

Design of large anchorages

Supplementary reinforcement

According to ETAG 001 annex C, section 7.2, anchorages with a resulting tensile load exceeding 60 kN (corresponding to roughly 90 kN at design level) need so called “hanger reinforcement” or embement depth of at least 80% of the member depth. (CEN-TS documents use the term “supplementary reinforcement”, in ACI 318, appendix D it is called “anchor reinforcement”.) In the further developments we will use the term “supplementary reinforcement”

Although Profis Achor does not explicitly take this paragraph into account, the user trying to design anchorages with high loads will often realize that the concrete cone or concrete edge capacity is insufficient and that Profis Achor will not provide a solution. According to the codes mentioned above, concrete cone or edge failure do not have to be taken into account if sufficiently anchored supplementary reinforcement can take up the corresponding loads. However, the codes state that supplementary reinforcement can in general only be taken into account for cast-in headed studs.

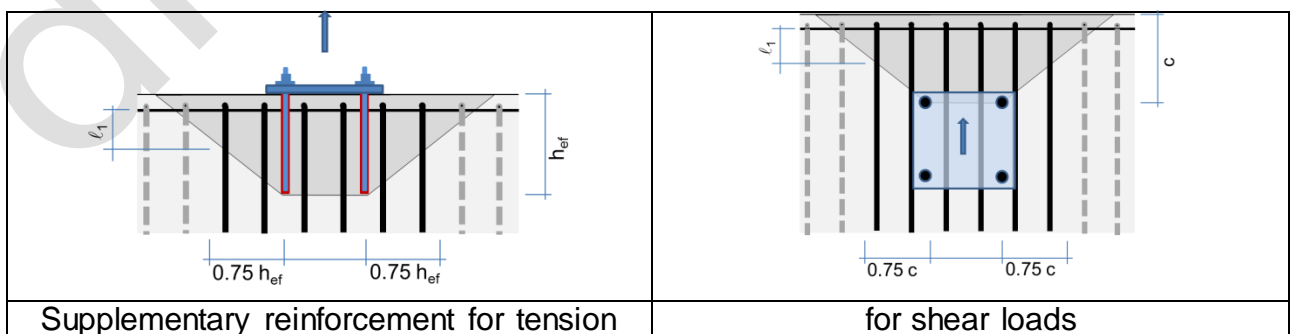
Post-installed anchors using supplementary reinforcement

The loads introduced by post installed anchors can be taken up by the reinforcement of the existing structure, if this reinforcement was foreseen for these loads already at design stage or if the surface reinforcement in place is not fully used to transfer loads present in the structure before applying the anchorage. The reinforcement taken into account as supplementary reinforcement should fulfill these requirements:

- Ribbed reinforcing bars with diameters $\phi \leq 16$ mm
- In general only bars of the same diameter should be taken into account as supplementary reinforcement.
- The supplementary bars should be ties or bent bars that encompass the surface reinforcement.
- Only bars at a distance of less than 0.75 times the depth of the relevant concrete breakout figure can be taken into account.
- Only those bars may be taken into account for which the anchorage length l_1 inside the breakout figure as well as the length outside it are at least equal to the minimum anchorage length:

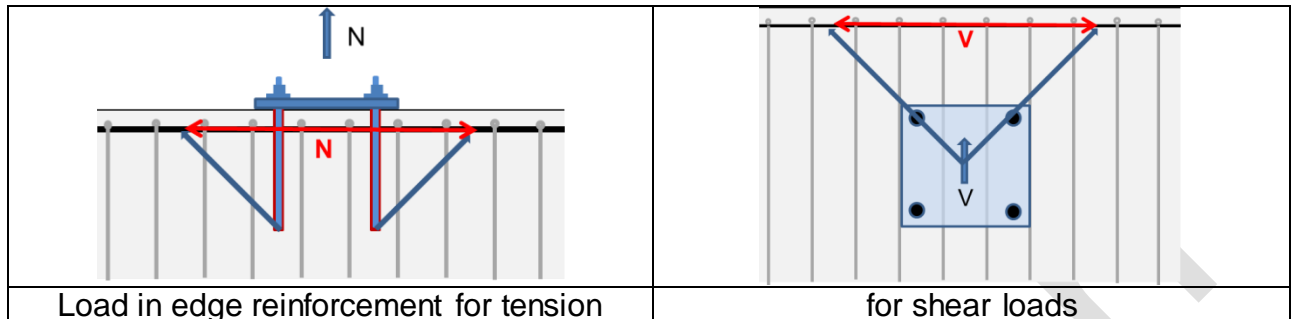
$$l_{\min} = 4\phi \quad \text{for ties and bars with end hooks or bends}$$

$$l_{\min} = 10\phi \quad \text{for bars with straight end}$$



- If the supplementary reinforcement ends inside the concrete section without leading the loads further into the structure, concrete cone and/or edge failure must be checked from the end of the supplementary reinforcement.

- A surface or edge reinforcement perpendicular to the anchor load is required to take up the splitting forces. The stress induced into this edge reinforcement can be estimated by a 45° strut and tie model:



Design of the supplementary reinforcement

Two design proofs are required: the steel resistance of the supplementary reinforcement must be sufficient to take up the loads and the supplementary reinforcement must be adequately anchored on both sides of the concrete breakout figure, so that the corresponding steel stress in the reinforcement can be developed at the concrete failure surface.

- a) Steel capacity of the supplementary reinforcement

$$N_{Rd,re} = n_{re} \cdot A_{s,re} \cdot f_{d,av,re}$$

n_{re} number of bars that can be taken into account as supplementary reinforcement. (in the figures above, the bars marked in black)

$A_{s,re}$ cross sectional area of one bar of the supplementary reinforcement

$f_{d,av,re}$ Steel capacity which is available to take up the anchor load.

If there is no other load transferred through the reinforcement, then $f_{d,av,re} = f_{yd}$ = design yield strength of the reinforcement ($f_{yd} \leq 520 \text{ N/mm}^2$).

If the reinforcement is already loaded by a design stress σ_{sd} before applying the anchorage, then: $f_{d,av,re} = f_{yd} - \sigma_{sd}$

- b) Anchorage of the supplementary reinforcement, to be checked for both sides of the failure plane
The force that can be developed inside a bar is

$$N_{Rd,a,i} = \frac{\ell_{1,i} \cdot \phi \cdot \pi \cdot f_{bd}}{\alpha_1 \cdot \alpha_2} \leq A_{s,re} \cdot f_{d,av,re}$$

$\ell_{1,i}$ anchorage length of the bar i

f_{bd} bond strength according to EN 1992-1-1. For normal cases and for concrete strengths up to C50/60 it can be taken as $f_{bd} = 0.315 \cdot f_{ck}^{2/3}$

α_1 factor for bar shape according to EN 1992-1-1:
 $\alpha_1 = 0.7$ for bars with hooks or bends
 $\alpha_1 = 1.0$ for bars with straight ends

α_2 factor for the influence of concrete cover according to EN 1992-1-1:
 $\alpha_2 = 0.7 \leq 1 - 0.15 \cdot \{(c_d - \phi) / \phi\} \leq 1.0$
 where c_d is the smaller of the concrete cover or half the bar spacing

The anchorage force that can be taken up by the supplementary reinforcement is limited by

$$N_{Rd,a} = \sum_{n_{re}} N_{Rd,a,i}$$

- c) Combination of tensile and shear loads

Sections a) and b) need to be checked separately for tensile and shear loads on the anchorage. If there is supplementary reinforcement for for one direction (either concrete cone or concrete edge), then the following equation shall be fulfilled:

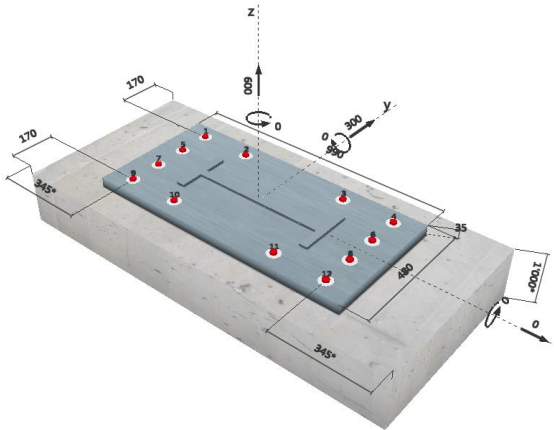
$$\left(\frac{N_{Ed}}{N_{Rd,i}} \right)^{2/3} + \left(\frac{V_{Ed}}{V_{Rd,i}} \right)^{2/3} \leq 1.0$$

If there is supplementary reinforcement for both tension and shear loads, then the standard interaction formulae according to ETAG or ACI apply.

- Cracked concrete
- Embedment depth $h_{ef} = 850$ mm
- Tension load $N_{Ed} = 600$ kN
- Shear load $V_{Ed} = 100$ kN
- M24 anchors

B) Try to provide a design with Profis Anchor!

Why is it not possible? List all the limits according to Profis Anchor.



It is not possible to design this case with Profis Anchor because:

1. Required embedment depth is out of approved values (max 20 diameters = 480mm)
2. Concrete cone and concrete edge limit approach to roughly 25% of the requirement (combined utilisation = 449%!).

design is only possible if the socket reinforcement is taken into account !

C) Engineering Judgement design assuming supplementary reinforcement

Design Basis

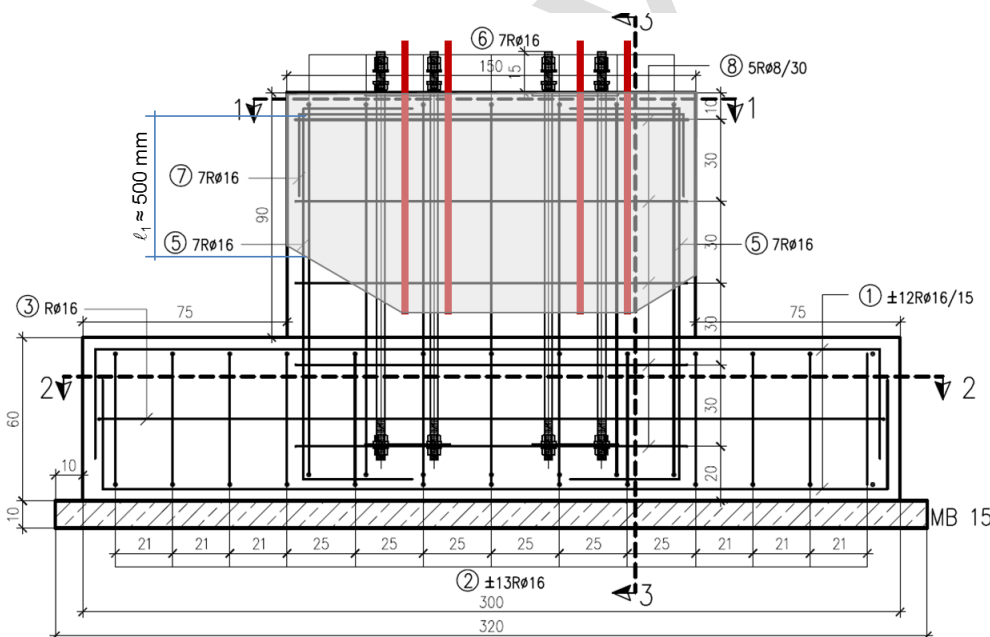
- [1] drawings of formwork and reinforcement received from customer by e-mail on 29/05/2012.
- [2] Mallée, Fuchs, Eligehausen: Design of Fastenings for Use in Concrete – the CEN/TS 1992-4 Provisions. Ernst & Sohn, Berlin, 2012.
- [3] Eurocode 2: design of concrete structures. BS-EN 1992-1-1:2004
- [4] EOTA: ETAG Technical Report TR 023: Design of Bonded Anchors. Brussels, 2010.
- [5] EOTA: ETA-08/0105: European Technical Approval for Injection System Hilti HIT-RE 500 for rebar connection. Berlin, 2008

Design proof of supplementary reinforcement [2]:

Note: according to [2], supplementary reinforcement can only be taken into account for cast-in headed anchors. In this specific case, by engineering judgement, the position of the reinforcement in the pedestal is sufficiently well known and the size of the concrete cone is large enough, so that the considerations can be adopted for bonded anchors.

a) Tension load

Position of supplementary reinforcement, M24 rods and concrete cone according to [1]



The reinforcement is BSt 500 with a design yield strength of $f_{yd} = 435 \text{ N/mm}^2$.

a1 Definition of supplementary reinforcement

Embedment depth of post-installed M24 anchors: $h_{ef} = 850\text{mm}$

Positions 5 and 6 [1] act as supplementary reinforcement, in total $n_{re} = 28$ bars $\phi 16$

Largest distance between post-installed M24 anchors and supplementary reinforcement is about 500mm $< 0.75h_{ef}$ -> all 28 bars $\phi 16$ (positions 5, 6) are close enough to the anchorage.

The length inside the concrete cone for the reinforcement bar farthest away from the anchorage is about 500mm, i.e. more than the minimum anchorage length of 4ϕ .

-> all 28 bars $\phi 16$ (positions 5, 6) can be considered as supplementary reinforcement for the cone.

a2 steel resistance of the supplementary reinforcement

Cross section $\phi 16$:	$A_{s, re} =$	201mm ²
Strength of supplementary reinf.	$f_{d, av, re} = f_{yd} =$	435 N/mm ² (no other vertical loads)
Resistance of supplementary reinf.:	$N_{Rd, re} = 28 \cdot 201 \cdot 0.435 =$	2448 kN $> N_{Ed}$ -> ok

a3 Anchorage of supplementary reinforcement according to EC2, section 8.4 [3]

maximum capacity per bar	$A_{s, re} \cdot f_{d, av, re} = 201 \cdot 0.435 =$	87.4 kN
anchorage length in worst case	$\ell_{1, min} =$	500 mm
factor for hooked bars:	$\alpha_1 =$	0.7
factor for concrete cover	$\alpha_2 =$	1.0 (no verification, value on safe side)
bond strength in C30/37	$f_{bd} = 0.315 \cdot 30^{2/3} =$	3.0 N/mm ²
strength developed per bar:	$N_{Rd, a, i} = \frac{0.5 \cdot 16 \cdot \pi \cdot 3}{0.7 \cdot 1.0} \leq 87 =$	87.4 kN
reinforcement anchorage:	$N_{Rd, a} = 28 \cdot 87.4 =$	2448 kN $> N_{Ed}$ -> ok

a4 tension in transverse reinforcement

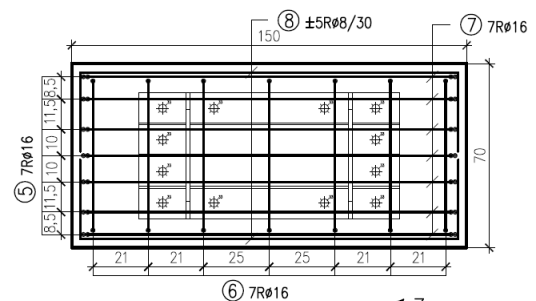
The surface reinforcement at the top of the pedestal acts as transverse reinforcement.

Positions 6 and 7 provide 7 pcs $\phi 16$ bars in each direction. Let's assume that half the splitting force is taken up in each of the directions.

With a 45° strut and tie model, the total splitting force is equal to the tension force. Therefore, the surface tension acting in each direction is $600/2 = 300$ kN

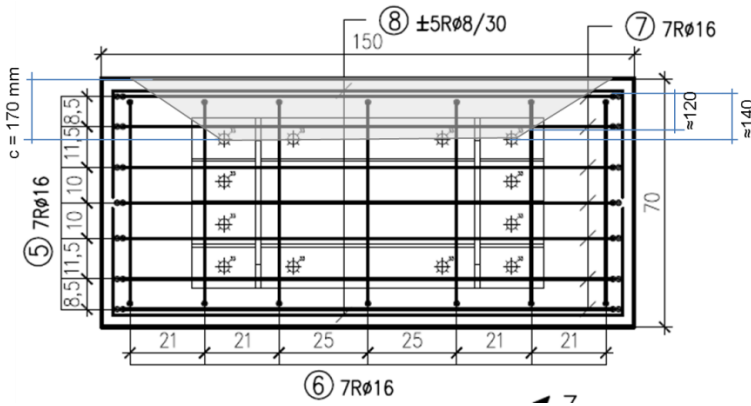
Position 7 works as splitting reinforcement: $7\phi 16$

Area of splitting reinforcement:	$A_{s, sp} = 7 \cdot 201 =$	1407 mm ²
Tensile stress from vertical load:	$\sigma_{sd, v} = 300000/1407 =$	213 N/mm ² $< f_{yd}$ -> ok



b) shear load

Position of supplementary reinforcement, M24 rods and concrete cone according to [1]



b1 Definition of supplementary reinforcement

Edge distance of post-installed M24 anchors: $c = 170\text{mm}$

Position 6 [1] can act as supplementary reinforcement, in total $n_{re} = 7$ bars $\phi 16$

According to the drawing above, 5 of the bars can be taken into account as supplementary reinforcement.

The length inside the concrete edge failure cone is at least 120mm, i.e. more than the minimum anchorage length of 4ϕ .

→ 5 bars $\phi 16$ of position 6 can be considered as supplementary reinforcement for the concrete edge.

b2 steel resistance of the supplementary reinforcement

The tension induced by the splitting forces due to the vertical load also act in the top reinforcement, see section a4. Therefore, the strength of the supplementary reinforcement has to be reduced by the stress $\sigma_{sd,v}$:

Strength of supplementary reinf. $f_{d,av, re} = 435 - 213 = 222 \text{ N/mm}^2$

Cross section $\phi 16$: $A_{s, re} = 201 \text{ mm}^2$

Resistance of supplementary reinf.: $N_{Rd, re} = 5 \cdot 201 \cdot 0.222 = 223 \text{ kN} > V_{Ed} \rightarrow \text{ok}$

b3 Anchorage of supplementary reinforcement according to EC2, section 8.4 [3]

maximum capacity per bar $A_{s, re} \cdot f_{d,av, re} = 201 \cdot 0.435 = 87.4 \text{ kN}$

factor for hooked bars: $\alpha_1 = 0.7$

factor for concrete cover $\alpha_2 = 0.7$ (assuming cover $> 3\phi = 48\text{mm}$)

bond strength in C30/37 $f_{bd} = 0.315 \cdot 30^{2/3} = 3.0 \text{ N/mm}^2$

strength developed per outer bar: $N_{Rd, a, i} = \frac{0.12 \cdot 16 \cdot \pi \cdot 3}{0.7 \cdot 0.7} \leq 87 = 36.9 \text{ kN}$

strength developed per inner bar: $N_{Rd, a, i} = \frac{0.14 \cdot 16 \cdot \pi \cdot 3}{0.7 \cdot 1.0} \leq 87 = 43.0 \text{ kN}$

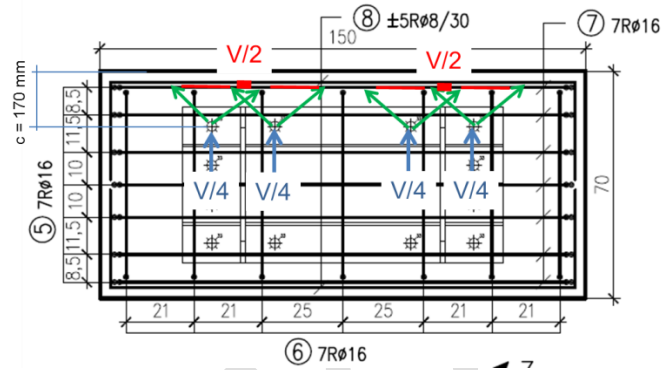
reinforcement anchorage:

$$N_{Rd,a} = 2 \cdot 36.9 + 2 \cdot 43.0 = 203 \text{ kN} > V_{Ed} \rightarrow \text{ok}$$

b4 tension in transverse reinforcement

As shown in the drawing to the right, the maximum force in the edge reinforcement according to a 45° strut and tie model will be $V/2$, i.e. 120 kN

One bar $\phi 16$ of position 7 and one tie $\phi 8$ of position 8 act as edge reinforcement.



Area of splitting reinforcement:

$$A_{s,sp} = 201 + 50 = 251 \text{ mm}^2$$

Tensile stress from shear load:

$$\sigma_{sd,v} = 120000 / 2 / 251 = 239 \text{ N/mm}^2 < f_{yd} \rightarrow \text{ok}$$

c) Interaction

$$\left(\frac{N_{Ed}}{N_{Rd,i}} \right)^{2/3} + \left(\frac{V_{Ed}}{V_{Rd,i}} \right)^{2/3} = \left(\frac{600}{2448} \right)^{2/3} + \left(\frac{100}{203} \right)^{2/3} \approx 1.0 \rightarrow \text{ok}$$

The supplementary reinforcement is sufficient to take up the load; therefore, concrete cone failure needs not be considered.

4 Anchorage of the post-installed threaded rods M24 [5]:

Note: Anchor design rules for bond according to ETAG [4] are valid only for embedment depths up to 20 times the anchor diameter. Therefore anchor approvals are not valid for the present case. Rebar approvals apply to larger embedment depth, but they only cover post-installed reinforcing bars, not threaded rods. Experience shows that bond strengths with threaded rods are consistently somewhat higher than those with reinforcing bars under the same conditions. Therefore, assessing the bond strength according to the rebar approval [5] is on the safe side.

Bond strength [5], table 6:	$f_{bd} =$	2.7N/mm ²
Diameter of threaded rods	$d_{nom} =$	24mm
Pullout resistance:	$N_{Rp,d} = 12 \cdot d_{nom} \cdot \pi \cdot h_{ef,d} \cdot f_{bd} =$	2080kN > N_{Ed} -> ok

Hilti HIT RE 500 can transmit the tension load into the concrete.

Disclaimer:

This proposal is a **free of charge** service of **HILTI** It has been established by our engineers according to the state of the art and on the basis of the informations and documents mentioned.

The calculations are **only valid in connection with HILTI products** which are installed and used according to our **installation guidelines**. It is the **user's duty** to verify for correctness, completeness and accordance with the conditions on the construction site, to check the information, on which the calculations are based and the calculation results for plausibility. The **user remains responsible** for the results obtained with this proposal.

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