HILTI

WHITEPAPER

Supplementary reinforcement

Designing for post-installed anchor connections with new Hilti design method

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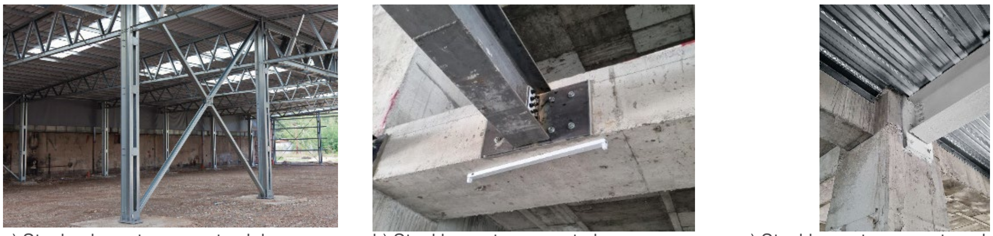
1. Introduction and background

Post-installed anchor connections are widely used to transfer loads from steel elements into existing reinforced concrete structures. Typical applications are shown in Fig. 1.1 and they include steel columns on foundations, façade brackets, safety barriers, industrial supports, and retrofit solutions where cast-in anchors are not feasible. Depending on the loading and geometry, such post-installed anchor connections may be governed by steel failure of the fastener, pullout, splitting, or concrete-related failure modes such as concrete cone breakout in tension or concrete edge breakout under shear loading. Among these, concrete breakout and edge failure are of particular concern because they are generally brittle and can govern the ultimate resistance of the connection, especially for anchor groups close to edges or subjected to high tensile or shear demands. Furthermore, the resistance to these failure modes is commonly decisive in design mainly due to the limited concrete that can be mobilized (see e.g., Fig. 1.1b,c). Design standards therefore apply conservative assumptions to ensure safety across a wide range of installation and material conditions. One of them is the neglection of the contribution of reinforcement present in a concrete member in resisting the loading resisted by an anchor group.

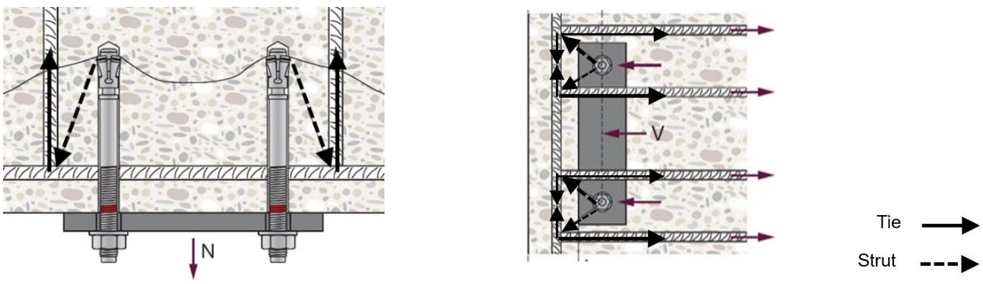


a) Steel column to concrete slab b) Steel beam to concrete beam c) Steel beam to concrete column

Fig. 1.1: Examples of steel member to concrete connections

However, to mitigate brittle concrete failure and improve load-bearing capacity and ductility, supplementary (anchor) reinforcement can be provided. Supplementary reinforcement consists of reinforcing bars typically arranged as closed stirrups, loops, or bars placed near the anchorage and detailed to transfer forces from the anchor group into the surrounding concrete member. When properly arranged, this reinforcement intercepts the potential concrete breakout surface and helps to provide an alternative load path after cracking, leading to increased resistance and more ductile behavior.

For tension loading, supplementary reinforcement is commonly detailed using closed stirrups enclosing the surface reinforcement. For shear loading near edges, it is typically provided in the form of stirrups or loops combined with edge reinforcement, forming a **strut-and-tie mechanism** that enables the transfer of forces into the concrete member reinforcement placed close to the anchorage and arranged symmetrically is significantly more effective than reinforcement located farther away, as only reinforcement intersected by the governing crack surface can be fully activated (Fig. 1.2). After formation of a concrete breakout or edge crack, forces are transferred from the anchors through inclined **concrete compression struts** into the supplementary **reinforcement acting as tension ties**. The reinforcement then transfers the loads into the surrounding concrete member and the global reinforcement system.



(a) Tension loading (b) Shear loading

Fig. 1.2: Supplementary reinforcement under tension and shear loading

This whitepaper addresses the design of post-installed anchorages with supplementary reinforcement, with a focus on both tension and shear loading. First, the current design approach according to EN 1992-4 is presented, highlighting its key assumptions and limitations. A new Hilti method for design of supplementary reinforcement is introduced, which is derived from state-of-the-art research and is intended to provide a more representative model of load transfer, reinforcement activation, and governing failure mechanisms.

2. Design in accordance with EN 1992-4

EN 1992-4 [1] provides a harmonized design framework for fastenings in concrete, including post-installed anchors with and without supplementary reinforcement. This standard addresses all relevant failure modes, such as steel failure, pull-out and splitting, concrete cone breakout under tension, and concrete edge breakout under shear. The design models are intentionally simplified and aim to offer generally conservative results across a wide range of practical applications and boundary conditions.

2.1 Anchorage without supplementary reinforcement

The characteristic concrete cone breakout in tension and concrete edge breakout in shear resistance is influenced by parameters such as embedment depth, spacing, edge distance, and concrete strength. For shear loading towards an edge, EN 1992-4 [1] assumes that the governing concrete edge breakout crack initiates at the front row of anchors closest to the edge. Consequently, only this anchor row is considered to contribute to the resistance against concrete edge failure, while anchors located further away from the edge are neglected in the corresponding resistance verification. This assumption reflects unfavourable but intentionally conservative conditions and is usually appropriate for anchorages with hole clearance, flexible load introduction, or progressive load redistribution. However, for anchorages without hole clearance and with rigid baseplates, experimental observations [2] show that load can be shared by multiple anchor rows prior to cracking. In such cases, the EN 1992-4 approach may result in conservative resistance predictions. The current Hilti method (formerly known as the SOFA method) enables a refined assessment of concrete edge breakout in shear verification beyond first row (closest to the edge) for without hole clearance (refer to [2] whitepaper for more details).

2.2 Anchorage with supplementary reinforcement

EN 1992-4 [1] allows the use of supplementary reinforcement in design of post-installed anchor connections. When sufficient supplementary reinforcement is provided in accordance with the standard the verifications, against specific concrete-related failure verifications such as concrete cone breakout and splitting in tension, or concrete edge breakout in shear may be omitted. Within the EN 1992-4 [1] framework, supplementary reinforcement may be designed to resist either tension or shear loading, but not simultaneously for the same anchorage action. Reinforcement is considered effective only if it satisfies specific detailing and anchorage requirements defined by the standard. The design philosophy can be summarized as follows:

The applied action (N_{Ed} or V_{Ed}) is evaluated against the relevant load-resisting mechanisms, including

the concrete-related resistance such as pull-out and combined pull-out and breakout in tension, and concrete pry-out in shear are verified, while checks for concrete cone breakout and splitting (in tension) and concrete edge breakout (in shear) may be omitted when supplementary reinforcement is considered.

the resistances provided by the supplementary reinforcement considering steel failure and anchorage (bond or hook) failure (see Equation 6.6 of EN1992-4 for shear) are verified.

- Only reinforcement placed sufficiently close to the anchors is considered effective. EN 1992-4 limits the effective distance between anchor and reinforcement, typically to a fraction of the embedment depth (i.e., ≤ $0.75h_{ef}$).
- A minimum anchorage length (l_{min}) within the assumed concrete failure body is required for reinforcement to be considered active. Reinforcement not satisfying this anchorage condition is ignored.
- For shear loading towards an edge, even when supplementary reinforcement is present, EN 1992-4) [1] assumes that the governing concrete edge failure originates at the front anchor row. Consequently, reinforcement activated by crack surfaces associated with back anchor rows is conservatively neglected.

The following section introduces a design approach based on published research and experimental evidence ([3], [4]), which aim to address these limitations while remaining compatible with the fundamental principles of EN-based anchor design.

3. New Hilti design method for supplementary reinforcement

This Hilti design method is based state-of-the-art research anchorages with supplementary reinforcement under tension and shear loading. The method is intended for use together with EN 1992-4, as applicable by providing a more realistic representation of load-transfer mechanisms observed in reinforced anchorages.

Research [4, 5] has consistently shown that the behavior of anchorages with supplementary reinforcement differs from the simplified assumptions adopted in EN 1992-4, particularly for anchor groups with multiple rows perpendicular to the edge and for configurations with closely spaced reinforcement. Observed behavior includes initiation of concrete breakout or edge cracks from back anchor rows rather than from the front row assumed in EN 1992-4, activation of multiple stirrup legs intersected by a larger failure body, continued residual contribution of concrete at peak load, even after cracking and the existence of an upper resistance limit governed by concrete compression strut failure (Fig. 3.1).

The Hilti method based on EN 1992-4 [1] and *fib* Bulletin 58 [6] provisions and its updated version [3], which currently under preparation is supported by following principles with reference to Fig. 3.1:

- After formation of a concrete breakout or edge crack, load is transferred through a strut-and-tie mechanism, consisting of concrete compression struts and reinforcement tension ties (see starting point of inclined (a).
- Supplementary reinforcement and concrete act together to resist the applied load, rather than acting as mutually exclusive resistance mechanisms (see inclined dashed red line in Fig. 3.1).
- The resistance of the anchorage increases with increasing effective reinforcement, but only up to a maximum limit governed by concrete strut resistance (see horizontal dashed red line in Fig. 3.1).
- Reinforcement effectiveness depends on its position relative to the anchorage and its intersection with the governing failure surface.

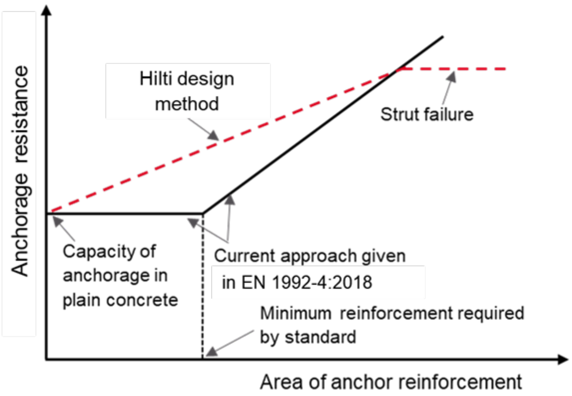
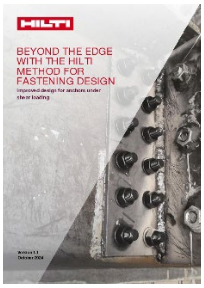


Fig. 3.1: Behavior of anchorage with supplementary reinforcement

The method also distinguishes between high effective, less effective, and non-effective reinforcement based on the relative position of stirrup legs with respect to the anchorage and the assumed breakout body (see Fig. 3.3). Redistribution of forces between reinforcement elements may be considered when detailing, material properties, and anchorage conditions satisfy the model requirements.

Note: Whitepaper on SOFA provides detailed insights into shear back-row verifications



Additionally, the supplementary reinforcement design extends the existing Hilti approach for shear back-row verification. For anchor layouts with up to three rows, shear distribution is determined in accordance with *fib* Bulletin 58 [6]. For configurations exceeding 3 rows, a uniform shear distribution is assumed, and no further increase in resistance against concrete edge breakout is considered (Fig. 3.2). This limitation is based on the current research experience [7]. Table 3.1 highlights the key differences between two methods.

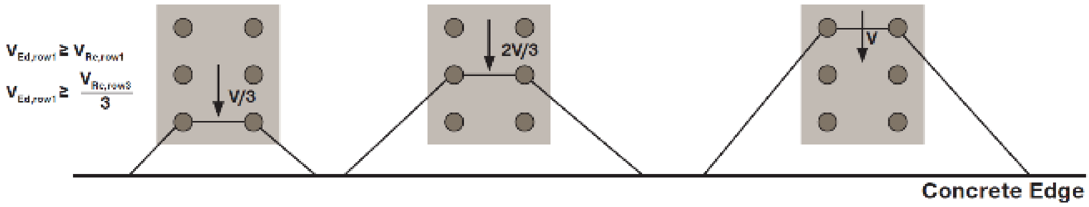


Fig. 3.2: Shear distribution in Hilti method

Table 3.1: Summary of differences between available supplementary reinforcement models

Parameter	EN 1992-4	Hilti method based on EN 1992-4 + draft fib Bulletin 2026
Effective distance of reinforcement from the anchor	$\leq 0.75h_{ef}$ (tension) and $\leq 0.75c_1$ (shear)	$\leq 1.5h_{ef}$ (tension) and $\leq 1.5c_1$ (shear)
Concrete breakout resistance	Concrete breakout resistance neglected if supplementary reinforcement present	50% contribution of concrete breakout resistance is taken into account
Tension loading	anchor configuration allowed up to 3x3	anchor configuration allowed beyond 3x3
Shear loading	only front row of anchors considered	verification up to 3rd back row with filled holes
Loading types	Static and seismic	Static (with advantage of 50% concrete breakout resistance), seismic (anchorage resistance with reinforcement only)

3.1 Resistance verification under tension loading

The resistance verifications against static tension loading are listed in Table 3.2. The detailed verification for anchorage failure are explained in the following sections. Other verifications follow the requirements of EN 1992-4 [1].

Table 3.2: Resistance verification for anchor under tension loading

Loading	Failure mode	Static
Tension	Steel	EN 1992-4, section 7.2.1.3
	Pullout	EN 1992-4, section 7.2.1.5
	Combined pullout and concrete breakout (Bonded anchors only)	EN 1992-4, section 7.2.1.6
	Splitting	EN 1992-4, section 7.2.1.7
	Blowout	EN 1992-4, section 7.2.1.8
	Supplementary reinforcement- shear	EN 1992-4 section 7.2.1.9.1 and 7.2.1.9.2
	Anchorage failure of the anchor reinforcement in the concrete edge breakout body	Hilti method based on EN 1992-4 and draft *fib* bulletin 2026 [3]. Concrete cone resistance calculated from EN 1992-4, section 7.2.1.4

3.1.1 Anchorage resistance

The design tensile resistance of an anchorage with supplementary reinforcement is evaluated by combining the contribution of the anchor reinforcement with a residual contribution of the concrete cone resistance, subject to an upper limit governed by concrete strut resistance, as expressed Eq.1 .

$$N_{Rd,a} = N_{Rd,re} + k_{fc} \cdot N_{Rd,c} \geq N_{Rd,c} \quad \text{(Eq.1)}$$

Where,

$N_{Rd,re}$ = the total design resistance of the anchor reinforcement according to Eq. 2

$N_{Rd,c}$ = the concrete cone design resistance of the anchorage without considering supplementary reinforcement

k_{fc} = 0.5 for $f_{ck} \leq 50$ MPa

k_{fc} = 0 for $f_{ck} > 50$ MPa

For normal strength concrete, the factor k_{fc} accounts for the residual contribution of concrete at peak load as a portion of the concrete cone is observed to remain effective at failure. This factor is conservatively neglected for high strength concrete which exhibits more brittle post-cracking behavior.

3.1.1.1 Resistance of anchor reinforcement

The design resistance of the anchor reinforcement is obtained by summing the resistance of all effective stirrup legs intersected by the theoretical concrete breakout body, given by Eq. 2.

$$N_{Rd,re} = \sum_n N^0_{Rd,re} \quad \text{(Eq. 2)}$$

Where, n is the total number of effective reinforcing bars. Only those stirrups legs that lie within the concrete breakout body and provide a minimum anchorage length are considered effective, as shown in Fig. 3.3, while reinforcement further away contributes progressively less, depending on whether yielding of the inner stirrup occurs and whether detailing and material requirements of the model are satisfied. The redistribution of forces between stirrups is permitted only when the detailing, material properties, and anchorage conditions satisfy the requirements of the detailed model. Where these conditions are not met, redistribution effects are neglected, and out stirrups are considered less effective.

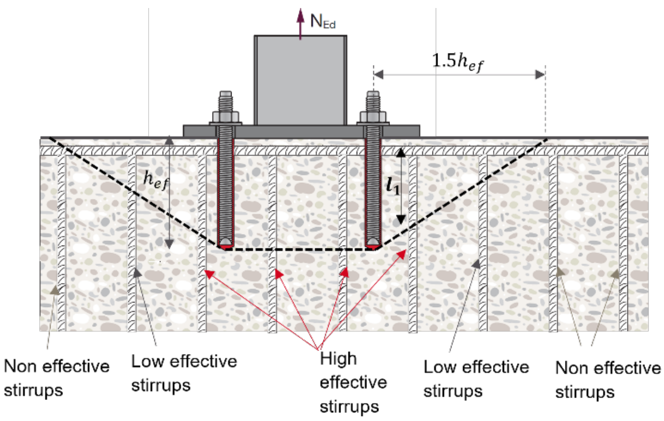


Fig. 3.3: Example of anchor group with supplementary reinforcement under tension load

The design anchorage resistance of one stirrup leg, $N^0_{Rd,re}$, (Eq. 3) represents the maximum tensile force that can be transferred from concrete to the reinforcement through the combined action of hook and bond resistance within the concrete breakout body, reduced to account for cracked concrete and concrete cover effects and is limited by the design yield resistance of the stirrup leg.

$$N^0_{Rd,re} = \psi_{cr} \cdot \psi_{cvr} \cdot \left(N^0_{Rd,hook} + N^0_{Rd,bond}\right) \leq A_{s,re} \cdot f_{yd,re} \quad \text{(Eq. 3)}$$

Where,

$A_{s,re}$ = cross-sectional area of one bar of one stirrup leg

$f_{yd,re}$ = design yield strength of stirrups= $f_{yk,re}/\gamma_{Ms,re}$

ψ_{cr} = factor to consider influence of cracks = 1.0 for uncracked concrete and 0.7 for cracked concrete

ψ_{cvr} = factor to consider the influence of concrete cover parallel to the plane of stirrup, defined as $\psi_{cvr} = \left(\frac{c_{min}}{3d_{s,re}}\right)^{0.5} \leq 1.0$

c_{min} = the least of the clear cover to the plane of the stirrup (c_{re}) and half the clear spacing between adjacent stirrups (s_{re})

$N^0_{Rd,hook}$ = design hook resistance of one stirrup(closed) leg =0 for straight/hooked bars

$N^0_{Rd,bond}$ = design bond resistance of one stirrup leg

3.1.2 Hook and bond resistance

The contribution of supplementary reinforcement is evaluated by considering the hook and bond resistance contribution of each stirrup separately. The **hook resistance** is applicable to stirrups located between anchor group and the first layer of stirrups placed outside of the anchor group (Eq. 4). For subsequent stirrups, their contribution depends on whether the previously activated stirrups have yielded. If yielding occurs, the effectiveness of the following stirrups increases; otherwise, their contribution remains limited (Eq. 5).

Accordingly, the design hook resistance of one stirrup leg is evaluated as-

- For high effective stirrups, $N^0_{Rd,hook} = \frac{0.6}{\gamma_{Mc}} A_{s,re} \cdot f_{yk,re} \cdot \left(\frac{l_1}{h_{ef}}\right)^{0.4}$ (Eq. 4)
- For low effective stirrups, $N^0_{Rd,hook} = \frac{0.1}{\gamma_{Mc}} A_{s,re} \cdot f_{yk,re} \cdot \left(\frac{l_1}{h_{ef}}\right)^{0.4}$ (Eq. 5)

Where,

$A_{s,re}$ = cross-sectional area of one reinforcement bar
$f_{yk,re}$ = characteristic yield stress of anchor reinforcement
l_1 = length of the anchor reinforcement in the assumed failure cone (see Fig. 3.3) and $l_1 \geq l_{1,min}$
$d_{s,re}$ = diameter of anchor reinforcement (stirrups)
h_{ef} = effective embedment depth

For **bond resistance**, only the portion of the stirrup extending beyond the minimum anchorage length contributes effectively. In the case of hooked bars, the hook is assumed to provide anchorage, and bond resistance develops only along the straight length beyond the hook. Therefore, the design bond resistance provided by one stirrup leg is as per Eq.6.

$$N^0_{Rd,bond} = \pi \cdot d_{s,re} \cdot (l_1 - l_{1,min}) \cdot f_{bd} \quad \text{(Eq.6)}$$

Where,

l_1 = length of the anchor reinforcement in the assumed breakout body $\geq l_{1,min}$
$l_{1,min}$ = minimum length of the anchor reinforcement in the assumed concrete breakout body required for the stirrup to be considered as active
$l_{1,min} = 4d_{s,re}$ for $d_{s,re} \leq 16$ mm and $5.5d_{s,re}$ for $d_{s,re} > 16$ mm
$d_{s,re}$ = diameter of anchor reinforcement (stirrups)
f_{bd} = design bond strength of stirrups as per EN 1992-1-1 [8]

The total anchorage resistance obtained from the sum of effective stirrup legs shall be verified against the governing upper limit imposed by concrete strut resistance, as described in section 3.1.3.

3.1.3 Upper limitation of concrete strut resistance

The tensile resistance of an anchorage with supplementary reinforcement is limited by the concrete strut resistance, which represents the maximum compressive resistance of the concrete strut developing between the anchorage and the surrounding concrete. Even when sufficient anchor reinforcement is provided, the load-bearing resistance cannot increase indefinitely. Failure may occur by crushing of the concrete before yielding of the reinforcement. Therefore, the design tensile resistance shall be limited as given in Eq.7,

$$N_{Rd,a} \leq N_{Rd,str} \quad \text{(Eq.7)}$$

The design concrete strut resistance is evaluated as,

$$N_{Rd,str} = \psi_{strut} \cdot N_{Rd,c} \qquad \text{(Eq.8)}$$

Where,

$N_{Rd,c}$ = the design concrete cone resistance for the anchorage without anchor reinforcement

ψ_{strut} = the strut factor for the anchorage which depends on the anchorage and stirrup configuration

The strut factor modifies the concrete cone resistance to reflect the compressive stress field that develops between the anchorage and the supplementary reinforcement.

a) Basic strut factor for single anchor

For anchorages, where the stirrups enclose the surface reinforcement, the basic strut factor for a single anchor is given by Eq.9.

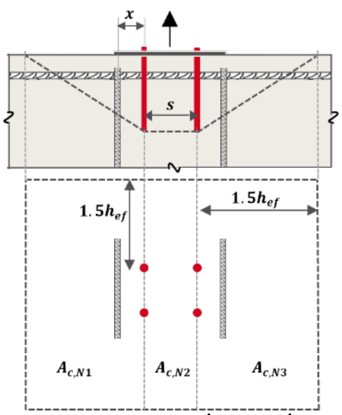
$$\psi^{0}_{strut,N}(x) = 2.5 - \frac{x}{h_{ef}} \geq 1.0 \qquad \text{(Eq.9)}$$

Where, x = distance between the centre line of anchor and the center line of anchor reinforcement and h_{ef} is the effective embedment depth of anchor.

b) Modification for anchor groups in tension

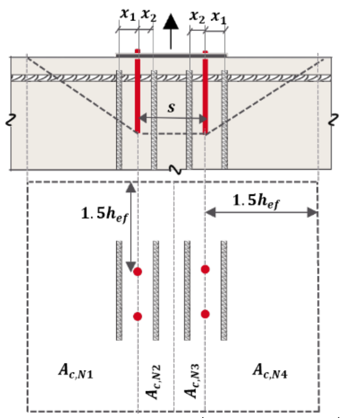
For anchor groups, the strut factor is modified to account for spacing between anchors, overlapping concrete cones and distribution of reinforcement within the anchorage. The group strut factor is obtained by summing the basic strut factor using the projected concrete associated with individual anchors, given by ψ_{strut}. Therefore, proper placement of reinforcement, preferably symmetric with respect to the anchorage , improves strut development.

Case 1: For anchorages with one stirrup leg per anchor and stirrup legs only outside the anchorage



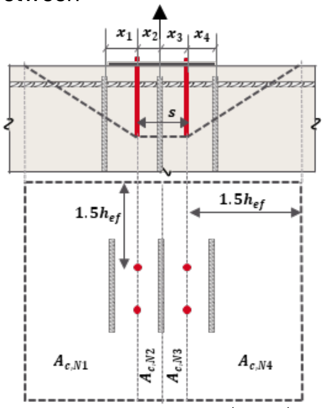
$$\psi_{strut} = \psi^{0}_{strut}(x) \cdot \frac{A_{c,N1}}{A_{c,N}} + \frac{A_{c,N2}}{A_{c,N}} + \psi^{0}_{strut}(x) \cdot \frac{A_{c,N3}}{A_{c,N}}$$

Case 2: For anchorages with two stirrup legs per anchor with anchor reinforcement lying within the outermost anchor rows



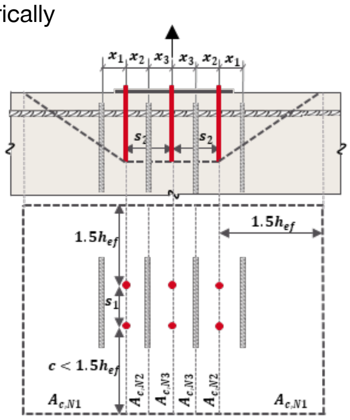
$$\psi_{strut} = \psi^{0}_{strut}(x_1) \cdot \left(\frac{A_{c,N1} + A_{c,N4}}{A_{c,N}}\right) + \psi^{0}_{strut}(x_2) \cdot \left(\frac{A_{c,N2} + A_{c,N3}}{A_{c,N}}\right)$$

Case 3: For anchorages with one stirrup leg lying in between the outermost anchors and one in between



$$\psi_{strut} = \psi^0_{strut}(x_1) \cdot \left(\frac{A_{c,N1}}{A_{c,N}}\right) + \psi^0_{strut}(x_2) \cdot \left(\frac{A_{c,N2}}{A_{c,N}}\right) + \psi^0_{strut}(x_3) \cdot \left(\frac{A_{c,N3}}{A_{c,N}}\right) + \psi^0_{strut}(x_4) \cdot \left(\frac{A_{c,N4}}{A_{c,N}}\right)$$

Case 4: For a group of 6 fasteners (3 anchor rows) placed close to an edge and stirrups placed symmetrically



$$\psi_{strut} = 2 \cdot \left[\psi^0_{strut}(x_1) \cdot \left(\frac{A_{c,N1}}{A_{c,N}}\right) + \psi^0_{strut}(x_2) \cdot \left(\frac{A_{c,N2}}{A_{c,N}}\right) + \psi^0_{strut}(x_3) \cdot \left(\frac{A_{c,N3}}{A_{c,N}}\right) \right]$$

3.2 Resistance verification shear loading

The resistance verification against static shear loading are mentioned in Table 3.3. The detailed verification for anchorage failure are explained in below sections. Other verifications follow the requirements of EN 1992-4 [1].

Table 3.3: Resistance verification for anchor under shear loading

Loading	Failure mode	Static
Shear	Steel without lever arm	EN 1992-4, section 7.2.2.3.1
	Steel with lever arm	EN 1992-4, section 7.2.2.3.2
	Pry-out	EN 1992-4, section 7.2.2.4
	Concrete edge breakout	EN 1992-4 section 7.2.2.5 with shear force distribution according to EN 1992-4 or Hilti method based on *fib* Bulletin 58
	Supplementary reinforcement-shear	EN 1992-4 section 7.2.2.2 and 7.2.2.6
	Anchorage failure of the anchor reinforcement in the concrete edge breakout body	Hilti method based on EN 1992-4 and draft *fib* bulletin 2026 with concrete edge breakout resistance: Where shear load transfer to the back row is not possible: EN 1992-4, section 7.2.2.5. Where shear load transfer to the back rows is possible: *fib* Bulletin 58

3.2.1 Anchorage resistance

The overall shear resistance is therefore evaluated by combining the contribution of reinforcement with a reduced concrete contribution, while ensuring that the total resistance does not exceed the limit imposed by the concrete strut mechanism, as given by Eq.10

$$V_{Rd,a} = V_{Rd,re} + k_{fc} \cdot V_{Rd,c} \geq V_{Rd,c} \tag{Eq.10}$$

Where,

$V_{Rd,re}$ = the total design shear resistance of the anchor reinforcement according to Eq. (. 11)

$V_{Rd,c}$ = the design concrete edge resistance calculated with back row of the anchorage without considering the anchor reinforcement per EN 1992-4

k_{fc} = 0.5 for f_{ck} $\leq$ 50 MPa

k_{fc} = 0 for f_{ck} $>$ 50 MPa

3.2.1.1 Resistance of anchor reinforcement

Under shear loading, the applied force is resisted by tension developed in reinforcement crossing the inclined failure surface. Only those reinforcement legs that intersect the assumed failure surface and possess sufficient anchorage are considered effective. The corresponding shear resistance is derived from equilibrium between tensile and shear forces is given by Eq . 11.

$$V_{Rd,re} = N_{Rd,re}/x \qquad \text{(Eq. 11)}$$

Where,

$N_{Rd,re}$ = total design tension resistance of the anchor reinforcement (Fig. 3.4).

$x = \left(1 + \frac{e_s}{z}\right)$

The factor x accounts for equilibrium between the tensile tie force in the supplementary reinforcement and the applied shear force acting on the anchorage.

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

z = internal lever arm of the concrete member = $0.85d$

d = distance between the opposite side of the concrete member and anchor reinforcement $\leq \min(2h_{ef}; 2c_1)$

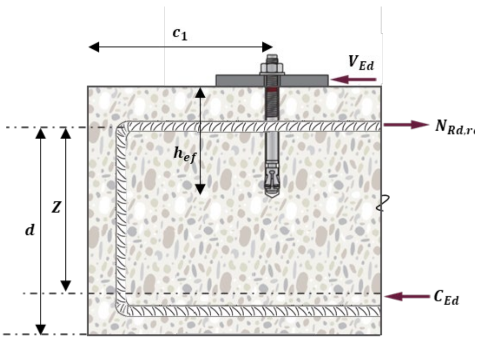


Fig. 3.4 Tension force in anchor reinforcement developed to take up shear loads

The total resistance of the reinforcement is obtained by summing the contribution of all effective stirrup legs as given in Eq.12.

$$N_{Rd,re} = \sum_n N^0_{Rd,re} \qquad \text{(Eq.12)}$$

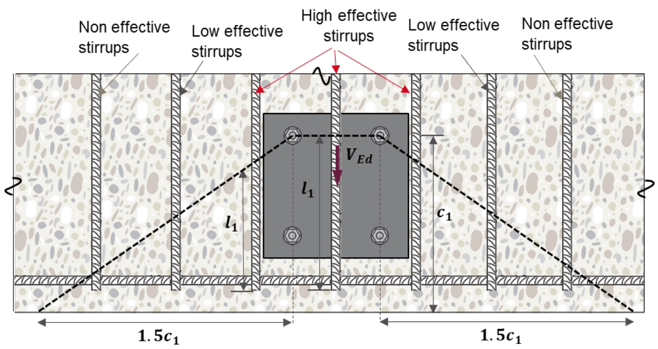


Fig. 3.5 Example of 2x2 anchor group with effective supplementary reinforcement (only back anchor row considered to take up shear force)

The resistance of a single reinforcement bar, $N^0_{Rd,re}$ is governed by the combined action of hook anchorage and bond along the embedded length, limited by the yielding capacity of the bar (Eq.13).

$$N^0_{Rd,re} = \psi_{cr} \cdot \psi_{cvr} \cdot \left(N^0_{Rd,hook} + N^0_{Rd,bond}\right) \leq A_{s,re} \cdot f_{yd,re} \qquad \text{(Eq.13)}$$

Where,

$A_{s,re}$ = cross-sectional area of one bar of anchor reinforcement
$f_{yd,re}$ = design yield strength of the reinforcement = $f_{yk,re}/\gamma_{Ms,re}$
$N^0_{Rd,hook}$ = design hook resistance of one reinforcement bar =0 for straight bars
$N^0_{Rd,bond}$ = design bond resistance of one reinforcement bar
ψ_{cr} = factor to consider influence of cracks
ψ_{cr} = 1.0 for non-cracked concrete
ψ_{cr} = 0.70 for cracked concrete

$\psi_{cvr} = \left(\frac{c_{min}}{3d_{s,re}}\right)^{0.5} \leq 1.0$

c_{min} = the least of the clear cover to the plane of the stirrup (c_{re}) and half the clear spacing between adjacent stirrups (s_{re}) (Refer to EN 1992-1-1)

In cracked concrete, the reduction in bond and hook performance is accounted for through a reduction factor, reflecting the reduced confinement and potential localization of cracks along reinforcement paths

3.2.2 Hook and bond resistance

The engagement of reinforcement is not simultaneous but progressive, governed by crack propagation. Stirrups closest to the anchorage intersect the crack first and are therefore the most effective. Subsequent stirrups may contribute differently depending on whether the previously activated stirrups have yielded. This behavior leads to a distinction between highly effective, less effective, and non-effective reinforcement layers, depending on their position and activation state (see Fig. 3.5).

Accordingly, the design **hook resistance** of one stirrup leg is evaluated as-

- For high effective stirrups $N^0_{Rd,hook} = \frac{0.6}{\gamma_{Mc}} A_{s,re} \cdot f_{yk,re} \cdot \left(\frac{l_1}{c_1}\right)^{0.4}$ (Eq.14)
- For low effective stirrups, $N^0_{Rd,hook} = \frac{0.1}{\gamma_{Mc}} A_{s,re} \cdot f_{yk,re} \cdot \left(\frac{l_1}{c_1}\right)^{0.4}$ (Eq.15)

Where,
$f_{yk,re}$ = characteristic yield stress of anchor reinforcement
l_1 = length of the anchor reinforcement in the assumed failure cone (see Fig. 3.5) and $l_1 \geq l_{1,min}$
$A_{s,re}$ = cross-sectional area of one reinforcement bar
$d_{s,re}$ = diameter of anchor reinforcement (stirrups)

As explained previously, for **bond resistance**, only the portion of the stirrup extending beyond the minimum anchorage length contributes effectively. The design bond resistance provided by one reinforcement bar is given as per Eq.16.

$$N^0_{Rd,bond} = \pi \cdot d_{s,re} \cdot (l_1 - l_{1,min}) \cdot f_{bd} \quad \text{(Eq.16)}$$

Where,

l_1 = length of the anchor reinforcement in the assumed breakout body $\geq l_{1,min}$ (see Fig. 3.5).
$l_{1,min}$ = minimum length of the anchor reinforcement in the assumed concrete breakout body required for the stirrup to be considered as active
$l_{1,min} = 4d_{s,re}$ for $d_{s,re} \leq$ 16 mm
$l_{1,min} = 5.5d_{s,re}$ for $d_{s,re} >$ 16 mm
$d_{s,re}$ = diameter of anchor reinforcement (stirrups)
f_{bd} = design ultimate bond strength of stirrups as per EN 1992-1-1

3.2.3 Upper limitation of concrete strut resistance

The increase in resistance due to reinforcement is bounded by the compressive capacity of the concrete strut formed between the anchorage and the surrounding concrete. The concrete strut resistance of an anchorage with anchor reinforcement loaded in shear towards the edge is given as per Eq.17.

$$V_{Rd,str} = \psi_{strut,V} \cdot V_{Rd,c} \quad \text{(Eq.17)}$$

Where,

$\psi_{strut,V}$ is the factor depending upon the geometry of the anchorage system and the arrangement of reinforcement. It reflects the ability of the concrete to sustain compressive stress without crushing.

$V_{Rd,c}$ is the design concrete edge resistance for the anchorage without anchor reinforcement

The factor, $\psi_{strut,V}$ for an anchorage is calculated from the basic shear strut factor for a single anchor, $\psi^0_{strut,V}$ by modifying it to account for the group behaviour.

For cases where anchor reinforcement enclose the surface reinforcement, the basic strut factor for a single anchor with anchor reinforcement, $\psi^0_{strut,V}$ is given as

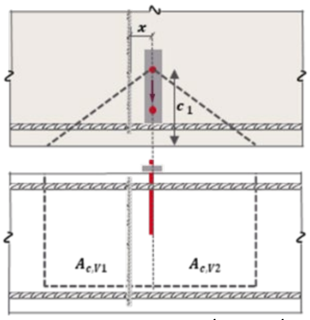
$$\psi^0_{strut,V}(x) = 2.5 - \frac{x}{c_1} \geq 1.0 \qquad \text{(Eq.18)}$$

Where, x = distance between the center line of anchor and the center line of anchor reinforcement

a) Modification for anchor groups in shear

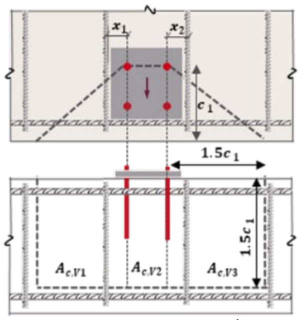
The group strut factor is obtained by summing the basic strut factor using the projected concrete associated with individual anchors, given by ψ_{strut}.

Case 1: For single anchors or for anchorages with a single anchor row perpendicular to the edge



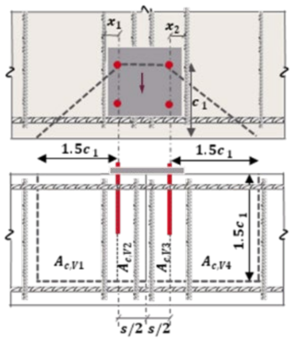
$$\psi_{strut} = \psi^0_{strut}(x) \cdot \frac{A_{c,V1}}{A_{c,V}} + \frac{A_{c,V2}}{A_{c,V}}$$

Case 2: For anchorages with more than one anchor row perpendicular to the edge and no stirrups lying between the outermost anchors



$$\psi_{strut} = \psi^0_{strut}(x_1) \cdot \frac{A_{c,V1}}{A_{c,V}} + \frac{A_{c,V2}}{A_{c,V}} + \psi^0_{strut}(x_2) \cdot \frac{A_{c,V3}}{A_{c,V}}$$

Case 3: For anchorages with more than one anchor row perpendicular to the edge and with stirrups lying also between the outermost anchors



$$\psi_{strut} = \sum_{i=1}^{4} \psi^0_{st,V}(x_i) \cdot \frac{A_{c,Vi}}{A_{c,V}}$$

3.3 Interaction of tension and shear

When post-installed anchorages with supplementary reinforcement are subjected to combined tension and shear loading, the interaction between these actions is treated differently depending on the adopted design approach. For failure modes other than steel Eq.19 is followed as per EN 1992-4. The suggested values for $\boldsymbol{k_{11}}$ are given in relevant ETA and listed in Table 3.4, in case not given in ETA.

$$\left(\frac{N_{Ed}}{N_{Rd,i}}\right)^{k_{11}} + \left(\frac{V_{Ed}}{V_{Rd,i}}\right)^{k_{11}} \leq 1.0 \qquad \text{(Eq.19)}$$

Table 3.4: tension-shear interaction exponents when supplementary reinforcement is taken into account k_{11}

<table>
<tr><th>Scope</th><th>EN 1992-4</th><th>Hilti method based on
EN 1992-4 + draft fib 2026</th></tr>
<tr><td>Interaction with supplementary reinforcement for
tension or shear only</td><td>$k_{11} = \frac{2}{3}$</td><td>$k_{11} = 1$</td></tr>
<tr><td>Interaction with supplementary reinforcement for
tension and shear</td><td colspan="2">$k_{11} = 1.5$ or
$\left(\frac{N_{Ed}}{N_{Rd,i}}\right) + \left(\frac{V_{Ed}}{V_{Rd,i}}\right) \leq 1.2$</td></tr>
</table>

4. Design example

4.1 Design post-installed connection for tension and shear loading with Hilti method

Project requirement: A steel profile is connected to a concrete element using post-installed mechanical anchors. The arrangement of anchors is of 3 × 3 rectangular layout, and the 3D view of the application is shown in Fig. 4.1and other information on this project is defined in Table 4.1.

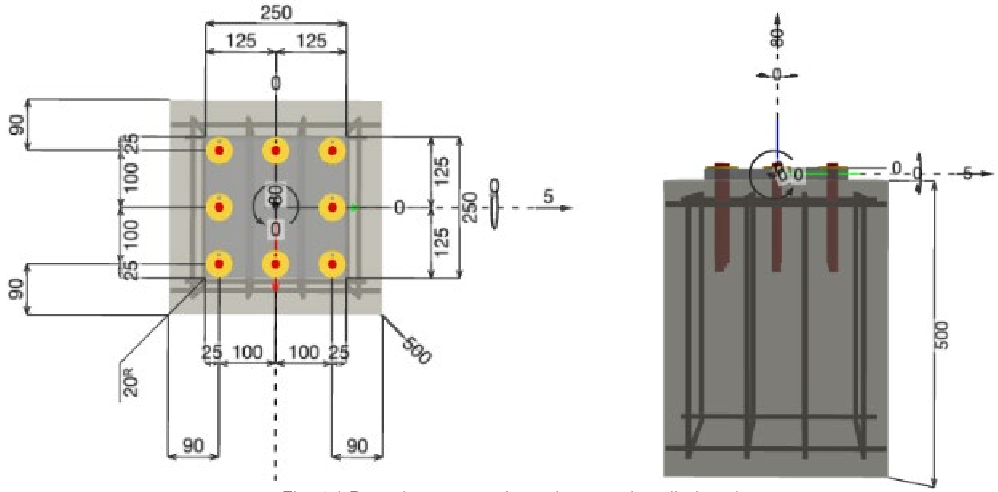


Fig. 4.1 Baseplate connection using post-installed anchors

Table 4.1 Project information and design inputs

Geometry	
Concrete thickness	500 mm
Baseplate	250 × 250 × 10 mm
Spacing between anchors (X and Y)	100 mm
Edge distance (X and Y)	90 mm
Others	
Materials	Concrete: C30/37, cracked Reinforcing steel $f_{yk} = 500\ N/mm^2$
Design life	50 years
Installation	Rotary-hammer drilling / horizontal, dry
Supplementary reinforcement	10Φ stirrups spaced at 100 mm c/c

ANCHOR LOADS

Anchor	N [kN]	Vx [kN]	Vy [kN]
1	10	0.625	0.625
2	10	0.625	0.625
3	10	0.625	0.625
4	10	0.625	0.625
5	10	0.625	0.625
6	10	0.625	0.625
7	10	0.625	0.625
8	10	0.625	0.625

Total tension force on anchor group, $N_{Ed} = 80\ kN$ and $V_{Ed} = 5\ kN$ a will be equally distributed among all anchors

Details of proposed anchor: The proposed anchor solution (without hole clearance) is defined in

Table 4.2.

Table 4.2: Anchor properties

Type of anchor	**Mechanical**	
Specification of anchor		HST4 M16
Diameter of anchor	d	$16\ mm$
Effective embedment depth	h_{ef}	$160\ mm$
Nominal embedment depth	h_{nom}	$172\ mm$

Design verifications are carried considering rigid baseplate as per [1] and characteristic resistances are taken from ETA-21/0878 [9]. Steel and pullout verifications in tension are as per EN 1992-4 [1]

Table 7.1. Steel, pry-out and concrete edge breakout verifications are as per EN 1992-4 [1] Table 7.2 The verifications for supplementary reinforcement in tension are explained below.

Supplementary reinforcement- tension:

Table 4.3: Forces on supplementary reinforcement

Rebar	Type	Orientation	Tension force (kN)
Surface reinforcement	Straight	Horizontal	4.547
		Vertical 1 (0-V1)	8.367
0	Closed stirrup	Vertical 2 (0-V2)	8.367
		Horizontal (0-H)	8.464
		Vertical 1 (1-V1)	11.363
1	Closed stirrup	Vertical 2 (1-V2)	11.363
		Horizontal (1-H)	8.464
		Vertical 1 (2-V1)	11.363
2	Closed stirrup	Vertical 2 (2-V2)	11.363
		Horizontal (2-H)	8.940
		Vertical 1 (3-V1)	8.367
3	Closed stirrup	Vertical 2 (3-V2)	8.367
		Horizontal (3-H)	8.464

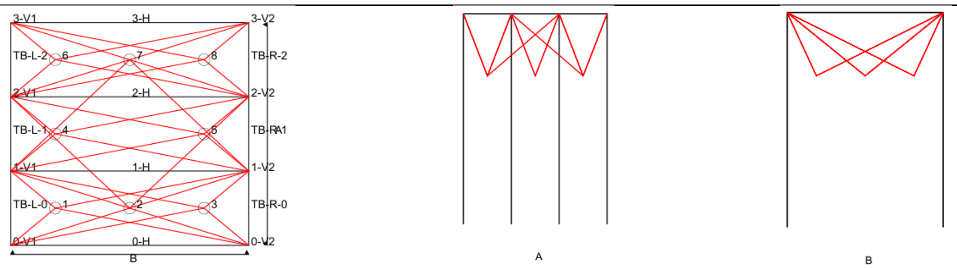


Fig. 4.2: Strut-and-tie model

Steel failure of longitudinal rebar:

The resistance against steel failure of longitudinal rebars are checked considering following equation:

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

$\gamma_{Ms.re} = 1.15$

$N_{Rk,re} = A_{s,re} \cdot f_{s,re}, A_{s,re} = 79\ mm^2$ and $f_{s,re} = 500\ MPa$, $N_{Rk,re} = 79 \cdot 500 = 39.27\ kN$

$N_{Rd,re} = \left(\frac{39.27}{1.15}\right) = 34.15\ kN > N_{Ed,re} = 4.547\ kN$ verification fulfilled ✓

Steel failure of supplementary reinforcement, horizontal:

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

$\gamma_{Ms.re} = 1.15$

$N_{Rk,re} = A_{s,re} \cdot f_{s,re}, A_{s,re} = 79\ mm^2$ and $f_{s,re} = 500\ MPa$, $N_{Rk,re} = 79 \cdot 500 = 39.27kN$

$N_{Rd,re} = \left(\frac{39.5}{1.15}\right) = 34.15\ kN > N_{Ed,re} = 8.940\ kN$ verification fulfilled ✓

Steel failure of supplementary reinforcement, vertical:

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

$\gamma_{Ms.re} = 1.15$

$N_{Rk,re} = A_{s,re} \cdot f_{s,re}, A_{s,re} = 79\ mm^2$ and $f_{s,re} = 500\ MPa$, $N_{Rk,re} = 79 \cdot 500 = 39.17\ kN$

$N_{Rd,re} = \left(\frac{39.5}{1.15}\right) = 34.15\ kN > N_{Ed,re} = 11.363\ kN$ verification fulfilled ✓

Anchorage failure of the anchor reinforcement in the concrete cone breakout body:

The resistance against concrete cone resistance is checked for the entire anchor group with the following equation:

$N_{Rd,c} = \frac{N_{Rk,c}}{\gamma_{Mc}}$ EN 1992-4, table 7.1

Since fasteners in this application have four edge distances less than $c_{cr,N}$ from fastener. For more precise results h_{ef} is substituted by h'_{ef}.

$h'_{ef} = max\left\{\frac{c_{max}}{c_{cr,N}}, \frac{s_{max}}{s_{cr,N}}\right\} \cdot h_{ef} = 60\ mm$ EN 1992-4, eq. (7.9)

$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5} = 8.9 \cdot \sqrt{30} \cdot 60^{1.5} = 22.65\ kN$ ETA-21/0878, Table C1 and EN 1992-4, eq. (7.2)

$s_{cr,N} = 2 \cdot c_{cr,N} = 3 \cdot h_{ef} = (3 \cdot 60) = 180\ mm, c_{cr,N} = 90\ mm$ EN 1992-4, sect. 7.2.1.4 (3)

$A_{c,N} = (90 + 100 + 100 + 90) \cdot (90 + 100 + 100 + 90) = 144{,}400\ mm^2$ EN 1992-4, fig. 7.4

$A^0_{c,N} = s_{cr,N} \cdot s_{cr,N} = (180 \cdot 180) = 32400\ mm^2$ EN 1992-4, eq. (7.3)

$\psi_{s,N} = 0.7 + 0.3 \cdot \frac{c}{c_{cr,N}} = 0.7 + 0.3 \cdot \left(\frac{100}{90}\right) = 1 \leq 1.0$ EN 1992-4, eq. (7.4)

$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1.0$ EN 1992-4, eq. (7.5)

$\psi_{re,N} = 0.5 + \frac{160}{200} = 0.8 > 1.0$

$\psi_{ec,N} = \frac{1}{1+\left(\frac{2 \cdot e_{c,N}}{s_{cr,N}}\right)}$ EN 1992-4, eq. (7.6)

Eccentricity along X axis $e_{c,N} = 0\ mm$, hence $\psi_{ec,N} = 1.0$

Eccentricity along Y axis $e_{c,N} = 0\ mm$, hence $\psi_{ec,N} = 1.0$

Factor for bending moment, $\psi_{M,N} = 1.0$ EN 1992-4, eq. (7.7)

$N_{Rk,c} = N^0_{Rk,c} \cdot \frac{A_{c,N}}{A^0_{c,N}} \cdot \psi_{s,N} \cdot \psi_{re,N} \cdot \psi_{ec,N} \cdot \psi_{M,N} = 22.65 \cdot \left(\frac{144400}{32400}\right) \cdot 1.0 \cdot 1.0 \cdot 1.0 \cdot 1.0 = 100.9\ kN$

$\gamma_{Mc} = 1.5$

$N_{Rd,c} = \left(\frac{100}{1.5}\right) = 67.2\ kN$, concrete cone resistance without considering anchor reinforcement

Strut resistance

$N^0_{Rd,hook} = \frac{0.6}{\gamma_{Mc}} A_{s,re} \cdot f_{yk,re} \left(\frac{l_1}{h_{ef}}\right)^{0.4}$ (all stirrups are “high effective”, see 3.3)

$N^0_{Rd,bond} = \pi \cdot d_{s,re} \cdot (l_1 - l_{1,min}) \cdot f_{bd}$

Rebar	$N^0_{Rd,re}$	$N^0_{Rd,hook}$	$N^0_{Rd,bond}$	ψ_{cr}	ψ_{cvr}	c_{min}	$l_{1,1}$	f_{bd}
0-V1	12.603	12.752	5.252	0.7	1	45.00	95	3.04
0-V2	11.501	12.752	3.678	0.7	1	45.00	95	2.13
1-V1	12.603	12.752	5.252	0.7	1	45.00	95	3.04
1-V2	11.501	12.752	3.678	0.7	1	45.00	95	2.13
2-V1	12.603	12.752	5.252	0.7	1	45.00	95	3.04
2-V2	11.501	12.752	3.678	0.7	1	45.00	95	2.13
3-V1	12.603	12.752	5.252	0.7	1	45.00	95	3.04
3-V2	11.501	12.752	3.678	0.7	1	45.00	95	2.13
$N_{Rd,re}$	**96.42**							

$N_{Rd,re} = 96.42\ kN$

$N_{Rd,a} = 96.42 + 0.5 \cdot 67.2 = 129.9\ kN$, should be > $N_{Rd,c}$ and < $N_{Rd,str}$

Concrete strut verification:

Strut	x_i	$\psi^0_{strut}(x_i)$	$A_{c,Ni}$	$\psi_{strut,N}(x_i)$
1	50	2.2	34200	0.52
2	50	2.2	19000	0.29
3	50	2.2	19000	0.29
4	50	2.2	19000	0.29
5	50	2.2	19000	0.29
6	50	2.2	34200	0.52
		Σ	**144400**	**2.2**

$N_{Rd,str} = \psi_{strut,N} \cdot N_{Rd,c} = 2.2 \cdot 67.2 = 147.8\ kN > N_{Rd,a}$

Therefore, $N_{Rd,a} = 129.9\ kN > N_{Ed} = 80\ kN$ verification fulfilled ✓

Combined tension and shear load:

Steel failure: EN 1992-4, eq. (7.54)

Ratio between action load and resistance in tension, $\beta_N = 0.187 \leq 1.0$

Ratio between action load and resistance in shear, $\beta_v = 0.012 \leq 1.0$

$\beta_N{}^{\alpha} + \beta_v{}^{\alpha} = 0.187^2 + 0.012^2 = 0.04 \leq 1.0$ verification fulfilled ✓

Failure other than steel: EN 1992-4, eq. (7.57) and fib

Ratio between action load and resistance in tension, $\beta_N = \left(\frac{80}{129.9}\right) = 0.62 \leq 1.0$

Ratio between action load and resistance in shear, $\beta_v = \left(\frac{5}{16.66}\right) = 0.31 \leq 1.0$

$\beta_N{}^{\alpha} + \beta_v{}^{\alpha} = 0.62^1 + 0.31^1 = 0.93 \leq 1.0.$ verification fulfilled ✓

Table 4.4 Brief comparison of utilization obtained through EN 1992-4 and Hilti method

EN 1992-4				Hilti method based on EN 1992-4 +fib			
Tension		Shear		Tension		Shear	
Steel	19%	Steel	2%	Steel	19%	Steel	2%
Concrete breakout	0%	Concrete edge breakout	36%	Concrete breakout	0%	Concrete edge breakout	31%
Pullout	33%	Pryout	4%	Pullout	33%	Pryout	4%
Splitting	0%	Combination		Splitting	0%	Combination	
Supplementary reinforcement steel	37%	Steel	4%	Supplementary reinforcement steel	34%	Steel	4%
Supplementary reinforcement anchorage	138% ✗	Concrete	175% ✗	Supplementary reinforcement anchorage	62%	Concrete	64%
Surface reinforcement steel	9%			Surface reinforcement steel	14%		

4.2 Design post-installed connection for shear loading with Hilti method

Project requirement: A steel profile is connected to a concrete element using post-installed chemical anchors. The arrangement of anchors is of 2 × 2 rectangular layout, and the 3D view of the application is shown in Fig. 4.3 and other information on this project is defined in Table 4.5.

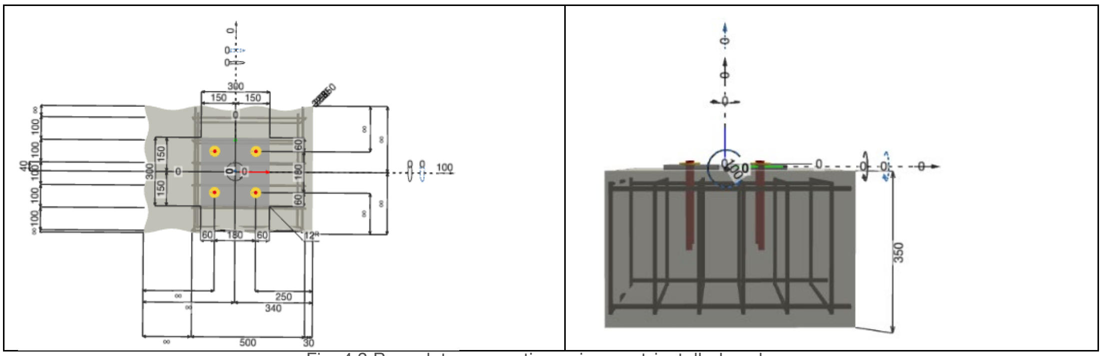


Fig. 4.3 Baseplate connection using post-installed anchors

Table 4.5 Project information and design inputs

Geometry	
Concrete thickness	350 mm
Baseplate	300 × 300 × 12 mm
Spacing between anchors (X and Y)	180 mm
Edge distance (X)	250 mm
Others	
Materials	Concrete: C20/25, cracked Reinforcing steel $f_{yk} = 500\ N/mm^2$
Design life	50 years
Installation	Rotary-hammer drilling /horizontal, dry
Supplementary reinforcement	10Φ stirrups spaced at 100 mm c/c

ANCHOR LOADS

Anchor	N [kN]	Vx [kN]	Vy [kN]
1	0	25	0
2	0	25	0
3	0	25	0
4	0	25	0

Total shear force on anchor group, $V_{Ed} = 100\ kN$ will be equally distributed among all anchors

Details of proposed anchor: The proposed anchor solution (without hole clearance) is defined in Table 4.6

Table 4.6: Anchor properties

Type of anchor		Chemical
Specification of anchor	HIT-HY 200-A V3 + HAS 8.8 M16	
Diameter of anchor	d	$16\ mm$
Effective embedment depth	h_{ef}	$200\ mm$

Design verifications are carried considering rigid baseplate as per EN 1992-4 [1] and characteristic resistances are taken from ETA-19/0601 [10]. Steel and pry-out verifications are as per EN 1992-4 Table 7.2. The verifications for supplementary reinforcement are explained below.

Supplementary reinforcement- tension:

Table 4.7: **Forces on supplementary reinforcement**

Rebar	Type	Tension force (kN)
E (Surface) reinforcement	Straight	21.89
2	Closed stirrup	13.41
3	Closed stirrup	18.48
4	Closed stirrup	21.76
5	Closed stirrup	22.45
6	Closed stirrup	20.57
7	Closed stirrup	16.55

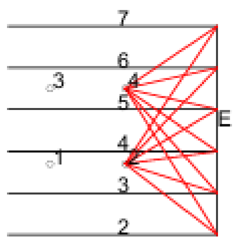


Fig. 4.4: Strut-and-tie model

Steel failure of longitudinal rebar, edge x+:

The resistance against steel failure of longitudinal rebars are checked considering following equation:

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

$\gamma_{Ms.re} = 1.15$

$N_{Rk,re} = A_{s,re} \cdot f_{s,re}, A_{s,re} = 113\ mm^2$ and $f_{s,re} = 500\ MPa$, $N_{Rk,re} = 113 \cdot 500 = 56.55\ kN$

$N_{Rd,re} = \left(\frac{56.55}{1.15}\right) = 49.17\ kN > N_{Ed,re} = 21.89\ kN$ verification fulfilled

Steel failure of supplementary reinforcement, edge x+:

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

$\gamma_{Ms.re} = 1.15$

$N_{Rk,re} = A_{s,re} \cdot f_{s,re}, A_{s,re} = 79\ mm^2$ and $f_{s,re} = 500\ MPa$, $N_{Rk,re} = 79 \cdot 500 = 39.27kN$

$N_{Rd,re} = \left(\frac{39.5}{1.15}\right) = 34.15\ kN > N_{Ed,re} = 22.45\ kN$ verification fulfilled

Anchorage failure of the anchor reinforcement in the concrete edge breakout body, edge x+ (SOFA based on EN1992-4 and fib design bulletin 58):

Supplementary reinforcement – shear:

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

$e_s = e_c + \frac{t}{2} + c + \frac{d_{s,re}}{2} = 0 + \frac{12}{2} + 25 + \frac{10}{2} = 36\ mm$

$d = h - c - \frac{d_{s,re}}{2} = 350 - 25 - \frac{10}{2} = 320\ mm$

$z = 0.85 \cdot d = 0.85 \cdot 320 = 272\ mm$

$\frac{e_s}{z} + 1 = 1.132$

Concrete edge breakout resistance:

$V_{Rd,c} = \frac{V_{Rk,c}}{\gamma_{Mc}}$ EN 1992-4, Table 7.2

$\gamma_{Mc} = 1.5$ ETA-21/0878, Table C2

$l_f = 192\ mm,\ c_1 = 430\ mm,\ k_9 = 1.7$ for cracked concrete

$\alpha = 0.1 \cdot \left(\frac{l_f}{c_1}\right)^{0.5} = 0.1 \cdot \left(\frac{192}{430}\right)^{0.5} = 0.067$ EN 1992-4, eq. (7.42)

$\beta = 0.1 \cdot \left(\frac{d_{nom}}{c_1}\right)^{0.2} = 0.1 \cdot \left(\frac{16}{430}\right)^{0.2} = 0.052$ EN 1992-4, eq. (7.43)

$V^0_{Rk,c} = k_9 \cdot d^{\alpha}_{nom} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c_1^{\ 1.5} = 1.7 \cdot 16^{0.066} \cdot 192^{0.052} \cdot \sqrt{20} \cdot 430^{1.5} = 107\ kN$ EN 1992-4, eq. (7.41)

$A^0_{c,V} = 4.5\ c_1^2 = 4.5 \cdot 430^2 = 832{,}050\ mm^2$ EN 1992-4, eq. (7.44)

$A_{c,V} = (1.5 \cdot 430 + 180 + 1.5 \cdot 430) \cdot (350) = 514{,}500\ mm^2$

$\psi_{s,V} = 1,\ \psi_{ec,V} = 1.0,\ \psi_{\alpha,V} = 1.0$

$\psi_{h,v} = \left(\frac{1.5 \cdot c_1}{h}\right)^{0.5} = \left(\frac{1.5 \cdot 430}{350}\right)^{0.5} = 1.35 \geq 1.0$

$V_{Rk,c} = V^0_{Rk,c} \cdot \frac{A_{c,V}}{A^0_{c,V}} \cdot \psi_{\alpha,V} \cdot \psi_{h,v} \cdot \psi_{s,V} \cdot \psi_{ec,V} \cdot \psi_{re,V} = 107 \cdot \frac{514500}{832050} \cdot 1.0 \cdot 1.0 \cdot 1.35 \cdot 1.0 \cdot 1.0$

$V_{Rk,c} = 89.82\ kN$

$V_{Rd,c} = \left(\frac{89.82}{1.5}\right) = 59.9\ kN$

Anchorage failure of the anchor reinforcement in the concrete cone breakout body:

Case: Two stirrup legs per anchor

$N^0_{Rd,re} = \psi_{cr} \cdot \psi_{cvr} \cdot \left(N^0_{Rd,hook} + N^0_{Rd,bond}\right) \leq A_{s,re} \cdot f_{yd,re}$

$N^0_{Rd,hook} = \frac{0.6}{\gamma_{Mc}} A_{s,re} f_{yk,re} \left(\frac{l_1}{c_1}\right)^{0.4}$ (for high effective stirrups number– 3,4,5 and 6)

$N^0_{Rd,hook} = \frac{0.1}{\gamma_{Mc}} A_{s,re} f_{yk,re} \left(\frac{l_1}{c_1}\right)^{0.4}$ (for less effective stirrups number- 2 and 7)

$N^0_{Rd,bond} = \pi \cdot d_{s,re} \cdot (l_1 - l_{1,min}) \cdot f_{bd}$

Rebar	$N^0_{Rd,re}$	$N^0_{Rd,hook}$	$N^0_{Rd,bond}$	ψ_{cr}	ψ_{cvr}	c_{min}	$l_{1,1}$	f_{bd}
2	14.41	2.24	18.35	0.7	1	45.00	291.7	2.32
3	26.46	14.60	23.20	0.7	1	45.00	358.3	2.32
4	28.12	15.03	25.15	0.7	1	45.00	385.0	2.32
5	27.30	14.82	24.18	0.7	1	45.00	371.7	2.32
6	27.30	14.82	24.18	0.7	1	45.00	371.7	2.32
7	15.12	2.28	19.31	0.7	1	45.00	305.0	2.32
$N_{Rd,re}$	**137.8**							

Concrete strut verification:

$V_{Rd,re} = \frac{138.7}{1.132} = 122.49\ kN$

$V_{Rd,c} = 59.9\ kN$, concrete edge breakout resistance without considering anchor reinforcement

$k_{fc} = 0.5$

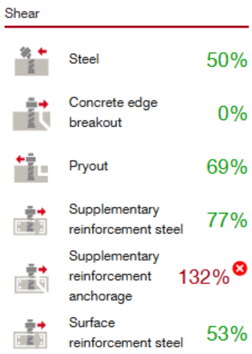
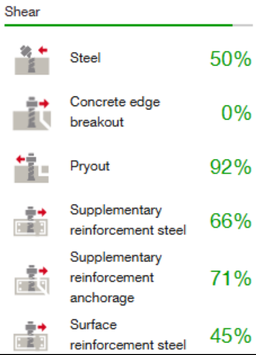
$V_{Rd,a} = 122.79 + 0.5 \cdot 59.9 = 152.74\ kN$, should be > $V_{Rd,c}$ and < $V_{Rd,str}$

Strut	x_i	$\psi^0_{strut}(x_i)$	$A_{c,Ni}$	$\psi_{strut,N}(x_i)$
1	70	2.34	225750	1.03
2	30	2.43	31500	0.15
3	50	2.38	31500	0.15
4	50	2.38	225750	1.05
		Σ	**514500**	**2.37**

$V_{Rd,str} = 2.37 \cdot 59.915 = 141.8\ kN < V_{Rd,a}$

Therefore, $V_{Rd,a} = 141.8\ kN \geq V_{Ed} = 100\ kN$ verification fulfilled ✓

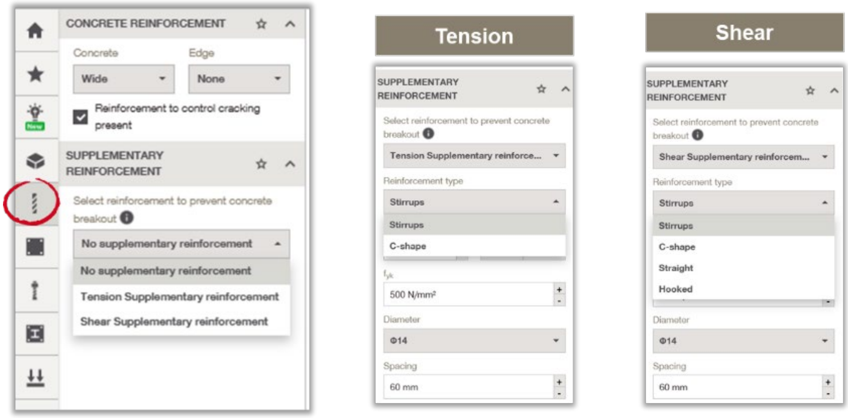
Table 4.8 Brief comparison of utilization obtained through EN 1992-4 and Hilti method

EN 1992-4	Hilti method based on EN1992-4 +fib
	

5. PROFIS Engineering

PROFIS Engineering is a cloud-based structural design platform that supports design engineers in the efficient and more transparent verification of steel-to-concrete connections. For post-installed anchorages with supplementary reinforcement, the software provides an implementation intended to be practical and transparent of both EN 1992-4 and the Hilti method, allowing engineers to select the design approach best suited to the application.

Within a consistent workflow, users can define anchorage geometry, loading, anchor type, and reinforcement arrangements. Supplementary reinforcement can be selected for tension or shear, depending on the project requirements. The selected design model either EN 1992-4 or the Hilti method governs the subsequent resistance verifications. This flexibility allows conventional code-based checks as well as more advanced assessments where the contribution of supplementary reinforcement with concrete is utilised. Additionally, the software generates a detailed and transparent design report documenting inputs, selected design method, governing assumptions, verified failure modes, and utilization ratios.



6. Conclusion

The EN 1992-4 design approach offers a well-established, standardized procedure appropriate for routine anchorage design, but its simplified assumptions can become conservative for multi-row groups or cases where supplementary reinforcement is intended to engage. The **Hilti method** based on EN 1992-4 and draft *fib* Bulleting 2026 is intended to provide an advanced alternative that incorporates additional load-transfer mechanisms for anchorages with supplementary reinforcement, enabling performance-optimized design for demanding applications.

PROFIS Engineering supports the design of anchorages with supplementary reinforcement by enabling the modelling of typical and standardized reinforcement layouts in accordance with EN 1992-4 and the Hilti design method. Together with our differentiated hardware systems, productive and safe installation methods, and our technical content and support in our Engineering Center, this design method is a part of our SPEC2SITE solutions. Our Field Force supports you in the office and in the field and we help connect with the contractor so the installation is done as per your specifications.

7. References

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Disclaimer: This document is for technical guidance purposes only. All design methods and calculations must be performed by qualified engineers and verified for the specific application and project conditions. The information is based on design provisions such as EN 1992-4 and related references, as applicable. Product performance depends on correct installation, material properties, and boundary conditions. Always refer to the relevant approvals, technical data, and applicable local regulations and standards.

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