Anchor design

Safety concept

Depending on the application and the anchor type one of the following two concepts can be applied:

For anchors for use in concrete having an European Technical Approval (ETA) the partial safety factor concept according to the European Technical Approval Guidelines ETAG 001 or ETAG 020 shall be applied. It has to be shown, that the value of design actions does not exceed the value of the design resistance: \( S_d \leq R_d \).

For the characteristic resistance given in the respective ETA, reduction factors due to e.g. freeze/thaw, service temperature, durability, creep behaviour and other environmental or application conditions are already considered.

In addition to the design resistance, in this manual recommended loads are given, using an overall partial safety factor for action \( \gamma = 1.4 \).

---

**Partial safety factor concept**

**Global safety factor concept**

For the global safety factor concept it has to be shown, that the characteristic value of action does not exceed the recommend load value.

The characteristic resistance given in the tables is the 5% fractile value obtained from test results under standard test conditions. With a global safety factor all environmental and application conditions for action and resistance are considered, leading to a recommended load.
Design methods

**Metal anchors for use in concrete according ETAG 001**

The design methods for metal anchors for use in concrete are described in detail in Annex C of the European Technical Approval guideline ETAG 001 and for bonded anchors with variable embedment depth in EOTA Technical Report TR 029. Additional design rules for redundant fastenings are given in Part 6 of ETAG 001.

The design method given in this Anchor Fastening Technology Manual is based on these guidelines. The calculations according to this manual are simplified and lead to conservative results, i.e. the results are on the save side. Tables with basic load values and influencing factors and the calculation method are given for each anchor in the respective section.

**Anchors for use in other base materials and for special applications**

If no special calculation method is given, the basic load values given in this manual are valid, as long as the application conditions (e.g. base material, geometry, environmental conditions) are observed.

**Redundant fastenings with plastic anchors**

Design rules for redundant fastenings with plastic anchors for use in concrete and masonry for non-structural applications are given in Annex C of ETAG 020. The additional design rules for redundant fastenings are considered in this manual.

**Resistance to fire**

When resistance to fire has to be considered, the load values given in the section “resistance to fire” should be observed. The values are valid for a single anchor.

**Hilti design software PROFIS Anchor**

For a more complex and accurate design according to international and national guidelines and for applications beyond the guidelines, e.g. group of anchors with more than four anchors close to the edge or more than eight anchors far away from the edge, the Hilti design software PROFIS Anchor yields customised fastening solutions. The results can be different from the calculations according to this manual.

The following methods can be used for design using PROFIS Anchor:

- ETAG
- CEN/TS
- ACI 318-08
- CSA (Canadian standard)
- Solution for Fastening (Hilti internal design method)
**Simplified design method**

Simplified version of the design method A according ETAG 001, Annex C or EOTA Technical Report TR 029. Design resistance according data given in the relevant European Technical Approval (ETA)

- Influence of concrete strength
- Influence of edge distance
- Influence of spacing
- Valid for a group of two anchors. (The method may also be applied for anchor groups with more than two anchors or more than one edge. The influencing factors must then be considered for each edge distance and spacing. The calculated design loads are then on the save side: They will be lower than the exact values according ETAG 001, Annex C. To avoid this, it is recommended to use the anchor design software PROFIS anchor)

The design method is based on the following simplification:

- No different loads are acting on individual anchors (no eccentricity)

The differences to the design method given in the guideline are shown in the following.

---

**Annex C of ETAG 001 and EOTA TR 029 compared to simplified design**

**Design tensile resistance**

The design tensile resistance is the lower value of

- Design steel resistance \( N_{Rd,s} \)
- Design pull-out resistance \( N_{Rd,p} \)
- Design concrete cone resistance \( N_{Rd,c} \)
- Design splitting resistance \( N_{Rd,sp} \)

**Design steel resistance \( N_{Rd,s} \)**

Annex C of ETAG 001 / EOTA TR 029 and relevant ETA

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

* \( N_{Rk,s} \): characteristic steel resistance
* \( \gamma_{Ms} \): partial safety factor for steel failure
* Values given in the relevant ETA

Simplified design method

\[
N_{Rd,s} = N_{0,Rd,s} \cdot f_B
\]

** \( N_{0,Rd,s} \)**: Basic design steel resistance
** \( f_B \)**: influence of concrete strength
* Values given in the respective tables in this manual

**Design pull-out resistance \( N_{Rd,p} \)** for anchors designed according Annex C of ETAG 001

Annex C of ETAG 001 and relevant ETA

\[
N_{Rd,p} = (N_{Rk,p} / \gamma_{Mp}) \cdot \psi_c
\]

* \( N_{Rk,p} \): characteristic pull-out resistance
* \( \gamma_{Mp} \): partial safety factor for pull-out failure
* \( \psi_c \): influence of concrete strength
* Values given in the relevant ETA

Simplified design method

\[
N_{Rd,p} = N_{0,Rd,p} \cdot f_B
\]

** \( N_{0,Rd,p} \)**: Basic design pull-out resistance
** \( f_B \)**: influence of concrete strength
* Values given in the respective tables in this manual
## Design combined pull-out and concrete cone resistance $N_{Rd,p}$ for bonded anchors designed according EOTA TR 029

### EOTA TR 029 and relevant ETA

$$N_{Rd,p} = \left( N_{Rk,p}^0 / \gamma_{N\text{p}} \right) \cdot \left( A_{p,N} / A_{p,k,N} \right) \cdot \gamma_{s,Np} \cdot \gamma_{g,Np} \cdot \gamma_{e,Np} \cdot \gamma_{c}$$

where

- $N_{Rk,p}^0 = \pi \cdot d \cdot h_{ef} \cdot \tau_{Rk}$
- $\gamma_{g,Np} = \psi_{g,Np} - \left( s / s_{cr,Np} \right)^{0.5} \cdot \left( \psi_{g,Np}^0 - 1 \right) \geq 1$
- $\psi_{g,Np}^0 = n^{0.5} - \left( n^{0.5} - 1 \right) \cdot \left\{ (d \cdot \tau_{Rk}) / \left[ k \cdot (h_{ef} \cdot f_{ck,cube})^{0.5} \right] \right\}^{1.5} \geq 1$
- $s_{cr,Np} = 20 \cdot d \cdot \left( \tau_{Rk,ucr} / 7,5 \right)^{0.5} \leq 3 \cdot h_{ef} \cdot * \gamma_{N\text{p}}$: partial safety factor for combined pull-out and concrete cone failure
- $A_{p,N}:$ influence area of an individual anchor with large spacing and edge distance at the concrete surface (idealised)
- $A_{p,k,N}:$ actual influence area of the anchorage at the concrete surface, limited by overlapping areas of adjoining anchors and by edges of the concrete member
- $\gamma_{s,Np}:$ influence of the disturbance of the distribution of stresses due to edges
- $\psi_{e,Np}:$ influence of eccentricity
- $\psi_{e,Np}:$ influence of dense reinforcement
- $\psi_{c}:$ influence of concrete strength
- $d$: anchor diameter
- $h_{ef}:$ (variable) embedment depth
- $\tau_{Rk}:$ characteristic bond resistance
- $s$: anchor spacing
- $s_{cr,Np}:$ critical anchor spacing
- $n$: number of anchors in a anchor group

<table>
<thead>
<tr>
<th>k:</th>
<th>= 2,3 in cracked concrete</th>
</tr>
</thead>
<tbody>
<tr>
<td>f_{ck,cube}:</td>
<td>concrete compressive strength</td>
</tr>
</tbody>
</table>

* Values given in the relevant ETA
+ Values have to be calculated according data given in the relevant ETA (details of calculation see TR 029. The basis of the calculations may depend on the critical anchor spacing).

### Simplified design method

$$N_{Rd,p} = N_{Rd,p}^0 \cdot f_{B,p} \cdot f_{1,N} \cdot f_{2,N} \cdot f_{3,N} \cdot f_{h,p} \cdot f_{e,N}$$

- $N_{Rd,p}^0$: Basic design combined pull-out and concrete cone resistance
- $f_{B,p}:$ influence of concrete strength
- $f_{1,N}, f_{2,N}:$ influence of edge distance
- $f_{3,N}:$ influence of anchor spacing
- $f_{h,p}:$ influence of (variable) embedment depth
- $f_{e,N}:$ influence of dense reinforcement

**Values given in the respective tables in this manual**

For the simplified design method the factor $\psi_{g,Np}$ (see TR 029) is assumed to be 1 and the critical anchor spacing is assumed to be $s_{cr,Np} = 3 \cdot h_{ef}$, both leading to conservative results = being on the save side.
Design concrete cone resistance $N_{Rd,c}$

**Annex C of ETAG 001 / EOTA TR 029 and relevant ETA**

$$N_{Rd,c} = \left( N_{Rk,c}^{0} / \gamma_{Mc} \right) \cdot (A_{c,N} / A_{c,N}^{0}) \cdot \psi_{s,N} \cdot \psi_{es,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{ef,N}.$$

where

- $N_{Rk,c}^{0} = k_1 \cdot f_{ck,cube}^{0.5} \cdot h_{ef}^{1.5}$
- $\gamma_{Mc}$: partial safety factor for concrete cone failure
- $A_{c,N}^{0}$: area of concrete cone of an individual anchor with large spacing and edge distance at the concrete surface (idealised)
- $A_{c,N}$: actual area of concrete cone of the anchorage at the concrete surface, limited by overlapping concrete cones of adjoining anchors and by edges of the concrete member
- $\psi_{s,N}$: influence of the disturbance of the distribution of stresses due to edges
- $\psi_{es,N}$: influence of dense reinforcement
- $\psi_{ec,N}$: influence of excentricity
- $k_1$: = 7.2 for anchorages in cracked concrete
  = 10.1 for anchorages in non-cracked concrete
- $f_{ck,cube}$: concrete compressive strength
- $h_{ef}$: effective anchorage depth

**Simplified design method**

$$N_{Rd,c} = N_{Rd,c}^{0} \cdot f_B \cdot f_{1,N} \cdot f_{2,N} \cdot f_{3,N} \cdot f_{re,N} \cdot f_{ec,N}.$$

**$N_{Rd,c}^{0}$**: Basic design concrete cone resistance

- $f_B$: influence of concrete strength
- $f_{1,N}$, $f_{2,N}$: influence of edge distance
- $f_{3,N}$: influence of anchor spacing
- $f_{re,N}$: influence of embedment depth
- $f_{ec,N}$: influence of dense reinforcement

**Values given in the respective tables in this manual**

*Values given in the relevant ETA*

*Values have to be calculated according data given in the relevant ETA (details of calculation see Annex C of ETAG 001 or EOTA TR 029)*
## Design concrete splitting resistance $N_{Rd,sp}$

### Annex C of ETAG 001 / EOTA TR 029 and relevant ETA

$$N_{Rd,sp} = \left( N_{Rk,c}^0 / \gamma_{Mc} \right) \cdot (A_{c,N} / A_{c,N}^0) \cdot \Psi_{s,N} \cdot \Psi_{re,N} \cdot \frac{\Psi_{ec,N} \cdot \Psi_{h,sp}}{}$$

where

- $N_{Rk,c}^0$: partial safety factor for concrete cone
- $A_{c,N}^0$: area of concrete cone of an individual anchor with large spacing
- $A_{c,N}$: actual area of concrete cone of the anchorage at the concrete surface, limited by overlapping concrete cones of adjoining anchors
- $\gamma_{Mc}$: failure
- $k_1$: influence of the disturbance of the distribution of stresses due to edges
- $\Psi_{s,N}$: influence of dense reinforcement
- $\Psi_{re,N}$: influence of excentricity
- $f_{ck,cube}$: concrete compressive strength
- $h_{ef}$: embedment depth
- $f_{h,N}$: influence of base material thickness (concrete member depth)
- $f_{re,N}$: influence of dense reinforcement
- $f_B$: influence of concrete strength
- $f_{1,sp}$, $f_{2,sp}$: influence of edge distance
- $f_{3,sp}$: influence of anchor spacing

### Simplified design method

$$N_{Rd,sp} = N_{Rd,c}^0 \cdot f_B \cdot f_{1,sp} \cdot f_{2,sp} \cdot f_{3,sp} \cdot f_{h,N} \cdot f_{re,N}$$

** $N_{Rd,c}^0$: Basic design concrete cone resistance
** $f_B$: influence of concrete strength
** $f_{1,sp}$, $f_{2,sp}$: influence of edge distance
** $f_{3,sp}$: influence of anchor spacing
** $f_{h,N}$: influence of base material thickness (concrete member depth)
** $f_{re,N}$: influence of dense reinforcement

Values given in the respective tables in this manual.

Values have to be calculated according to data given in the relevant ETA (details of calculation see Annex C of ETAG 001 or EOTA TR 029).

++ Values of $A_{c,N}^0$ and $A_{c,N}$ for splitting failure may be different from those for concrete cone failure, due to different values for the critical edge distance and critical anchor spacing.

Values given in the relevant ETA (details of calculation see Annex C of ETAG 001 or EOTA TR 029).

++ Values of $A_{c,N}^0$ and $A_{c,N}$ for splitting failure may be different from those for concrete cone failure, due to different values for the critical edge distance and critical anchor spacing.
Design shear resistance

The design shear resistance is the lower value of
- Design steel resistance $V_{Rd,s}$
- Design concrete pryout resistance $V_{Rd,cp}$
- Design concrete edge resistance $V_{Rd,c}$

### Design steel resistance $V_{Rd,s}$ (without lever arm)

<table>
<thead>
<tr>
<th>Annex C of ETAG 001 / EOTA TR 029 and relevant ETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{Rd,s} = \frac{V_{Rk,s}}{\gamma_{Ms}}$</td>
</tr>
<tr>
<td>* $V_{Rk,s}$: characteristic steel resistance</td>
</tr>
<tr>
<td>* $\gamma_{Ms}$: partial safety factor for steel failure</td>
</tr>
<tr>
<td>* Values given in the relevant ETA</td>
</tr>
</tbody>
</table>

For steel failure with lever arm see Annex C of ETAG 001 or EOTA TR 029

### Simplified design method

** $V_{Rd,s}$

** Value given in the respective tables in this manual

Steel failure with lever arm is not considered for the simplified design method

### Design concrete pryout resistance $V_{Rd,cp}$ for anchors designed according Annex C of ETAG 001

<table>
<thead>
<tr>
<th>Annex C of ETAG 001 and relevant ETA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{Rd,cp} = (\frac{V_{Rk,cp}}{\gamma_{Mc}}) = k \cdot N_{Rd,c}$</td>
</tr>
<tr>
<td>* $V_{Rk,cp}$: characteristic tension resistance for concrete cone failure</td>
</tr>
<tr>
<td>* $\gamma_{Mc}$: partial safety factor for concrete cone failure</td>
</tr>
<tr>
<td>* $k$: influence of embedment depth</td>
</tr>
<tr>
<td>* Values given in the relevant ETA</td>
</tr>
</tbody>
</table>

### Simplified design method

** $V_{Rd,cp}$

** $N_{Rd,c}$: characteristic tension resistance for concrete cone failure  (see design concrete cone failure)

** $k$: influence of embedment depth

** Value given in the respective tables in this manual
Design concrete pryout resistance $V_{Rd,cp}$ for bonded anchors designed according EOTA TR 029

### EOTA TR 029 and relevant ETA

$$V_{Rd,cp} = \left( \frac{V_{Rk,cp}}{\gamma_{Mp}/\gamma_{Mc}} \right) = k \cdot \text{lower value of } N_{Rd,p} \text{ and } N_{Rd,c}$$

- $N_{Rd,p} = N_{Rk,p} / \gamma_{Mp}$
- $N_{Rd,c} = N_{Rk,c} / \gamma_{Mc}$
- $N_{Rd,p}$: characteristic tension resistance for combined pull-out and concrete cone failure (see design combined pull-out and concrete cone failure)
- $N_{Rk,p}$: characteristic tension resistance for combined pull-out and concrete cone failure (see design combined pull-out and concrete cone failure)
- $N_{Rk,c}$: characteristic tension resistance for concrete cone failure (see design concrete cone failure)
- $\gamma_{Mp}$: partial safety factor for combined pull-out and concrete cone failure (see design combined pull-out and concrete cone failure)
- $\gamma_{Mc}$: partial safety factor for concrete cone failure (see design concrete cone failure)
- $k$: influence of embedment depth

### Simplified design method

$$V_{Rd,cp} = k \cdot \text{lower value of } N_{Rd,p} \text{ and } N_{Rd,c}$$

- $N_{Rd,p}$: characteristic tension resistance for combined pull-out and concrete cone failure (see design combined pull-out and concrete cone failure)
- $N_{Rk,c}$: characteristic tension resistance for concrete cone failure (see design concrete cone failure)
- $k$: influence of embedment depth

*Values given in the respective tables in this manual
Design concrete edge resistance $V_{rd,c}$

**Annex C of ETAG 001 / EOTA TR 029 and relevant ETA**

$$V_{rd,c} = (V^0_{Rk,c} / \gamma_{Mc}) \cdot (A_{c,V} / A^0_{c,V}) \cdot \psi_{s,V} \cdot \psi_{h,V} \cdot \psi_{u,V} \cdot \psi_{w,V} \cdot \psi_{ec,V} \cdot \psi_{re,V}$$

where

$$V^0_{Rk,c} = k_1 \cdot d^\alpha \cdot h_{ef}^\beta \cdot f_{ck,cube}^{0.5} \cdot c_1^{1.5}$$

$$\alpha = 0.1 \cdot (h_{ef} / c_1)^{0.5}$$

$$\beta = 0.1 \cdot (d / c_1)^{0.2}$$

* $\gamma_{Mc}$: partial safety factor for concrete edge failure
+ $A^0_{c,V}$: area of concrete cone of an individual anchor at the lateral concrete surface not affected by edges (idealised)
+ $A_{c,V}$: actual area of concrete cone of anchorage at the lateral concrete surface, limited by overlapping concrete cones of adjoining anchors,

by edges of the concrete member and by member thickness
+ $\psi_{s,V}$: influence of the disturbance of the distribution of stresses due to further edges
+ $\psi_{h,V}$: takes account of the fact that the shear resistance does not decrease proportionally to the member thickness as assumed by the idealised ratio $A_{c,V} / A^0_{c,V}$
++ $\psi_{u,V}$: Influence of angle between load applied and the direction perpendicular to the free edge
++ $\psi_{ec,V}$: influence of eccentricity
++ $\psi_{re,V}$: influence of reinforcement

$k_1$: $= 1.7$ for anchorages in cracked concrete
$= 2.4$ for anchorages in non-cracked concrete

* $d$: anchor diameter
$f_{ck,cube}$: concrete compressive strength
$c_1$: edge distance

**Simplified design method**

$$V_{rd,c} = V^0_{Rd,c} \cdot f_B \cdot f_h \cdot f_4 \cdot f_{hef} \cdot f_c$$

** $V^0_{Rd,c}$**: Basic design concrete edge resistance
** $f_B$**: influence of concrete strength
** $f_h$**: Influence of angle between load applied and the direction perpendicular to the free edge
** $f_4$**: Influence of anchor spacing and edge distance
** $f_{hef}$**: influence of embedment depth
** $f_c$**: influence of edge distance

**Values given in the respective tables in this manual**

The factors $f_{hef}$ and $f_c$ replace the function $d^\alpha \cdot h_{ef}^\beta$, leading to conservative results = being on the safe side.

**Special case: more than 2 anchors close to an edge**

For a group of anchors $f_4$ can be calculated according to the following equation, if all anchors are equally loaded. This can be achieved by filling the annular gaps with a high performance injection mortar (e.g. Hilti HIT-RE 500-SD or Hilti HIT-HY 150 MAX).

$$f_4 = \left( \frac{c \cdot \left( 1 + \frac{s_1 + s_2 + \ldots + s_{n-1}}{3 \cdot c} \right)}{\eta_{ef}} \right)^{15}$$

Where $s_1, s_2, \ldots, s_{n-1} \leq 3 \cdot c$

And $c_{2,1}, c_{2,2} \geq 1.5 \cdot c$
### Combined tension and shear loading

The following equations must be satisfied:

\[ \beta_N \leq 1 \]

\[ \beta_V \leq 1 \]

\[ \beta_N + \beta_V \leq 1,2 \text{ or } \beta_N^* + \beta_V^* \leq 1 \]

With

\[ \beta_N = \frac{N_{sd}}{N_{Rd}} \]

\[ \beta_V = \frac{V_{sd}}{V_{Rd}} \]

\[ N_{sd} (V_{sd}) = \text{tension (shear) design action} \]

\[ N_{Rd} (V_{Rd}) = \text{tension (shear) design resistance} \]

### Annex C of ETAG 001

<table>
<thead>
<tr>
<th>( \alpha )</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>2,0</td>
<td>( N_{Rd} ) and ( V_{Rd} ) are governed by steel failure</td>
</tr>
<tr>
<td>1,5</td>
<td>for all other failure modes</td>
</tr>
</tbody>
</table>

### Simplified design method

Failure mode is not considered for the simplified method

\[ \alpha = 1,5 \]

for all failure modes (leading to conservative results = being on the save side)