{ch,Ed} \le M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$$

M^{ch}_{Ed} = 0.11 kNm $M_{Rk,s,flex}$ = 2.19 kNm

$\gamma_{Ms,flex}$ = 1.15 $M_{Rd,s,flex}$ = 1.90 kNm

$$\beta_{N,s,flex} = \frac{0.11}{1.90} = 6\%$$

4.2 Concrete failure

4.2.1 Pull-out failure (Anchor a$_2$) (EN 1992-4 section 7.4.1.4)

$$N^{a}_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$$

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

$$N_{Rk,p} = 7.5 \times 258 \times 35 = 67.72\,\text{kN}$$

A_h = 258 mm2 k_2 = 7.5

f_{ck} = 35 MPa N^{a}_{Ed} = 2.54 kN

$N_{Rk,p}$ = 67.72 kN γ_{Mp}= 1.5

$N_{Rd,p}$ = 45.15 kN

$$\beta_{N,p} = \frac{2.54}{45.15} = 6\%$$

4.2.2 Concrete cone failure (Anchor a$_2$) (EN 1992-4 section 7.4.1.5)

$$N^{a}_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$

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

$$N^{0}_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5}$$

$$N^{0}_{Rk,c} = 8.6 \times \sqrt{35} \times 148^{1.5} = 91.61\,\text{kN}$$

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}}\right) \cdot \frac{N_i}{N_0}\right]} \le 1.0$$

$$\psi_{ch,s,N} = \frac{1}{1 + \left(1 - \frac{150}{512}\right)^{1.5} \cdot \frac{1.59}{2.54} + \left(1 - \frac{150}{512}\right)^{1.5} \cdot \frac{1.59}{2.54}} = 0.57$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3h_{ef}}{180}\right) \cdot h_{ef} \geq 3h_{ef}$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 \cdot 148}{180}\right) \cdot 148 = 512 \text{ mm}$$

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

$c_{cr,N}$ = critical edge distance i.e. 0.5 $s_{cr,N} \geq 1.5h_{ef}$

$c_{cr,N}$ = 0.5 x 512 = 256 mm ≥ 222 mm

$$\psi_{ch,e,N} = \left(\frac{200}{256}\right)^{0.5} = 0.88$$

$$\psi_{ch,c,N,1} = \left(\frac{c_{2,1}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{2,1} \text{ given)}$$

$$\psi_{ch,c,N,2} = \left(\frac{c_{2,2}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No c2,2 given)}$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0$$

$$N_{Rk,c} = 91.61 \times 0.57 \times 0.88 \times 1.0 \times 1.0 \times 1.0 = 45.95 \text{ kN}$$

k_1 = 8.6	f_{ck} = 35 MPa
h_{ef} = 148 mm	$N^0_{Rk,c}$ = 91.60 kN
s = 150 mm	$s_{cr,N}$ = 512 mm
$\psi_{ch,s,N}$ = 0.57	c_1 = 200 mm
$c_{cr,N}$ = 256 mm	$\psi_{ch,e,N}$ = 0.88
$\psi_{ch,e,N,1}$ = 1.0	$\psi_{ch,e,N,2}$ = 1.0
$\psi_{re,N}$ = 1.0	N^a_{Ed} = 2.54 kN
$N_{Rk,c}$ = 45.95 kN	γ_{Mc} = 1.5
$N_{Rd,p}$ =30.63 kN	

$$\beta_{N,c} = \frac{2.54}{30.63} = 9\%$$

5. Verifications under fatigue loads

5.1 Steel failure (EOTA TR 50 section 5.2)

5.1.1 Proof of steel failure anchor and connection between anchor and channel

Design case 3 where nr. Of cycles n= 3 million and lower loads are known:

$$\Delta N_{Rk,s,0,n} = 3.5 \text{ kN}$$

$N^a_{Ed,eq}$ = 1.97 kN

$\gamma_{M,fat}$ = 1.35

γ_M = 1.8

N_{Rk}= 50.1 kN

$\gamma_{M,fat,n}$ = $\gamma_{M,fat}$ + (γ_M - $\gamma_{M,fat}$) x ($\Delta_{NRk,n}$ - $\Delta_{NRk,\infty}$)/(N_{Rk} - $\Delta_{NRk,\infty}$)

$\gamma_{M,fat,n}$ = 1.35 + (1.8 – 1.35) x (3.5 – 3.5)/(50.1 – 3.5)

$\gamma_{M,fat,n}$ = 1.35

$$N_{Rd} = \frac{50.1 \text{ kN}}{1.8} = 27.83 \text{ kN}$$

$$\Delta N_{Rd,s,0,n} = \frac{3.5 \text{ kN}}{1.35} = 2.59 \text{ kN}$$

$$\Delta N_{Rd,s;E;n} = \Delta N_{Rd,s;0;n} \cdot \left(1 - \frac{N^a_{Ed,eq}}{N_{Rd}}\right)$$

$$\Delta N_{Rd,s;E;n} = 2.59 \cdot \left(1 - \frac{1.97}{27.83}\right)$$

$$\Delta N_{Rd,s;E;n} = 2.41 \text{ kN}$$

$$\Delta N^a_{Ed} = 2.40 \text{ kN}$$

$$\beta_{\Delta N,s} = \frac{2.40}{2.41} = 100\%$$

5.2 Concrete failure (EOTA TR 50 section 5.2)

5.2.1 Pull-out failure - fatigue

N^{Eud} =1.2 x 1 = 1.2 kN (fatigue load)

$\gamma_{M,fat}$ = 1.35

$\gamma_{M,c}$ = 1.5

$\eta_{c,fat,n}$ = 0.571

$N_{Rk,p}$ = 67.72 kN

ΔN_{Rkp0n} = 0.571x67.72=38.67 kN

$\eta_{c,fat,\infty}$=0.50

$\Delta N_{Rkp0\infty}$ = 0.5x67.72=33.86 kN

$\gamma_{M,fat,n}$ = $\gamma_{M,fat}$ + (γ_M - $\gamma_{M,fat}$)·($\Delta N_{Rk,p,n}$ - $\Delta N_{Rk,p,\infty}$)/($N_{Rk,p}$ - $\Delta N_{Rk,p,\infty}$)

$\gamma_{M,fat,n}$ = 1.35 + (1.5 – 1.35) x (38.67 – 33.86)/(67.72 – 33.86)

$\gamma_{M,fat,n}$ = 1.37

$$N_{Rd,p} = \frac{67.72 \text{ kN}}{1.5} = 45.15 \text{ kN}$$

$$\Delta N_{Rd,p,0,n} = \frac{38.67 \text{ kN}}{1.37} = 28.22 \text{ kN}$$

$$\Delta N_{Rd,p;E;n} = \Delta N_{Rd,p;0;n} \cdot \left(1 - \frac{N^{a}_{Ed,eq}}{N_{Rd,p}}\right)$$

$$\Delta N_{Rd,p;E;n} = 28.22 \cdot \left(1 - \frac{0.87}{45.15}\right)$$

$$\Delta N_{Rd,p;E;n} = 27.67 \text{ kN}$$

$$\Delta N^{a}_{Ed,eq} = 1.07 \text{ kN}$$

$$\beta_{\Delta N,p} = \frac{1.07}{27.67} = 4\%$$

5.2.2 Concrete cone failure-fatigue

$N^{a}_{Ed,eq}$ = 0.87 kN

$\gamma_{M,fat}$ = 1.35

$\gamma_{M,c}$ = 1.5

$\eta_{c,fat,n}$ = 0.571

$N_{Rk,c}$ = 45.95 kN

ΔN_{Rkc0n} = 0.571x45.95=26.24 kN

$\eta_{c,fat,\infty}$ = 0.50

$\Delta N_{Rkc0\infty}$ = 0.5x45.95=22.98 kN

$\gamma_{M,fat,n} = \gamma_{M,fat} + (\gamma_{M} - \gamma_{M,fat}) \cdot (\Delta N_{Rk,c,n} - \Delta N_{Rk,c,\infty})/(N_{Rk,c} - \Delta N_{Rk,c,\infty})$

$\gamma_{M,fat,n}$ = 1.35 + (1.5 – 1.35) x (26.24 – 22.98)/(45.95 – 22.98)

$\gamma_{M,fat,n}$ = 1.37

$$N_{Rd,c} = \frac{45.95 \text{ kN}}{1.5} = 30.63 \text{ kN}$$

$$\Delta N_{Rd,c,0,n} = \frac{26.24\text{kN}}{1.37} = 19.15 \text{ kN}$$

$$\Delta N_{Rd,c;E;n} = \Delta N_{Rd,c;0;n} \cdot \left(1 - \frac{N^{a}_{Ed,eq}}{N_{Rd,c}}\right)$$

$$\Delta N_{Rd,p;E;n} = 19.15 \cdot \left(1 - \frac{0.87}{30.63}\right)$$

$$\Delta N_{Rd,p;E;n} = 18.60 \text{ kN}$$

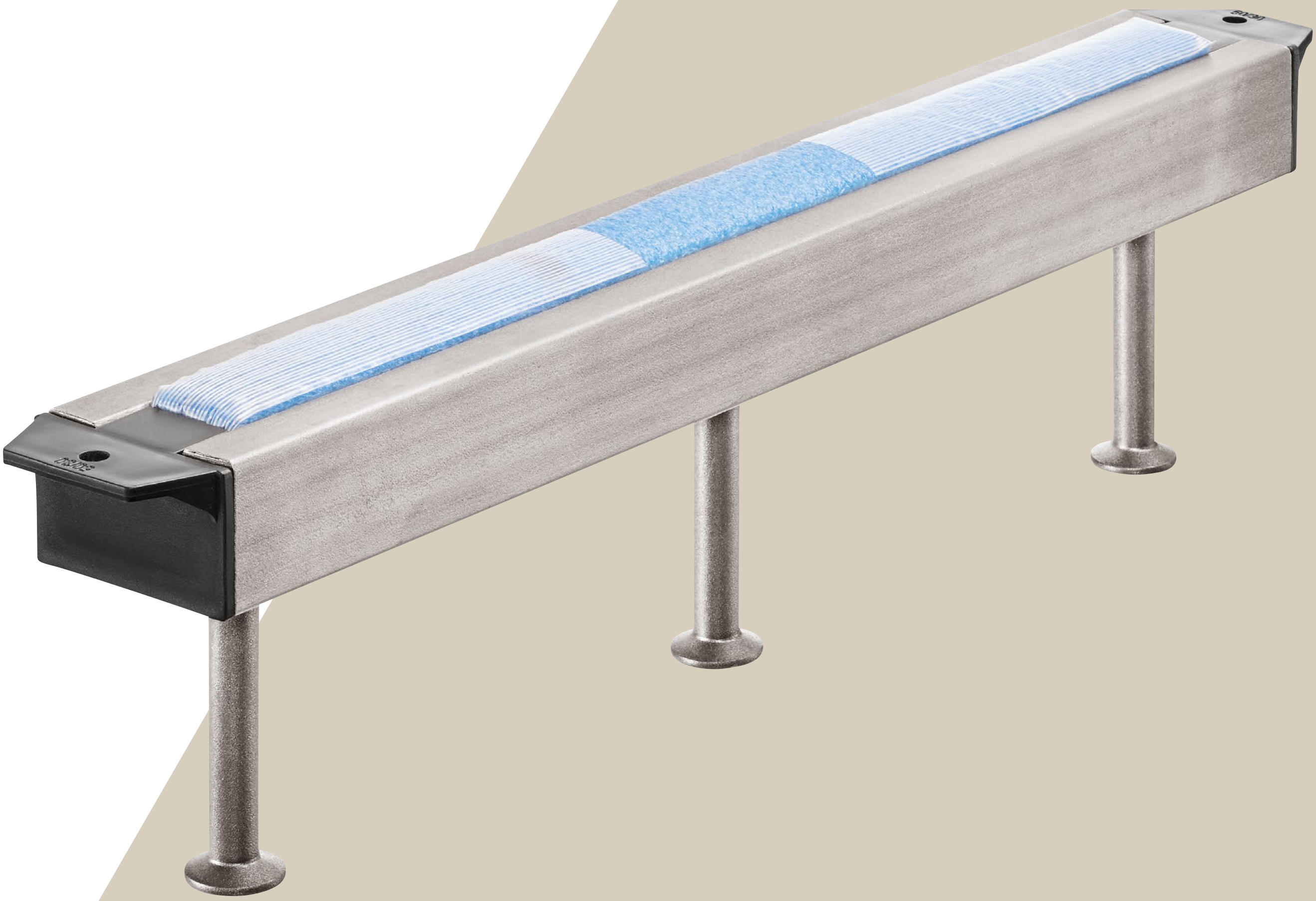
$$\Delta N^{a}_{Ed} = 1.07 \text{ kN}$$

$$\beta_{\Delta N,p} = \frac{1.07}{18.60} = 6\%$$

Design ok! (Maximum utilization: 100%)

HAC-C HOT-ROLLED ANCHOR CHANNELS

Design example



DESIGN EXAMPLE

Design of HAC-C hot rolled anchor channel with 2D loading

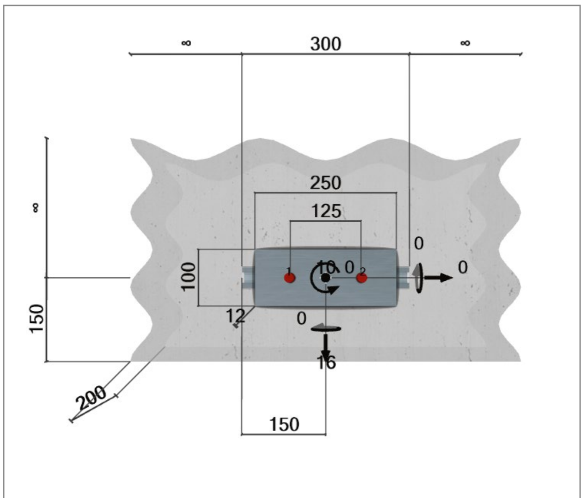
INPUT DATA

Base Material:

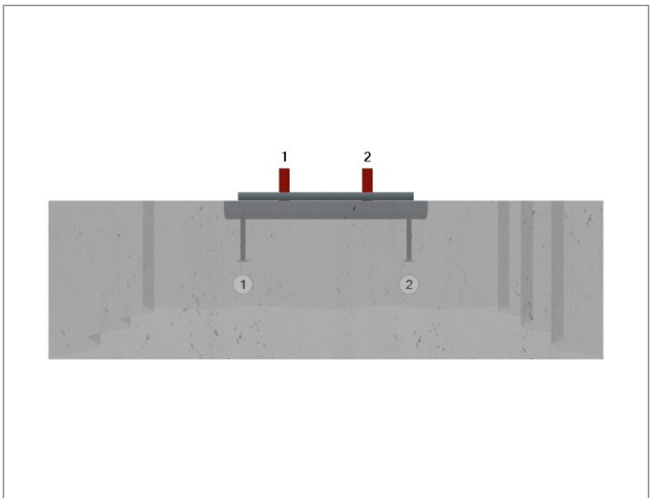
Concrete C30/37, Normal weight concrete
Concrete condition: cracked
Member thickness h = 200 mm
Edge distance c_1 = 150 mm, no corner influence
Existing reinforcement widely spaced

Design basics:

Standard: EOAT TR 047 / EN 1992-4
European Technical Assessment: ETA-17/0336



Top view



Side view

Applied loads:

Tension load N_{Ed} = 10 kN
Shear load V_{Ed} = 16 kN

Applied loads are on the center of the bracket

Solution

Selected product:

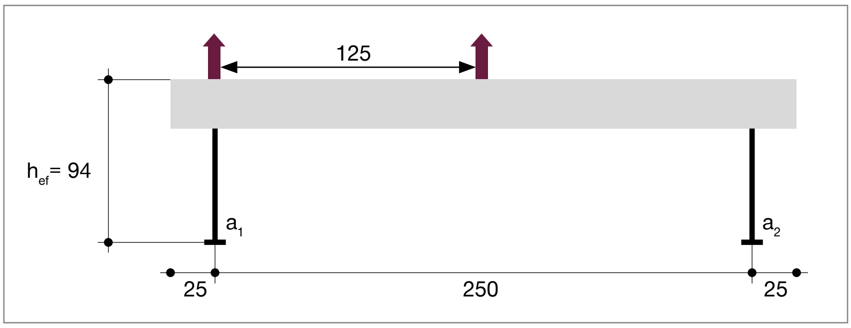
Anchor channel: HAC-C 50/30 300 F
Channel bolt: HBC-50/30 8.8F, M12 x 50 mm

DESIGN STEPS

1.Calculation of bolt forces

Bolt	N^{cb}_{Ed} [kN]	V^{cb}_{Ed} [kN]
1	5	8
2	5	8

2. Calculation of anchor forces



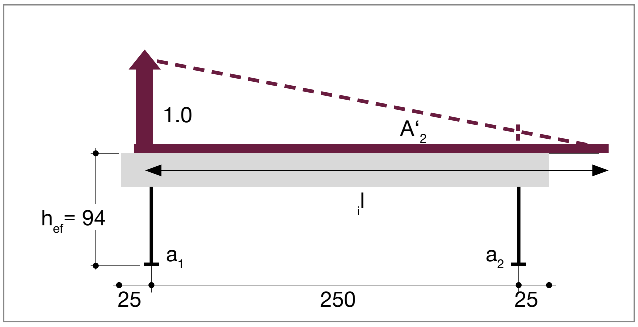
Critical load position on anchor channel

Influence length:

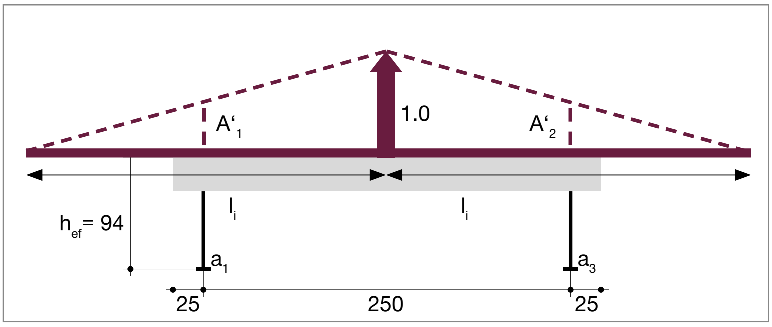
l_i = 13 x $l_y^{0.05}$ x $s^{0.5}$

l_i = 13 x $53652^{0.05}$ x $250^{0.5}$

l_i = 354 mm



Anchor load due to bolt 1



Anchor load due to bolt 2

Anchor forces tension N and perpendicular shear V_y

	Anchor a_1	Anchor a_2
Load 1 distance from anchor [mm]	0	250
$A'_i = (l_i - s)/l_i$	(354 - 0)/354 = 1	(354 - 250)/354 = 0.29
$k = \frac{1}{\sum A'_i}$	k = 1/ (1+0.29) = 0.77	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,1}$	**0.77 x 1 x 5 = 3.85 kN**	0.77 x 0.29 x 5 = **1.11 kN**
Load 2 distance from anchor [mm]	125	125
$A'_i = (l_i - s)/l_i$	(354 - 125)/354 = 0.65	(354 - 125)/354 = 0.65
$k = \frac{1}{\sum A'_i}$	k = 1/ (0.65 + 0.65) = 0.77	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,2}$	0.77 x 0.65 x 5 = **2.50 kN**	0.77 x. 0.65 x 5 = **2.50 kN**
Sum of anchor loads N^a_{Ed}	**3.85 + 2.50 = 6.35 kN**	**1.11 + 2.50 = 3.61 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,1}$	0.77 x 1 x 8 = **6.16 kN**	0.77 x 0.29 x 8 = **1.78 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,2}$	0.77 x 0.65 x 8 = **4.0 kN**	0.77 x 0.65 x 8 = **4.0 kN**
Sum of anchor loads V^a_{Ed}	**6.35 + 4.00 = 10.35 kN**	**1.78 + 4.00 = 5.78 kN**

3. Verifications

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Anchor	6.35	17.22	37	Ok
Connection anchor-channel	6.35	17.22	37	Ok
Channel lip	5.00	20.00	25	Ok
Channel bolt	5.00	23.60	21	Ok
Flexure channel	0.31	1.810	17	Ok
Pull-out	6.35	35.40	18	Ok
Concrete cone	6.35	20.67	31	Ok

Tension loading

3.1 Steel failure (EN 1992-4 section 7.4.1.3)

3.1.1 Anchor (Anchor a_1)

$$N^{a}_{Ed} \leq N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$$

N^{a}_{Ed} = 6.35 kN
γ_{Ms} = 1.8
$N_{Rk,s,a}$ = 31 kN
$N_{Rd,s,a}$ = 17.22 kN

$$\beta_{N,s,a} = \frac{6.35}{17.22} = 37\%$$

3.1.2 Connection between anchor and channel (Anchor a_1)

$$N^{a}_{Ed} \leq N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$$

N^{a}_{Ed} = 6.35 kN
$\gamma_{Ms,ca}$ = 1.8
$N_{Rk,s,c}$ = 31 kN
$N_{Rd,s,c}$ = 17.22 kN

$$\beta_{N,s,c} = \frac{6.35}{17.22} = 37\%$$

3.1.3 Local flexure of channel lip (bolt 1)

$$N^{cb}_{Ed} \leq N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$$

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

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \leq 1.0$$

s_{cbo} = 125 mm (given bolt spacing)
$\psi_{l,N}$ = 98 mm

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{125}{98}\right) = 1.0$$

N^{cb}_{Ed} = 5.0 kN
$N_{Rk,s,l}$ = 36 kN
$N_{Rd,s,l}$ = 20 kN
$N^{0}_{Rk,s,l}$ = 36 kN
$\gamma_{Ms,l}$ = 1.8

$$\beta_{N,s,l} = \frac{5.0}{20.0} = 25\%$$

3.1.4 Channel bolt (bolt 1)

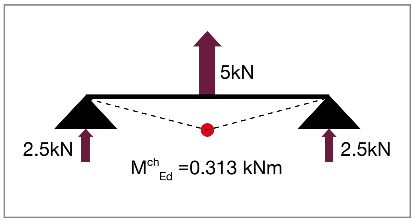
$$N^{cb}_{Ed} \leq N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$$

N^{cb}_{Ed} = 5.0 kN
γ_{Ms} = 1.5
$N_{Rk,s,}$ = 35.4 kN
$N_{Rd,s,}$ = 23.60 kN

$$\beta_{N,s} = \frac{5.0}{23.60} = 21\%$$

3.1.5 Flexure of channel (assume a beam with two loads to calculate the bending moment)

$$M_{ch,Ed} \leq M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$$



M^{ch}_{Ed} = 0.31 kNm
$M_{Rk,s,flex}$ = 2.084 kNm
$\gamma_{Ms,flex}$ = 1.15
$M_{Rd,s,flex}$ = 1.81 kNm

$$\beta_{N,s,flex} = \frac{0.31}{1.81} = 17\%$$

Spacing between supports s=250 mm

3.2 Concrete failure

3.2.1 Pull-out failure (Anchor a_1) (EN 1992 section 7.4.1.4)

$$N^{a}_{Ed} \leq N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$$

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

A_h = 236 mm2
f_{ck} = 30 MPa
N^{a}_{Ed} = 6.35 kN
$N_{Rd,p}$ = 35.4 kN
k_2 = 7.5
$N_{Rk,p}$ = 53.1 kN
γ_{Mp} = 1.5

$$\beta_{N,p} = \frac{6.35}{35.4} = 18\%$$

3.2.2 Concrete cone failure (Anchor a_1) (EN 1992 section 7.4.1.5)

$$N^{a}_{Ed} \leq N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$

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

$$N^{0}_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5}$$

$$N^{0}_{Rk,c} = 8.1 \cdot \sqrt{30} \cdot 94^{1.5} = 40.43 \text{ kN}$$

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}}\right) \cdot \frac{N_i}{N_0}\right]} \leq 1.0$$

$$\psi_{ch,s,N} = \frac{1}{1 + \left(1 - \frac{250}{399}\right)^{1.5} \cdot \frac{3.61}{6.35}} = 0.88$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 h_{ef}}{180}\right) \cdot h_{ef} \geq 3 h_{ef}$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 \cdot 94}{180}\right) \cdot 94 = 399 \text{ mm}$$

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \leq 1.0$$

$c_{cr,N}$ = critical edge distance i.e. 0.5 $s_{cr,N} \geq 1.5h_{ef}$
$c_{cr,N}$ = 0.5 x 399 = 199 mm ≥ 141 mm

$$\psi_{ch,e,N} = \left(\frac{150}{199}\right)^{0.5} = 0.87$$

$$\psi_{ch,c,N,1} = \left(\frac{c_{2,1}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{212} \text{ given)}$$

$$\psi_{ch,c,N,2} = \left(\frac{c_{2,2}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{2,2} \text{ given)}$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0$$

$$N_{Rk,c} = 40.43 \times 0.88 \times 0.87 \times 1.0 \times 1.0 \times 1.0 = 30.95 \text{ kN}$$

k_1 = 8.1	f_{ck} = 30 MPa
h_{ef} = 94 mm	$N^0_{Rk,c}$ = 40.43 kN
s = 250 mm	$s_{cr,N}$ = 399 mm
$\psi_{ch,s,N}$ = 0.88	c_1 = 150 mm
$c_{cr,N}$ = 199 mm	$\psi_{ch,e,N}$ = 0.87
$\psi_{ch,e,N,1}$ = 1.0	$\psi_{ch,e,N,2}$ = 1.0
$\psi_{re,N}$ = 1.0	N^a_{Ed} = 6.35 kN
$N_{Rk,c}$ = 30.95 kN	γ_{Mc} = 1.5
$N_{Rd,p}$ =20.63 kN	

$$\beta_{N,c} = \frac{6.35}{20.63} = 31\%$$

Shear loading

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Channel bolt w/o lever arm	8.00	26.96	30	Ok
Flexure channel lip w/o lever arm perpendicular	8.00	20.00	40	Ok
Anchor perpendicular	10.35	17.22	60	Ok
Connection anchor-channel perpendicular	10.35	17.22	60	Ok
Concrete pry out perpendicular	10.35	41.27	25	Ok
Concrete edge perpendicular	10.35	12.43	83	Ok

3.3 Steel failure (EN 1992-4 section 7.4.2.3)

3.3.1 Channel bolt

$$V^{cb}_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$

$V^{cbEd,y}$ = 8.0 kN
γ_{Ms} = 1.25
$V_{Rk,s,}$ = 33.7 kN
$V_{Rd,s,}$ = 26.96 kN

$$\beta_{V,s} = \frac{8.0}{26.96} = 30\%$$

3.3.2 Local flexure of channel lips (EN 1992-4 section 7.4.2.3)

$$V^{cb}_{Ed,y} \leq V_{Rd,s,l,y} = \frac{V_{Rk,s,l,y}}{\gamma_{Ms,l}}$$

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

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

s_{cbo} = 125 mm (bolt spacing) $s_{l,v}$ = 98 mm

$$\psi_{l,v} = 0.5\left(1 + \frac{125}{98}\right) = 1.0$$

$V^{cb}_{Ed,y}$ = 8.0 kN
$V_{Rk,s,l,y}$ = 40.3 kN
$V_{Rd,s,l,y}$ = 20 kN
(taken same as $N_{Rd,s,l}$ for quadratic interaction)
$V^0_{Rk,s,l,y}$ = 40.3 kN
$\gamma_{Ms,l,y}$ = 1.8

$$\beta_{V,s,l,y} = \frac{8.0}{20.0} = 40\%$$

3.3.3 Anchor-shear perpendicular (Anchor a_1) (EN 1992-4 section 7.4.2.3)

$$V^a_{Ed,y} \leq V_{Rd,s,a,y} = \frac{V_{Rk,s,a,y}}{\gamma_{Ms}}$$

$V^a_{Ed,y}$ = 10.35 kN $V_{Rk,s,a,y}$ = 40.3 kN
γ_{Ms} = 1.5 $V_{Rd,s,a,y}$ = 17.22 kN
(same as tension capacity $N_{Rd,s,a}$ for quadratic interaction)

$$\beta_{V,s,a,y} = \frac{10.35}{17.22} = 60\%$$

3.3.4 Connection between anchor and channel - shear perpendicular (Anchor a_1) (EN 1992-4 section 7.4.2.3)

$$V^a_{Ed,y} \leq V_{Rd,s,c,y} = \frac{V_{Rk,s,c,y}}{\gamma_{Ms}}$$

$V^a_{Ed,y}$ = 10.35 kN $V_{Rk,s,c,y}$ = 40.3 kN
$\gamma_{Ms,ca}$ = 1.8 $V_{Rd,s,c,y}$ =17.22 kN
(same as tension capacity $N_{Rd,s,c}$ for quadratic interaction)

$$\beta_{V,s,c,y} = \frac{10.35}{17.22} = 60\%$$

3.4 Concrete failure

3.4.1 Concrete pry-out failure – shear perpendicular (Anchor a_1) (EN 1992-4 section 7.4.2.4)

$$V^a_{Ed,y} \leq V_{Rd,cp,y} = \frac{V_{Rk,cp,y}}{\gamma_{Mc}}$$

$$V_{Rk,cp,y} = k_8 \cdot N_{Rk,c}$$

$N_{Rk,c}$ taken from section 3.2.2

$N_{Rk,c}$ = 30.95 kN

$V_{Rk,cp,y}$ = 2 x 30.95 = 61.9 kN

$V^a_{Ed,y}$ = 10.35 kN K_8 = 2.0
$V_{Rk,cp,y}$ = 61.9 kN γ_{Mc} = 1.5
$V_{Rd,cp,y}$ = 41.27 kN

$$\beta_{V,cp,y} = \frac{10.35}{41.27} = 25\%$$

3.4.2 Concrete edge failure – shear perpendicular y- (Anchor a_1) (EN 1992-4 section 7.4.2.5)

$$V^a_{Ed,y} \leq V_{Rd,c,y} = \frac{V_{Rk,c,y}}{\gamma_{Mc}}$$

$$V_{Rk,c,y} = V^0_{Rk,c} \cdot \psi_{ch,s,V} \cdot \psi_{ch,c,V,1} \cdot \psi_{ch,c,V,2} \cdot \psi_{ch,h,V} \cdot \psi_{ch,90^\circ,V} \cdot \psi_{re,V}$$

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

$$V^0_{Rk,c} = 7.5 \cdot \sqrt{30} \cdot 150^{4/3} = 32.74 \text{ kN}$$

$$\psi_{ch,s,V} = \frac{1}{1 + \sum_{i=1}^{n_{ch,V}} \left[\left(1 - \frac{s_i}{s_{cr,V}}\right)^{1.5} \cdot \frac{V_i}{V_0} \right]} \leq 1.0$$

$$\psi_{ch,s,V} = \frac{1}{1 + \left(1 - \frac{250}{698}\right)^{1.5} \cdot \frac{5.78}{10.35}} = 0.77$$

$s_{cr,V}$ = 4 c1 + 2 b_{ch} $s_{cr,V}$ = 4 x150 + 2 x 49 =698 mm
$c_{cr,v}$ = 0.5 scr,V $c_{cr,v}$ = 0.5 x 698 =349 mm

$$\psi_{ch,c,V,1} = \left(\frac{c_{2,1}}{c_{cr,V}}\right)^{0.5} = 1.0 \text{ (no } c_{2,1} \text{ given)}$$

$$\psi_{ch,c,V,2} = \left(\frac{c_{2,2}}{c_{cr,V}}\right)^{0.5} = 1.0 \text{ (no } c_{2,2} \text{ given)}$$

$$\psi_{ch,h,V} = \left(\frac{h}{h_{cr,V}}\right)^{0.5} \leq 1.0$$

$$h_{cr,V} = 2c_1 + 2h_{ch}$$

$$h_{cr,V} = 2 \times 150 + 2 \times 30 = 360 \text{ mm}$$

$$\psi_{ch,h,V} = \left(\frac{200}{360}\right)^{0.5} = 0.74$$

$$V_{Rk,c,y} = 32.74 \times 0.77 \times 1.0 \cdot 1.0 \times 0.74 \times 1.0 \times 1.0 = 18.65 \text{ kN}$$

k_{12} = 7.5 f_{ck} = 30 MPa
c_1 = 150 mm $V^0_{Rk,c}$ = 32.74 kN
s = 250 mm $s_{cr,V}$ = 698 mm
$\psi_{ch,s,V}$ = 0.77 $c_{cr,V}$ = 349 mm
$\psi_{ch,c,V,1}$ = 1.0 $\psi_{ch,c,V,2}$ = 1.0
h = 200 mm $h_{vr,V}$ = 360 mm
$\psi_{ch,h,V}$ = 0.74 $\psi_{ch,90°,V}$ = 1.0
$\psi_{re,V}$ = 1.0 $V_{aEd,y}$ = 10.35 kN
$V_{Rk,c,y}$ = 18.65 kN γ_{Mc} = 1.5
$V_{Rd,c,y}$ = 12.43 kN

$$\beta_{V,c,y} = \frac{10.35}{12.43} = 83\%$$

3.5 Combined tension and shear loads (EN 1992-4 section 8.3.3)

3.5.1 Channel bolt (bolt 1)

$$\beta_{N+V,s} = \left(\beta_{N,s}\right)^2 + \left(\beta_{V,s}\right)^2 \leq 1.0$$

$$\beta_{N+V,s} = \left(0.21\right)^2 + \left(0.30\right)^2 = 0.14$$

Utilization: 14%

3.5.2 Point of load application – channel lip (bolt 1)

$$\beta_{N+V,la,c} = \left(\beta_{N,s,l}\right)^{k_{13}} + \left(\beta_{V,s,l,y}\right)^{k_{13}} \leq 1.0$$

k_{13} = 2.0 if $V_{Rd,s,l} \leq N_{Rd,s,l}$

$$\beta_{N+V,la,c} = \left(0.25\right)^2 + \left(0.40\right)^2 = 0.23$$

Utilization: 23%

3.5.3 Anchor and connection between anchor and channel (anchor a_1)

$$\beta_{N+V,ac} = \max\left(\beta_{N,s,a};\beta_{N,s,c}\right)^{k_{14}} + \max\left(\beta_{V,s,a,y};\beta_{V,s,c,y}\right)^{k_{14}} \leq 1.0$$

k_{14} = 2.0 if max ($V_{Rd,s,a}$;$V_{Rd,s,c}$) ≤ min ($N_{Rd,s,a}$, $N_{Rd,s,c}$)

$$\beta_{N+V,ac} = \max\left(0.37;0.37\right)^2 + \max\left(0.60;0.60\right)^2 \leq 1.0$$

$$\beta_{N+V,ac} = \left(0.37\right)^2 + \left(0.60\right)^2 = 0.50$$

Utilization: 50 %

3.5.4 Concrete (anchor a_1)

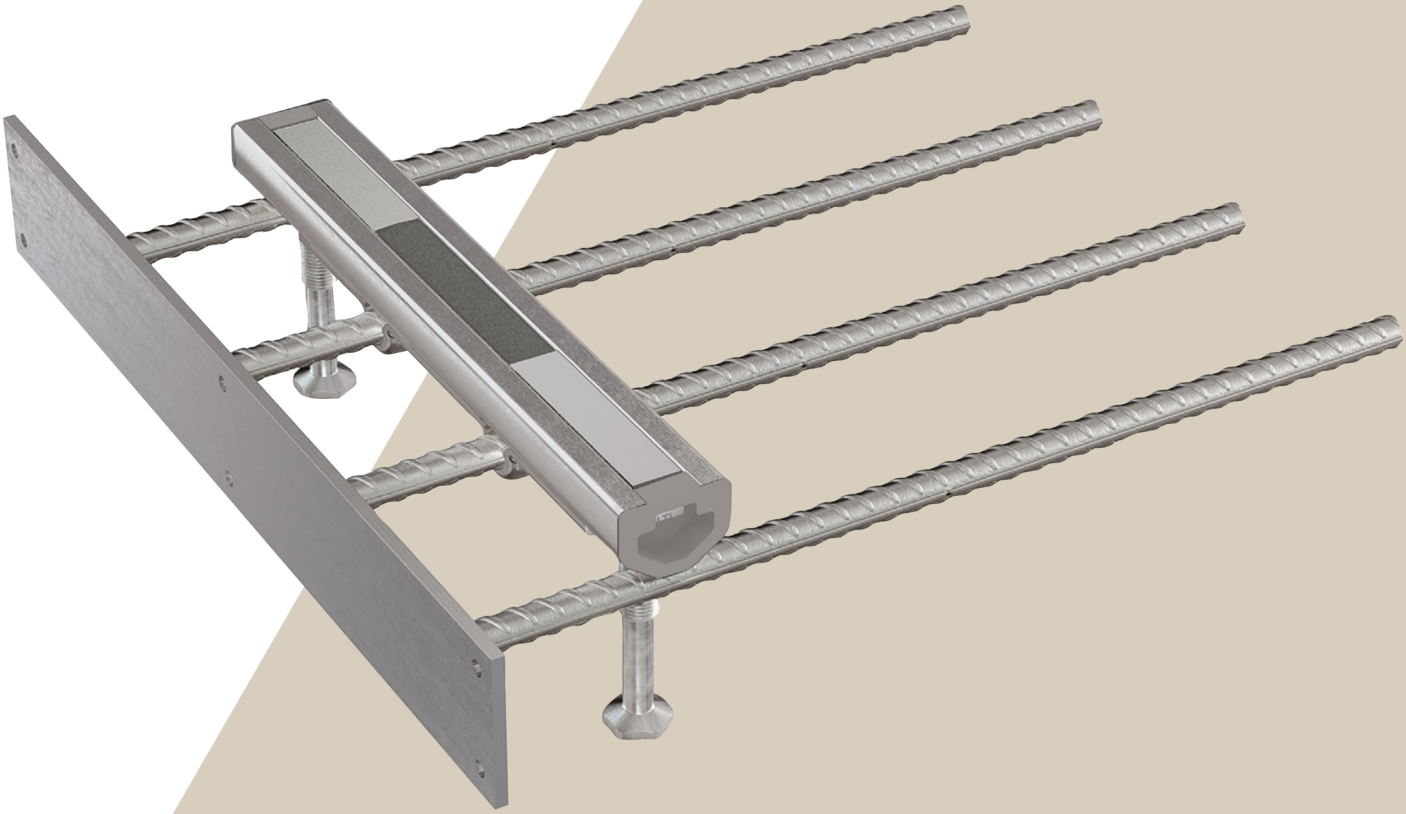
$$\beta_{N+V,c} = \left(\beta_{N,c}\right)^{1.5} + \left(\beta_{V,c,y}\right)^{1.5} \leq 1.0$$

$$\beta_{N+V,c} = \left(0.31\right)^{1.5} + \left(0.83\right)^{1.5} = 0.93$$

Utilization: 93%

Design ok! (Maximum utilization: 93%)

HAC EDGE
ANCHOR CHANNELS



DESIGN EXAMPLE

HAC EDGE - static 2D loads

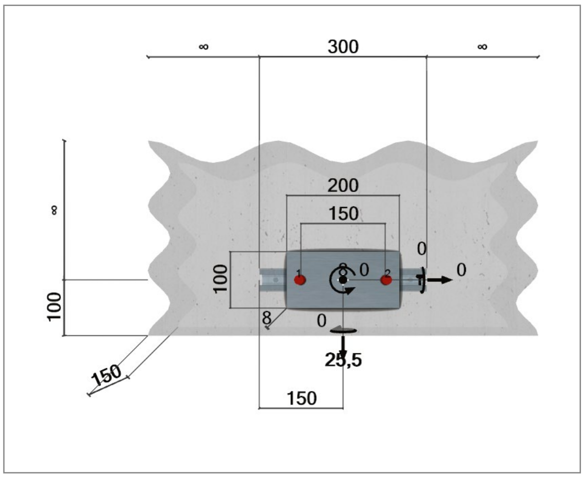
INPUT DATA

Base Material:

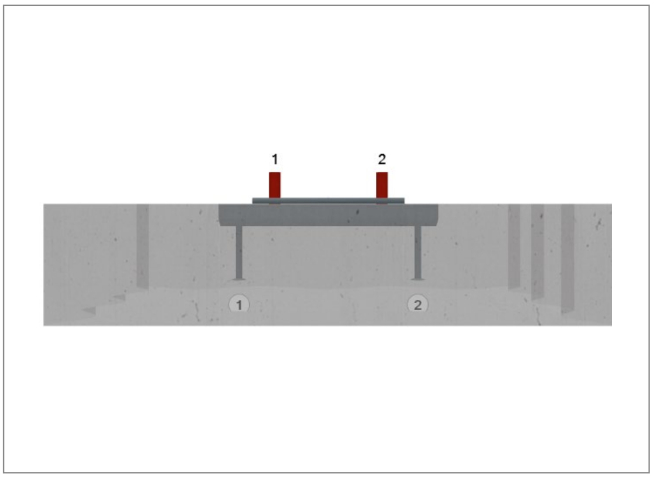
Concrete C30/37, Normal weight concrete
Concrete condition: cracked
Member thickness h = 150 mm
Edge distance c_1 = 100 mm, no corner influence
Existing reinforcement widely spaced

Design basics:

Standard: Hilti design method based on EOAT TR 047 or EN 1992-4
European Technical Assessment: Internal tests for concrete edge as the product is not covered in European framework



Top view



Side view

Applied loads:

Tension load N_{Ed} = 8 kN
Shear load V_{Ed} = 25.5 kN

Applied loads are on the center of the bracket.

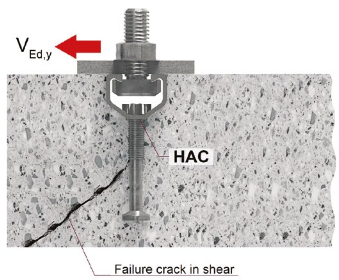
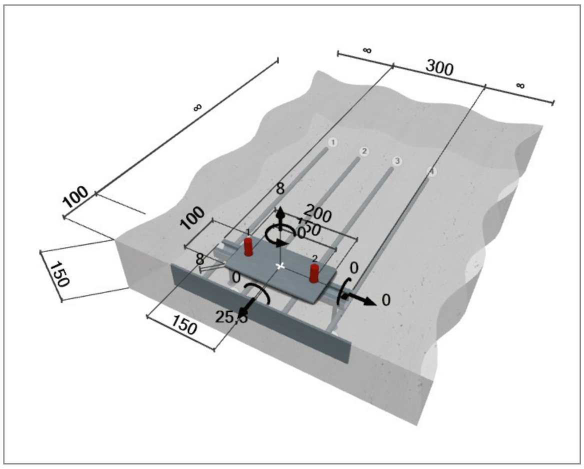


Figure: edge failure of a standard anchor channel

Solution

Under the high shear loads and with the given boundary conditions standard anchor channels does not work due to concrete edge failure.

Max. anchor load on HAC-50	Max. concrete edge resistance standard anchor channel HAC-50	Utilization
V^a_{Ed} = 15.64 kN	$V_{Rd,c,y}$ = 7.94 kN	β_v = 15.64/7.94 = **198% > 1 Not OK**



HAC EGDE: Boundary conditions

A suitable solution for the given situation is with Hilti HAC EDGE:

Selected product:
Anchor channel: Rebar HAC-50 106/300 F EDGE 100 mm
Channel bolt: HBC-C 8.8F, M12 x 50 mm

Max. anchor load on HAC-50	Max. concrete edge resistance special anchor channel HAC EDGE	Utilization
V^a_{Ed} = 15.64 kN	$V_{Rd,c,y}$ = 40.05 kN	β_v = 15.64/40.05 = **40 % < 1 OK**

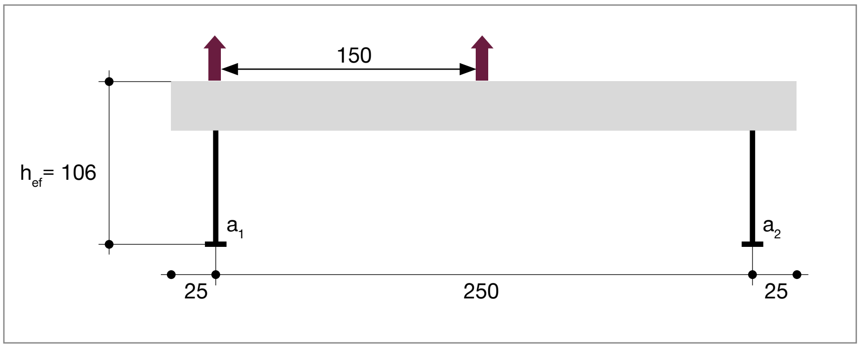
Technical data HAC-50 EDGE (based on the current European Technical Assessment (ETA) and internal tests):

Characteristic values		Partial safety factors γ	Parameters	
Tension				
$N_{Rk,s,a}$	52.5 kN	1.8	I_y	33125 mm^4
$N_{Rk,s,c}$	35 kN	1.8	h_{ef}	106 mm
$N_{Rk,s,l}$	35 kN	1.8	k_1	8.2
$N_{Rk,s}$	125.6 kN	1.5	k_2	7.5
$M_{Rk,s,flex}$	1.596 kNm	1.15	s	250 mm
$N_{Rk,p}$	23.2 x 2.5 = 58 kN	1.5	$s_{cr,N}$	431 mm
Shear			$c_{cr,N}$	216 mm
$V_{Rk,s,a,y}$	53.6 kN	1.5	$k_{cr,v}$	7.5
$V_{Rk,s,c,y}$	53.6 kN	1.8	k_8	2.0
$V^0_{Rk,s,l}$	47.5 kN	1.8	x_1	0.97
$V_{Rk,s}$	62.8	1.25	x_2	0.18
-	-	-	x_3	0.250
-	-	-	x_4	0.110
-	-	-	$\alpha_{1,V}$	0.60
-	-	-	$s_{cr,V}$	290 mm
-	-	-	Rebar ϕ	12 mm

DESIGN STEPS

1.Calculation of bolt forces

Bolt	N^{cb}_{Ed} [kN]	V^{cb}_{Ed} [kN]
1	4	12.75
2	4	12.75



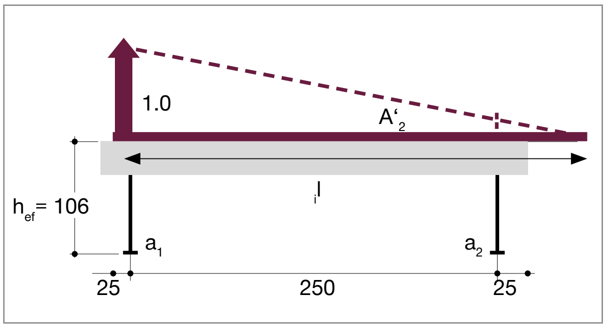
Critical load position on anchor channel

Influence length:

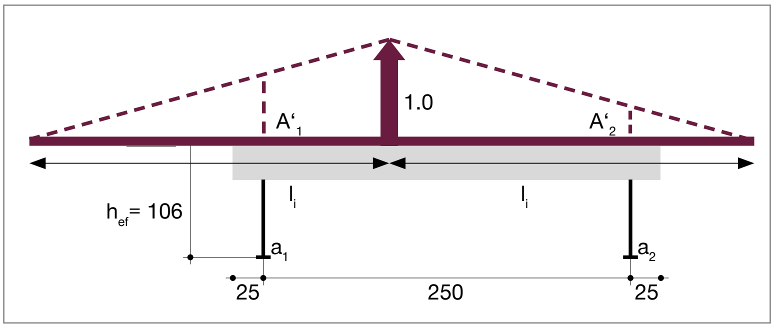
$l_i = 13 \times l_y^{0.05} \times s^{0.5}$

$l_i = 13 \times 33125^{0.05} \times 250^{0.5}$

$l_i = 345.87$ mm



Anchor load due to bolt 1



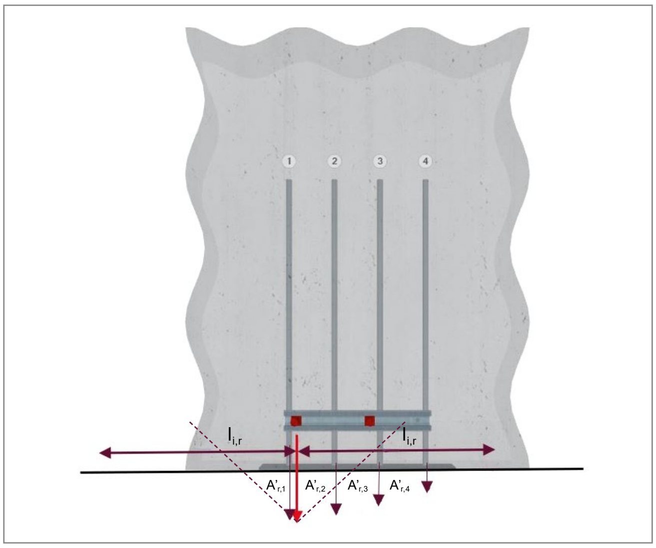
Anchor load due to bolt 2

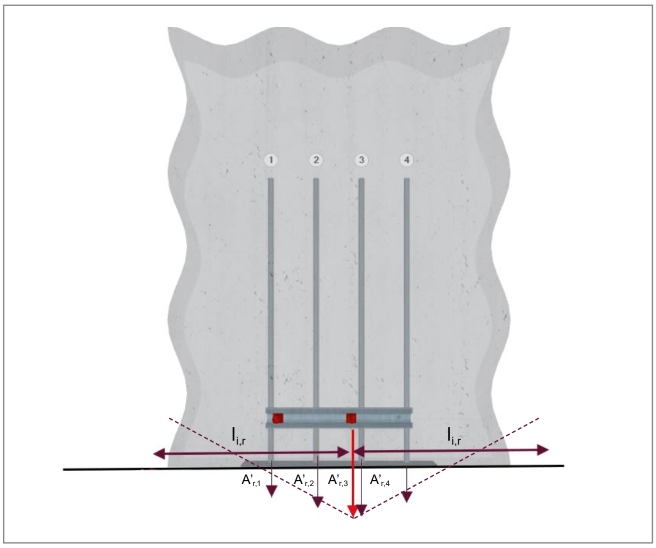
2. Calculation of anchor forces

	Anchor a_1	Anchor a_2
Load 1 distance from anchor	0	250
$A'_i = (l_i - s)/l_i$	(345.87 - 0)/345.87 = 1	(345.87 - 250)/345.87 = 0.27
$k = \frac{1}{\sum A'_i}$	k = 1/ (1 + 0.27) = 0.79	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,1}$	0.79 x 1 x 4 = **3.16 kN**	0.79 x 0.28 x 4 = **0.88 kN**
Load 2 distance from anchor	150	100
$A'_i = (l_i - s)/l_i$	(345.87 - 150)/345.87 = 0.56	(345.87 - 100)/345.87 = 0.71
$k = \frac{1}{\sum A'_i}$	k = 1/(0.566+0.710) = 0.783	
$N^a_{Ed} = k \times A'_i \times N^{Ed}_{cb,2}$	0.79 x 0.56 x 4 = **1.77 kN**	0.79 x 0.71 x 4 = **2.24 kN**
Sum of anchor loads N^a_{Ed}	**3.16 + 1.77 = 4.93 kN**	**0.88 + 2.24 = 3.12 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,1}$	0.79 x 1 x 12.75 = **10.10 kN**	0.79 x 0.27 x 12.75 = **2.72 kN**
$V^a_{Ed} = k \times A'_i \times V^{Ed}_{cb,2}$	0.79 x 0.56 x 12.75 = **5.65 kN**	0.79 x 0.71 x 12.75 = **7.10 kN**
Sum of anchor loads V^a_{Ed}	**10.10 + 5.65 = 15.75 kN**	**2.72 +7.10 = 9.82 kN**

3. Calculation of tensile forces in rebars

Rebar	1	2	3	4
A'_i	0.92	0.63	0.17	0
$k = \frac{1}{\sum A'_i}$	0.58			
$N^1_{Ed,R,i} = k \times A'_I \times N^{cb}_{Ed,1}$	**6.80 kN**	**4.66 kN**	**1.25 kN**	**0**
A'_i	0.19	0.65	0.89	0.43
$k = \frac{1}{\sum A'_i}$	0.46			
$N^2_{Ed,R,i} = k \times A'_I \times N^{cb}_{Ed,2}$	**1.11 kN**	**3.82 kN**	**5.22 kN**	**2.52 kN**
N= Sum of bolt 1 and bolt 2	6.8 + 1.11 =7.91	4.66 + 3.82 =8.48	1.25 + 5.22 = 6.47	0 + 2.52 = 2.52
$N^a_{Ed,R} = x. N$	**11.31 kN**	**12.12 kN**	**9.25 kN**	**3.60 kN**





Calculation of rebar forces due to applied bolt loads

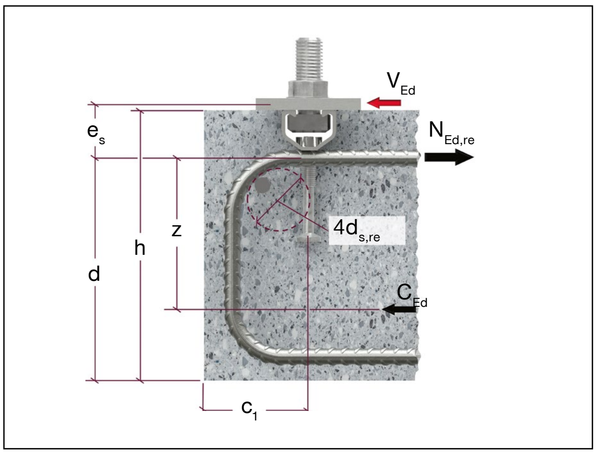
Influence length:

$l_i = 13 \times ly^{0.05} \times s^{0.5}$
$l_i = 13 \times 33125^{0.05} \times 95^{0.5}$
$l_{i,r} = 345.87$ mm
$l_{i,r} = (0.2 + 0.004_{c1})l_i$
$c_1 = 100$ mm
$l_{i,r} = 207.53$ mm

e_c =standoff distance = 0
t = thickness of the steel plate on channel 8 mm
$e_R = 0.5 \times$ bar diameter (d)
$h_{ch} = 31$ mm
$e_s = 0 + 8/2 + 0.5 \times 12 + 31 = 41$ mm
load eccentricity $x = e_s/z + 1$
$z = 0.85d$ where $d = h\text{-max}(c\ ;\ h_{ch}) - d/2$
$d = 150 - 31 - 12/2 = 113$ mm
$z = 0.85 \times 113 = 96$ mm
$x = 41/96 + 1 = 1.43$

Load eccentricity:

The effect of the load eccentricity is calculated as for shear supplementary reinforcement.
$e_s = e_c + t/2 + e_R$ + max (concrete cover, c; channel height, h_{ch})



Stand-off installation

4. Verifications

Tension loading summary

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Anchor	4.93	29.17	17	Ok
Connection anchor-channel	4.93	19.44	26	Ok
Channel lip	4.00	19.44	21	Ok
Channel bolt	4.00	44.93	9	Ok
Flexure channel	0.24	1.39	18	Ok
Pull-out	4.93	38.7	13	Ok
Concrete cone	4.93	18.98	26	Ok

4.1 Steel failure (EN 1992-4 section 7.4.1.3)

4.1.1 Anchor (Anchor a_1)

$$N^{a}{}_{Ed} \le N_{Rd,s,a} = \frac{N_{Rk,s,a}}{\gamma_{Ms}}$$

$N^{a}{}_{Ed}$ = 4.93 kN $N_{Rk,s,a}$ = 52.5 kN

γ_{Ms} = 1.8 $N_{Rd,s,a}$ = 29.17 kN

$$\beta_{N,s,a} = \frac{4.93}{29.17} = 17\%$$

4.1.2 Connection between anchor and channel (Anchor a_1)

$$N^{a}{}_{Ed} \le N_{Rd,s,c} = \frac{N_{Rk,s,c}}{\gamma_{Ms,ca}}$$

$N^{a}{}_{Ed}$ = 4.93 kN $N_{Rk,s,c}$ = 35 kN

$\gamma_{Ms,ca}$ = 1.8 $N_{Rd,s,c}$ =19.44 kN

$$\beta_{N,s,c} = \frac{4.93}{19.44} = 26\%$$

4.1.3 Local flexure of channel lip (bolt 1)

$$N^{cb}{}_{Ed} \le N_{Rd,s,l} = \frac{N_{Rk,s,l}}{\gamma_{Ms,l}}$$

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

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{s_{cbo}}{s_{l,N}}\right) \le 1.0$$

s_{cbo} = 150 mm (given bolt spacing)

$\psi_{l,N}$ = 84 mm

$$\psi_{l,N} = 0.5 \cdot \left(1 + \frac{150}{84}\right) = 1.0$$

$N^{cb}{}_{Ed}$ = 4.0 kN $N^{0}{}_{Rk,s,l}$ = 35 kN

$N_{Rk,s,l}$ = 35 kN $\gamma_{Ms,l}$ = 1.8

$N_{Rd,s,l}$ = 19.44 kN

$$\beta_{N,s,l} = \frac{4.0}{19.44} = 21\%$$

4.1.4 Channel bolt (bolt 1)

$$N^{cb}{}_{Ed} \le N_{Rd,s} = \frac{N_{Rk,s}}{\gamma_{Ms}}$$

$N^{cb}{}_{Ed}$ = 4.0 kN $N_{Rk,s}$ = 67.4 kN

γ_{Ms} = 1.5 $N_{Rd,s}$ = 44.93 kN

$$\beta_{N,s} = \frac{4.0}{44.93} = 9\%$$

4.1.5 Flexure of channel (assume a beam with two loads to calculate the bending moment)

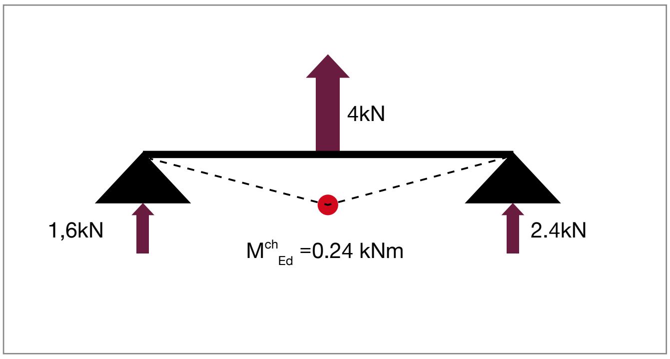
$$M_{ch,Ed} \le M_{Rd,s,flex} = \frac{M_{Rk,s,flex}}{\gamma_{Ms,flex}}$$

$M^{ch}{}_{Ed}$ =0.24 kNm $M_{Rk,s,flex}$ = 1.596 kNm

$\gamma_{Ms,flex}$ = 1.15 $M_{Rd,s,flex}$ = 1.39 kNm

$$\beta_{N,s,flex} = \frac{0.24}{1.39} = 18\%$$

anchor spacing = 250



4.2 Concrete failure

4.2.1 Pull-out failure (Anchor a1) (EN 1992-4 section 7.4.1.4)

$$N^{a}_{Ed} \le N_{Rd,p} = \frac{N_{Rk,p}}{\gamma_{Mp}}$$

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

A_h = 258 mm^2
f_{ck} = 30 MPa
$N_{Rk,p}$ = 58 kN
$N_{Rd,p}$ = 38.70 kN

k_2 = 7.5
N^a_{Ed} = 4.93 kN
γ_{Mp} = 1.5

$$\beta_{N,p} = \frac{4.93}{38.70} = 13\%$$

4.2.2 Concrete cone failure (Anchor a_1) (EN 1992-4 section 7.4.1.5)

$$N^{a}_{Ed} \le N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$$

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

$$N^0{}_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}{}^{1.5}$$

$$N^0{}_{Rk,c} = 8.2 \times \sqrt{30} \times 106^{1.5} = 49.02 \text{ kN}$$

$$\psi_{ch,s,N} = \frac{1}{1 + \sum_{i=1}^{n_{ch,N}} \left[\left(1 - \frac{s_i}{s_{cr,N}}\right) \cdot \frac{N_i}{N_0}\right]} \le 1.0$$

$$\psi_{ch,s,N} = \frac{1}{1 + \left(1 - \frac{250}{431}\right)^{1.5} \cdot \frac{3.12}{4.93}} = 0.85$$

$$s_{cr,N} = 2 \cdot \left(2.8 - \frac{1.3 h_{ef}}{180}\right) \cdot h_{ef} \ge 3 h_{ef}$$

$$s_{cr,N} = 2 \times \left(2.8 - \frac{1.3 \times 106}{180}\right) \times 106 = 431 \text{ mm}$$

$$\psi_{ch,e,N} = \left(\frac{c_1}{c_{cr,N}}\right)^{0.5} \le 1.0$$

$c_{cr,N}$ = critical edge distance i.e. 0.5 $s_{cr,N}$ ≥ 1.5h_{ef}
$c_{cr,N}$ = 0.5 x 431 = 216 mm ≥ 159 mm

$$\psi_{ch,e,N} = \left(\frac{100}{216}\right)^{0.5} = 0.68$$

$$\psi_{ch,c,N,1} = \left(\frac{c_{2,1}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{2,1} \text{ given)}$$

$$\psi_{ch,c,N,2} = \left(\frac{c_{2,2}}{c_{cr,N}}\right)^{0.5} = 1.0 \text{ (No } c_{2,2} \text{ given)}$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \le 1.0$$

$$N_{Rk,c} = 49.02 \times 0.85 \times 0.68 \times 1.0 \times 1.0 \times 1.0 = 28.33 \text{ kN}$$

k_1 = 8.2
h_{ef} = 106 mm
s = 250 mm
$\psi_{ch,s,N}$ = 0.85
$c_{cr,N}$ = 216 mm
$\psi_{ch,e,N,1}$ = 1.0
$\psi_{re,N}$ = 1.0
$N_{Rk,c}$ = 28.33 kN
$N_{Rd,p}$ = 18.89 kN

f_{ck} = 30 MPa
$N^0{}_{Rk,c}$ = 38.04 kN
$s_{cr,N}$ = 431 mm
c_1 = 100 mm
$\psi_{ch,e,N}$ = 0.68
$\psi_{ch,e,N,2}$ = 1.0
N^a_{Ed} = 4.93 kN
γ_{Mc} = 1.5

$$\beta_{N,c} = \frac{4.93}{18.89} = 26\%$$

Shear loading summary

Type of failure mode	Applied Load [kN]	Resistance [kN]	Utilization [%]	Status
Channel bolt w/o lever arm	12.75	26.96	48	Ok
Flexure channel lip w/o lever arm perpendicular	12.75	19.44	66	Ok
Anchor perpendicular	15.75	35.73	44	Ok
Connection anchor-channel perpendicular	15.75	29.78	53	Ok
Rebar steel-perpendicular	12.12	49.17	25	Ok
Rebar anchorage- perpendicular	12.12	49.60	25	Ok
Concrete pry out-perpendicular	15.75	37.77	42	Ok
Concrete edge perpendicular	15.75	40.05	40	Ok

4.3 Steel failure (EN 1992-4 section 7.4.2.3)

4.3.1 Channel bolt

$$V^{cb}_{Ed} \leq V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$$

$V^{cb}_{Ed,y}$ = 12.75 kN $V_{Rk,s,}$ = 33.7 kN
γ_{Ms} = 1.25 $V_{Rd,s,}$ = 26.96 kN

$$\beta_{V,s} = \frac{12.75}{26.96} = 48\%$$

4.3.2 Local flexure of channel lips (EN 1992-4 section 7.4.2.3)

$$V^{cb}_{Ed,y} \leq V_{Rd,s,l,y} = \frac{V_{Rk,s,l,y}}{\gamma_{Ms,l}}$$

$$V_{Rk,s,l,y,red} = V^{0}_{Rk,s,l,y} \cdot \psi_{sl,V,red}$$

$$\psi_{sl,v,red} = \frac{1}{1 + \sum_{i=2}^{n+1}\left[\left(1 - \frac{s_{chb,i}}{s_{chb,cr,V}}\right) \times \frac{V^{cb}_{Ed,y,i}}{V^{cb}_{Ed,y,1}}\right]} \leq 1.0$$

(Equation based on Hilti design method)

$s_{chb,cr,V}$ = $s_{chb,cr,0}$ - 0.9 c1 ≥ 3 . ds
$s_{chb,cr,0}$ = 240 mm (basic critical bolt spacing, fixed value) ,
$s_{chb,cr,V}$ = 150 mm

$$\psi_{sl,v,red} = \frac{1}{1 + \left[\left(1 - \frac{150}{150}\right) \times \frac{12.75}{12.75}\right]} \leq 1.0$$

$\psi_{sl,v,red}$ = 1.0

$V_{cbEd,y}$ = 12.75 kN $V^{0}_{Rk,s,l,y}$ = 47.50 kN
$V_{Rk,s,l,y}$ = 47.5 kN $\gamma_{Ms,l,y}$ = 1.8
$V_{Rd,s,l,y}$ = 19.44 kN

$$\beta_{V,s,l,y} = \frac{12.75}{19.44} = 66\%$$

4.3.3 Anchor-shear perpendicular (Anchor a1) (EN 1992-4 section 7.4.2.3)

$$V^{a}_{Ed,y} \leq V_{Rd,s,a,y} = \frac{V_{Rk,s,a,y}}{\gamma_{Ms}}$$

$V^{a}_{Ed,y}$ = 15.75 kN $V_{Rk,s,a,y}$ = 53.6 kN
γ_{Ms}= 1.5 $V_{Rd,s,a,y}$ = 35.73 kN
(same as tension capacity for quadratic interaction)

$$\beta_{V,s,a,y} = \frac{15.75}{35.73} = 44\%$$

4.3.4 Local flexure of channel lips (EN 1992-4 section 7.4.2.3)

$$V^{a}_{Ed,y} \leq V_{Rd,s,c,y} = \frac{V_{Rk,s,c,y}}{\gamma_{Ms}}$$

$V^{a}_{Ed,y}$ = 15.75 kN $V_{Rk,s,c,y}$ = 53.6 kN
$\gamma_{Ms,ca}$ = 1.8 $V_{Rd,s,c,y}$ = 29.78 kN
(interaction)

$$\beta_{V,s,c,y} = \frac{15.75}{29.78} = 53\%$$

4.3.5 Rebar – Perpendicular (rebar 2)

$$N^{r}_{Ed,re} \leq N_{Rd,re} = \frac{N_{Rk,re}}{\gamma_{Ms}}$$

$N^{r}_{Ed,re}$ = 12.12 kN $N_{Rk,re} = \frac{\pi}{4} \times 12^2 \times 500\text{ Mpa} = 56.55\text{ kN}$
γ_{Ms} = 1.15 $N_{Rd,re}$ = 49.17 kN

$$\beta_{V,re,y} = \frac{12.12}{49.17} = 25\%$$

4.3.6 Rebar anchorage – Perpendicular (rebar 2) (EN 1992-1-1 section 2.4.2.4,3.1.6,8.4.2,8.4.4, 8.7.3,8.7.4)

$$N^{a}_{Ed,R} \leq N_{Rd,p,R}$$

$$l_{b,prov} \geq l_0 \geq l_{0,min}{}' = \max(0.3 \times \alpha_6 \times l_{b,req}, 15d_{sR}, 200mm)$$

$$l_{b,rqd} = \frac{d_{sR}}{4} \times \frac{\sigma_{sd}}{f_{bd}}$$

$$f_{bd} = 2.25 \times \eta_1 \times \eta_2 \times f_{ctd}$$

$$l_0 = \alpha_1 \times \alpha_2 \times \alpha_3 \times \alpha_5 \times \alpha_6 \times l_{b,rqd}$$

$$\alpha_1 = \alpha_3 = \alpha_5 = 1.0$$

$$0.7 \leq \alpha_2 = 1 - 0.15 \times \frac{c_d - d_{s,R}}{d_{s,R}}$$

$$\sigma_{Rd} = \frac{l_{b,prov}}{\alpha_2 \times \alpha_6} \times \frac{4}{d_{s,R}} \times f_{bd}$$

$$N_{Rd,p,R} = \frac{\pi \times d^2_{sR}}{4} \times \sigma_{Rd} = \frac{l_{b,prov}}{\alpha_2 \times \alpha_6} \times \pi \times d_{s,R} \times f_{bd}$$

η_1 = 1.0 η_2 = 1.0 f_{ctd} = 1.4 Mpa
f_{bd} = 3.0 MPa c_d = 31 mm (concrete cover)
$d_{s,R}$ = 12 mm α_2 = 0.76 α_6 = 1.50
$N^{a}_{Ed,R}$ = 12.12 kN $l_{b,prov}$ = 500 mm
σ_{Rd} = 438.60 Mpa $N_{Rd,p,R}$ = 49.60 kN

$$\beta_{V,R,y} = \frac{12.12}{49.60} = 25\%$$

4.4 Concrete failure

4.4.1 Concrete pry-out failure – shear perpendicular (Anchor a1) (EN 1992-4 section 7.4.2.4)

$$V^a_{Ed,y} \leq V_{Rd,cp,y} = \frac{V_{Rk,cp,y}}{\gamma_{Mc}}$$

$$V_{Rk,cp,y} = k_8 \times N_{Rk,c}$$

$N_{Rk,c}$ taken from section 4.2.2
$N_{Rk,c}$ = 28.33 kN
K_8 = 2.0

$V^a_{Ed,y}$ = 15.75 kN	$N_{Rk,c}$ = 28.33 kN	$V_{Rk,cp,y}$ = 56.66 kN
γ_{Mc} = 1.5	$V_{Rd,cp,y}$ = 37.77 kN	

$$\beta_{V,cp,y} = \frac{15.75}{37.77} = 42\%$$

$h_{cr,v} = 2c_1$

$h_{cr,v}$ = 2x100=200 mm

$$\psi_{ch,h,V} = \left(\frac{150}{200}\right)^{0.25} = 0.93$$

$$V_{Rk,c,y} = 66.67 \times 0.97 \times 1.0 \times 1.0 \times 0.93 \times 1.0 = 60.14 \text{ kN}$$

$K_{(c)RTOS}$ = 415	x_1 = 0.97	x_2 = 0.18
x_3 = 0.25	x_4 =0.11	f_{ck} = 30 MPa
c_1 = 100 mm	$V^0_{Rk,c}$= 66.67 kN	
s = 250 mm	$\alpha_{1,V}$ = 0.60	$s_{cr,V}$ = 290 mm
$\psi_{ch,s,V,r}$ = 0.97	$c_{cr,V}$ = 242 mm	$\psi_{ch,c,V,1,r}$ = 1.0
$\psi_{ch,c,V,2,r}$ = 1.0	h = 150 mm	$h_{cr,V}$ = 200 mm
$\psi_{ch,h,V}$ = 0.93	$\psi_{re,V,r}$ = 1.0	$V^a_{Ed,y}$ = 15.75 kN
$V_{Rk,c,y}$ = 60.14 kN	γ_{Mc}= 1.5	$V_{Rd,c,y}$ = 40.1 kN

$$\beta_{V,c,y} = \frac{15.75}{40.10} = 40\%$$

4.4.2 Concrete edge failure – shear perpendicular (Anchor a1) (Hilti design method)

$$V^a_{Ed,y} \leq V_{Rd,c,y} = \frac{V_{Rk,c,y}}{\gamma_{Mc}}$$

$$V_{Rk,c,y} = V^0_{Rk,c} \times \psi_{ch,s,V,r} \times \psi_{ch,c,V,1,r} \times \psi_{ch,c,V,2,r} \times \psi_{ch,h,V,r} \times \psi_{re,V,r}$$

$$V^0_{Rk,c} = k_{(C)RTOS} \cdot c_1^{x_1} \cdot f_{ck}^{x2}$$

$$V^0_{Rk,c} = 415 \times 100^{0.97} \times 30^{0.18} = 66.67 \text{ kN}$$

$$\psi_{ch,s,V,r} = \frac{1}{1 + \sum_{i=2}^{n_{ch,V+1}} \left[\left(1 - \frac{s_i}{s_{cr,V}}\right)^{1.5} \cdot \frac{V_i}{V_0}\right]} \leq 1.0$$

$$\psi_{ch,s,V} = \frac{1}{1 + \left(1 - \frac{250}{290}\right)^{1.5} \cdot \frac{9.86}{15.63}} = 0.97$$

$s_{cr,V}$ = $\alpha_{1,V}$ x (4 c_1 + 2 b_{ch})
$s_{cr,V}$ = 0.6 x (4 x100 + 2 x 42) =290 mm
$c_{cr,V}$ = 2 x c_1 + b_{ch}
$c_{cr,V}$ = 2 x100 x 42 = 242 mm

$$\psi_{ch,c,V} = \left(\frac{c_{2,1}}{c_{cr,V}}\right)^{x_4} \leq 1.0$$

$$\psi_{ch,c,V,1,r} = 1.0 \text{ (no } c_{2,1} \text{ given)}$$

$$\psi_{ch,c,V,2,r} = 1.0 \text{ (no } c_{2,2} \text{ given)}$$

$$\psi_{ch,h,V,r} = \left(\frac{h}{h_{cr,V}}\right)^{x_3} \leq 1.0$$

4.4.3 Crack width at channel side in SLS (rebar a_1 channel a)

$N^r_{Ed,\ (first/last)}$ [kN] = 11.340 γ_{SLS} = 1.000

N^r_{SLS} [kN] = 11.340 α_{LC} = 0.430

Cracking of the concrete may occur at service load levels. The characteristic crack width w_k is less than 0.3 mm (0.012 in.). This value is calculated based on experimental investigations on anchor channels loaded in shear in unreinforced concrete slabs.

4.5 Combined tension and shear loads (EN 1992-4 section 8.3.3, Hilti method based on CEN-TR section 7.3)

4.5.1 Channel bolt (bolt 1)

$$\beta_{N+V,s} = (\beta_{N,s})^2 + (\beta_{V,s})^2 \leq 1.0$$

$$\beta_{N+V,s} = (0.09)^2 + (0.48)^2 = 0.24$$

Utilization = 24%

4.5.2 Point of load application – channel lip (bolt 1)

$$\beta_{N+V,la,c} = (\beta_{N,s,l})^{k_{13}} + (\beta_{V,s,l,y})^{k_{13}} \leq 1.0$$

k_{13} = 2.0 if $V_{Rd,s,l} \leq N_{Rd,s,l}$

$$\beta_{N+V,la,c} = (0.21)^2 + (0.66)^2 = 0.48$$

Utilization = 48%

4.5.3 Anchor and connection between anchor and channel (anchor a1)

$$\beta_{N+V,ac} = \max\left(\beta_{N,s,a};\beta_{N,s,c}\right)^{k_{14}} + \max\left(\beta_{V,s,a,y};\beta_{V,s,c,y}\right)^{k_{14}} \leq \left(1-\max\left(\beta_{V,s,a,x};\beta_{V,s,c,x}\right)\right)^{k_{14}}$$

$k_{14} = 1.0$

$$\beta_{N+V,ac} = \max\left(0.17;0.26\right)^{1.0} + \max\left(0.44;0.53\right)^{1.0} \leq 1.0$$

$$\beta_{N+V,ac} = \left(0.26\right)^{1.0} + \left(0.53\right)^{1.0} = 0.79$$

Utilization = 79%

4.5.4 Concrete (anchor a1)

$$\beta_{N+V,c} = \left(\beta_{N,c}\right)^{1.5} + \left(\beta_{V,c,y}\right)^{1.5} \leq 1.0$$

$$\beta_{N+V,c} = \left(0.26\right)^{1.5} + \left(0.42\right)^{1.5} = 0.41$$

Utilization = 41%

Design ok! (Maximum utilization: 79%)

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