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Hormigón y Acero 2023; 74(299-300):211-222
https://doi.org/10.33586/hya.2023.3108

Eurocode Practice: Design of Fastenings for Use in Concrete in Accordance with Eurocode 2

Práctica del Eurocódigo: Diseño de fijaciones para uso en hormigón de acuerdo con el Eurocódigo 2

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Recibido el 29 de septiembre de 2022; aceptado el 20 de marzo de 2023

SUMMARY

Since 1997, the design of fastenings for anchoring in concrete has been regulated at European level by Annex C of the European Technical Approval Guideline and the subsequently published, supporting and referenced "Technical Report" TR029 and TR045 or by the pre-standard series CEN/TS 1992-4. The new EN 1992-4 standard, which is published in 2017 and has been formally accepted by the CEN members in the voting process. It summarizes the existing design rules while taking into account state of the art and applies to all main fasteners used in construction engineering. It is far more comprehensive in terms of the fastening systems it covers, and the load conditions it takes into consideration. Consequently, it represents an important and necessary step in harmonizing the design of fasteners for use in concrete. The following paper briefly presents the contents of the new European Standard EN 1992-4 "Design of fasteners for use in concrete" and the major changes that have been introduced compared to CEN/TS 1992-4 and ETAG 001, Annex C.

There is an added chapter regarding "post-installed rebar anchorage length", which is covered by FprEN 1992-1-1:2023 [15]. This application is used for design of rigid connections between concrete members.

KEYWORDS: EN 1992-4, EN 1992-1-1, concrete fasteners, post-installed rebar, anchor.

RESUMEN

Desde 1997, el diseño de las fijaciones para el anclaje en hormigón está regulado a nivel europeo por el Anexo C de la Directriz Europea de aprobación técnica y los "Informes técnicos" TR029 y TR045 publicados posteriormente, de apoyo y referenciados o por la serie prenorma CEN/TS 1992-4. La nueva norma EN 1992-4, que se publica en 2017, ha sido aceptada formalmente por los miembros del CEN en el proceso de votación. Resume las reglas de diseño existentes teniendo en cuenta el estado de la técnica y se aplica a todos los principales anclajes utilizados en la ingeniería de la construcción. Es mucho más completo en términos de los sistemas de fijación que cubre y las condiciones de carga que tiene en cuenta. En consecuencia, representa un paso importante y necesario en la armonización del diseño de anclajes para su uso en hormigón. El artículo presenta brevemente el contenido de la nueva Norma Europea EN 1992-4 "Diseño de fijaciones para uso en hormigón" y los principales cambios que se han introducido en comparación con CEN/TS 1992-4 y ETAG 001, Anexo C.

Hay un capítulo añadido con respecto a la "longitud de anclaje de las barras corrugadas post-instalada", que está cubierto por la nueva EN1991-1-1. Esta aplicación se utiliza para el diseño de conexiones rígidas entre elementos de hormigón.

PALABRAS CLAVE: EN 1992-4, EN 1992-1-1, fijaciones en hormigón, barras corrugadas post-instaladas, anclaje.

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How to cite this article: Appl, J., & Cardo, A. (2023) Eurocode Practice: Design of Fastenings for Use in Concrete in Accordance with Eurocode 2, *Hormigón y Acero* 74(299-300):211-222, https://doi.org/10.33586/hya.2023.3108

1. INTRODUCTION

Since 1997, the design of fastenings for anchoring in concrete has been regulated at European level by Annex C of the European Technical Approval Guideline [1] and the subsequently published, supporting and referenced "Technical Report" TR029 [2] and TR045 [3] or by the pre-standard series CEN/TS 1992-4 [4]. The new EN 1992-4 standard [18], which was published in 2017, has been formally accepted by the CEN members in the voting process. It summarizes the existing design rules while taking into account state of the art and applies to all fasteners either cast into concrete or installed in hardened concrete. It is far more comprehensive in terms of the fastening systems it covers, and the load conditions it takes into consideration. Consequently, it represents an important and necessary step in harmonizing the design of fasteners for use in concrete. The following paper briefly presents the contents of the new European Standard EN 1992-4 "Design of fasteners for use in concrete" [18] and the major changes that have been introduced compared to CEN/TS 1992-4 [4] and ETAG 001, Annex C [1].

There is an added chapter regarding "post-installed rebar anchorage length", which is cover by FprEN 1992-1-1:2023 [15]. This application is used for design of rigid connection between concrete members.

2 EN 1992-4 [18]

2.1. General

While the CEN/TS series 1992-4 [4] consists of 5 parts with approximately 170 pages, EN 1992-4 [18] is considerably shorter but technically much more comprehensive. The abridged background information will be still available as supplementary documents as part of the CEN/TR 17080 "Anchor channels – Supplementary rules", CEN/ TR 17081 "Design based on plasticity theory" and CEN/TR 17079 "Redundant systems".

EN 1992-4 [18] applies to cast-in place systems such as anchor channels, headed bolts, headed studs in combination with welded steel plates, mechanical fasteners such as metal expansion anchors, undercut anchors, concrete screws and post-installed chemical fasteners such as bonded anchors and bonded expansion anchors. Cast-in place systems, which are embedded in precast concrete elements under controlled production, and which are only used temporarily for the lifting and transportation of pre-cast elements, are covered in the document CEN/TR 15728: 2008 [5] "Design and use of inserts for lifting and handling precast concrete elements".

2.1.1. Anchor channels, headed bolts and headed anchors

Anchor channels consist of a cold-formed or hot-rolled, V-shaped or U-shaped steel profile with special anchoring elements that are attached directly to the inside of the formwork (Figure 1). The open steel profiles are filled with foam or provided with environmentally compatible foam filling with pull-out tape to prevent concrete from penetrating the channel during the casting process. Once the filling has been stripped and removed, the fixtures can be attached using special T-headed bolts. Anchor channels are usually held in place by headed bolts or studs which are either welded, forged or screwed on. Depending on the product, the anchor channel can only be loaded perpendicularly to the axis of the channel because transferring forces along the length of the channel is only achieved by way of friction between the T-headed bolt and the lip of the rail, and the magnitude of friction is uncertain. To transfer loads along the length of the channel there are special channels or special T-headed bolts to guarantee an interlock connection which transfers the loads. EN 1992-4 [18] does not cover shear in the direction of the longitudinal axis of anchor channels.

Headed stud anchors consist of a steel plate with a headed studs welded on it. Headed studs are also made of ribbed or profiled rebar and are arc-welded to the anchor plate.

2.1.2. Mechanical fasteners

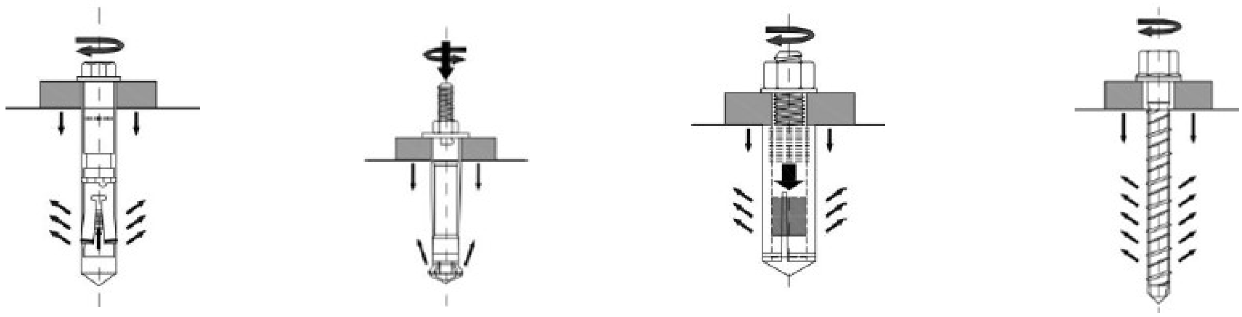
The fasteners covered by EN 1992-4 [18] can be divided into different groups:

- ***Metal expansion anchors*** (Figure 2a/2c)
  In the case of torque-controlled fasteners (Figure 2a) a hole is drilled, the fastener is inserted into the drill hole and anchored by tightening the screw or nut with a cal-

Figure 1. Anchor channel before installation (left) and after installation (right).

a) Torque-controlled expansion anchors b) Undercut anchors c) Deformation-controlled expansion anchors d) Concrete screws

Figure 2. Mechanical fastening systems



a) Torque-controlled expansion anchors b) Undercut anchors c) Deformation-controlled expansion anchors d) Concrete screws

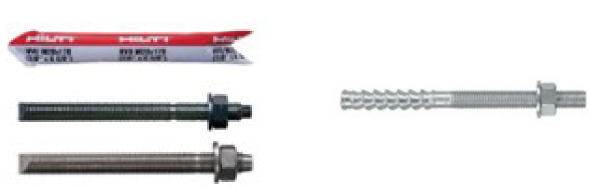
Figure 2. Mechanical fastening systems. Load transfer to concrete mechanism. Source [19].

ibrated torque wrench. A tensile force is produced in the bolt, the cone at the tip of the anchor is drawn into the expansion sleeve and forced against the sides of the drilled hole. Deformation-controlled anchors (Figure 2c) comprise an expansion sleeve and cone. They are set in place by expanding the sleeve through controlled deformation. This is achieved either by driving the cone into the sleeve or the sleeve over the cone.

- ***Undercut anchors*** (Figure 2b)
  As with cast-in-place systems, undercut anchors develop a mechanical interlock between anchor and the base material. To do this, a cylindrically drilled hole is modified to create a notch, or undercut, of a specific dimension at a defined location either by means of a special drilling apparatus, or by the undercutting action of the anchor itself. In case of self-undercutting the undercut is generated using the expansion element inserted into the pre-drilled hole. Use of rotary-impact action permits the expansion element to simultaneously undercut the concrete and widen to their fully installed position. The cone bolt provides at its end space for the drilling dust which accumulates during formation of the undercut. This process results in a precise match between the undercut form and the anchor geometry.
- ***Concrete screws*** (Figure 2d)
  Concrete screws or screw anchors are typically hardened to permit the thread to engage the base material during installation. They are installed in drilled holes. The thread pitches at the tie may be provided with special cutting surface and or geometries in order to assist the process of cutting threads in the wall of the drilled hole. They may be driven by mean of special impact driver or, in other systems with a conventional drill equipped with an adapter. The diameter of the drilled hole is matched to the geometry of the screw so that the thread cuts into the concrete and an external force can be transferred to the concrete through this positive interlocking connection.

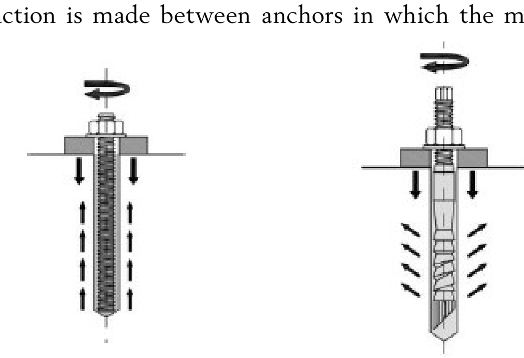
2.1.3. Chemical fasteners

- ***Bonded anchors***:
  Bonded anchors are available in various systems. A distinction is made between anchors in which the mortar



a) Bonded anchors, cartridge system b) Torque-controlled bonded anchors

Figure 3. Chemical fastening systems.



a) Bonded anchors b) Torque-controlled bonded anchors and mode of action

Figure 3. Chemical fasteners. Load transfer to concrete mechanism. Source [19].

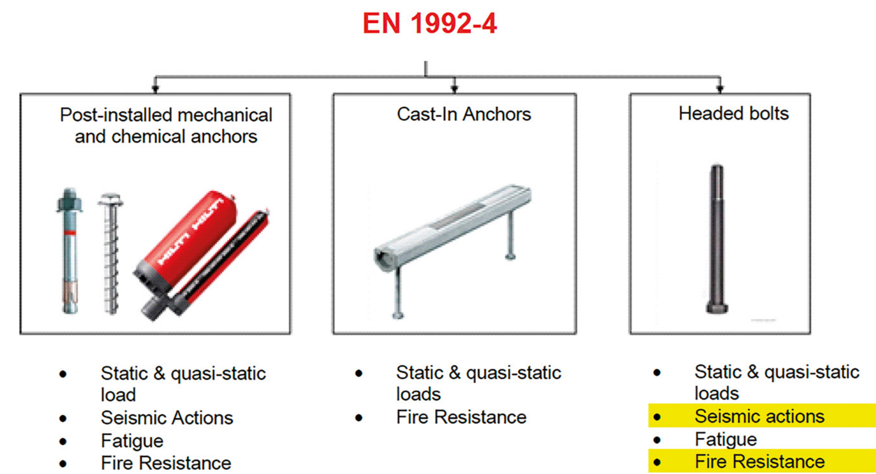


Figure 4. Verifications for different fasteners in accordance with EN 1992-4 [18].

is contained in plastic or glass capsules (Figure 3a) and injection systems in which the mortar is delivered in cartridges. Irrespective of the system, forces are applied from the threaded rod to the mortar via mechanical interlocking and to the anchor base via micro-interlock, friction and bonding between the mortar and hole wall.

- ***Torque-controlled bonded anchors***:
  Torque-controlled expansion anchors use an anchor rod with multiple cones (Figure 3b). They are coated and can be protected with a wire sleeve if necessary. When a tension force is applied to the anchor rod, the cones are drawn into the mortar, which acts as an expansion sleeve. This results in expansion and frictional forces between the mortar and the borehole wall, sufficient enough to induce a tensile force to the base material regardless of the adhesive effect of the mortar.

2.2. Field of Application

The basic requirement for the usage of EN 1992-4 [18] is an European Technical Approval ETA (until June 2013), called Assessment (since July 2013) of the covered fastening systems on the basis of the applicable European Technical Approval Guideline ETAG [6] (until June 2013), called European Assessment Document (EAD) [7] (since July 2013).

The Guideline or Assessment document specifies the requirements and acceptance criteria which must be fulfilled by the fastening system. Based on this approach, tests need to be carried out in order to assess the suitability of the system and determine the permissible conditions of use. The tests involve, among other things, low-strength and high-strength concrete, with tests being carried out on both cracked or non-cracked concrete, depending on the intended application range. The effects of possible deviations during installation of the fastening system, such as borehole tolerances, level of borehole cleaning, extent of expansion, positioning of anchors with respect to reinforcing bars (reinforcing contact), the impact of moisture and concrete temperature on the load-bearing behavior of the fastener should be checked specifically, where relevant. The tests also take into account the impact of sustained and/or variable loads on the fasteners.

Gross installation errors cannot and are not be covered by these tests. EADs are produced by the European Organization for Technical Assessment (EOTA). The EOTA works closely with the European Committee for Standardization CEN.

The design in accordance with EN 1992-4 [18] is based on the characteristic resistance and spacing of the fasteners as specified in the Approval/Assessment. EN 1992-4 [18] is intended for the design of fastenings which connect structural and non-structural components with structural components, in which the failure of fastenings will:

- result in a complete or partial collapse of the structure.
- cause risk to human life or
- lead to significant economic loss.

The design in accordance with EN 1992-4 [18] can be applied to both new buildings and existing structures which are covered by EN 1992 (Eurocode 2, concrete structures) and EN 1994 (Eurocode 4, composite structures). For applications where special conditions may apply, e.g. nuclear power plants or civil defense structures, modifications and supplements of the design may be necessary.

Fastenings can be designed as both single fasteners and groups of fasteners for anchoring in concrete, whereby it is assumed that only fasteners of the same type, manufacturer, diameter and anchoring depth are used within a group. With the introduction of EN 1992-4 [18], the permissible concrete strength classes C20/25 to C50/60 [6] will also be extended to C12/15 to C90/105 if the fasteners qualify for these concrete strength classes in accordance with [7].

For a group of fastenings, the loads are transferred to the individual anchors by means of a common fixture – usually a steel plate. Although the design of the fixture itself is not considered in EN 1992-4 [18], the design must, nevertheless, correspond to the standard to be applied. The load transfer from anchor group to the supports of the reinforced concrete structure has to be verified for both the ultimate limit state and the serviceability limit state in accordance with EN 1992-1-1 [8].

Fasteners must be designed for static, quasi-static, dynamic (fatigue and earthquakes) and fire actions. Whether and to what extent a fastener qualifies for the above-mentioned ac-

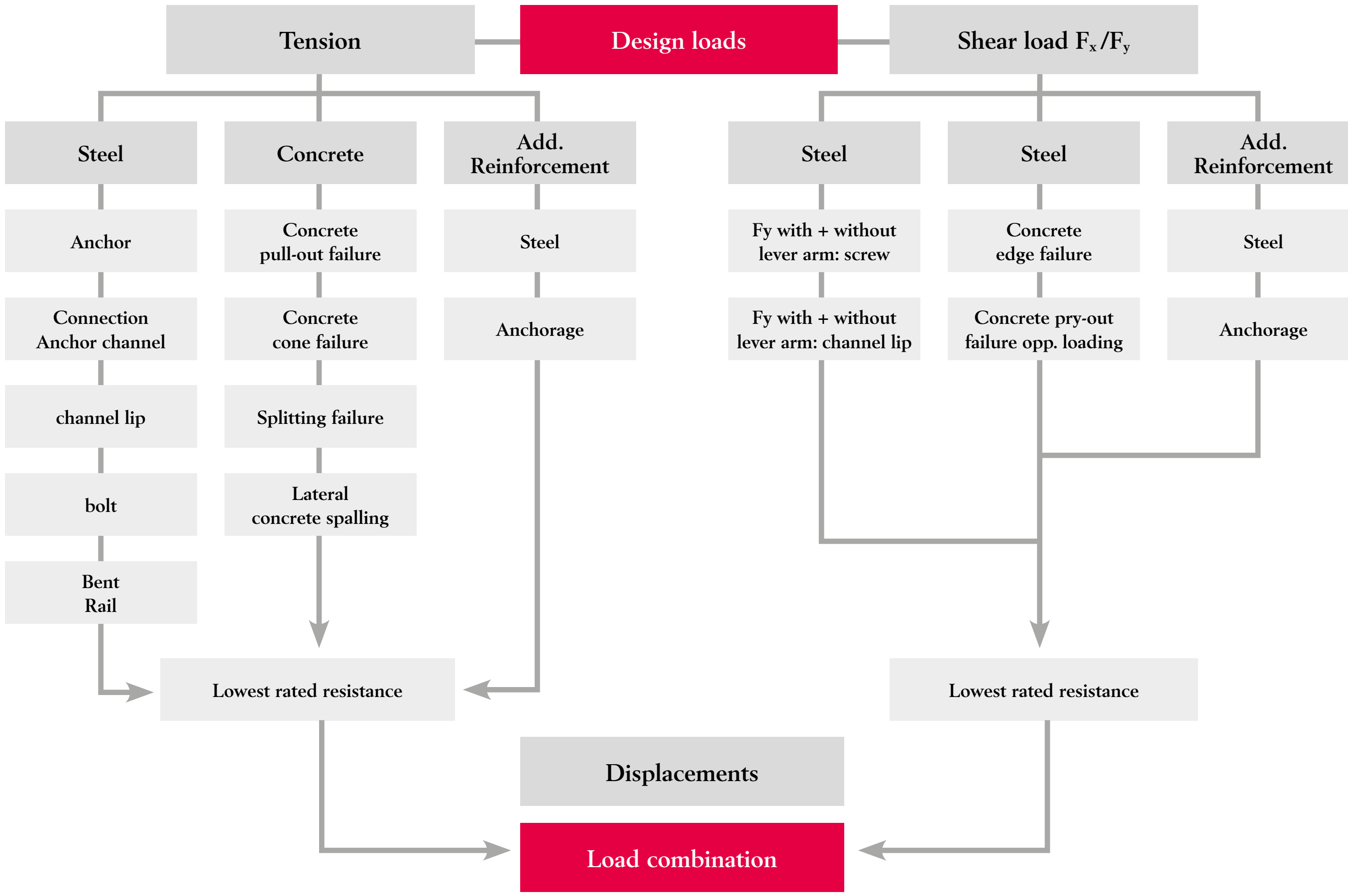


Figure 5. Possible failure modes for anchor channels.

tion effects can be derived from the product-related approval/assessment (ETA). Figure 4 shows the verifications that will be covered taking account of the different types of fastening systems in accordance with EN 1992-4 [18].

The load-bearing characteristics of fasteners can be significantly influenced by cracks due to tension loads. Fasteners can generally be qualified and approved for cracked and/or non-cracked concrete. It is therefore up to the designer to decide which national standards need to be taken into consideration and, consequently, which usage conditions need to be assumed for specific reinforced concrete components. In the design of flexural or tension components, it will be prudent to assume that concrete is cracked. Tensile Stresses caused by restraint will often exceed the low tensile strength of concrete.

If non-cracked concrete conditions are assumed and fasteners with an ETA for non-cracked concrete are selected, verification needs to be provided in accordance with EN 1992-4 [18] that no cracks will appear in the anchorage area of the fastener for the entire service life of the fastener. To avoid such complex verification – if this is at all possible – fasteners suitable for use in cracked concrete are generally preferred.

2.3. Basis of design

Verification for the following two states needs to be performed:
- Ultimate limit state.
- Serviceability limit state.

For the ultimate limit state, it must be shown that the value of the design actions does not exceed the value of the design resistance, whereby the failure mode with the mathematically lowest resistance value is decisive for the design.

In the serviceability limit state, it shall be shown that the displacement occurring under characteristic actions is not larger than the admissible displacement. The admissible displacement depends on the item to be fastened and must be specified by the structural engineer. The functionality of the component being fastened also needs be observed when subjected to displacement. The characteristic displacements as given in the approval/assessment can generally be interpolated linearly, but in the case of combined tension and shear loads they should be added vectorially.

Optimum and sufficiently safe utilization of the fastener is only possible if the design takes into account the loading direction (tension load, shear load, combined tension and shear load) as well as the type of action (predominantly static, dynamic, variable, etc.) and differentiates the different modes of failure. In 1995 the Committee Euro-International du Béton (CEB) published a design method based on the CC-method [9] (concrete capacity) that meets the above requirements. In 1997 this design concept was fully adopted by the EOTA. This basic approach or its philosophy to other fastening systems can be found in the European standard EN 1992-4 [18].

For post-installed mechanical and chemical fasteners under tension loads, the CC method [9] differentiates between steel failure, pull-out failure, concrete cone failure, splitting as well as blow-out failures of headed studs near to an edge. For shear loads, the differentiated modes of failure include steel failure (bolt shearing or bending failure), concrete edge failure and pry-out failure. Where existing reinforcement in the concrete member is utilized in the design for the above-mentioned fasteners, such reinforcement also needs to be verified against steel and anchorage failure.

The CC method [9] optimally utilizes the performance capabilities for the given marginal conditions but can also be considered as relatively complex as the load-bearing capacity of fasteners is described for all loading directions and all modes of failure. This is illustrated in Figure 5, which shows schematically the flowchart for the required verifications for anchor channels.

Various manufacturers have developed design software to simplify the design process. Such design programs make it is possible to solve almost every fastening task quickly while optimizing the utilization rate and thus the required number of fasteners.

Unlike CEN/TS [4] or [2], EN 1992-4 [18] is adapted to the current state of the art and the regulatory framework of the Construction Products Ordinance. This has resulted in both minor and major changes. In the following section, only the major differences will be discussed.

2.4. Technical changes

2.4.1. Consideration of the effect of sustained tension loads

Fasteners must ensure a safe load transfer over many years. Therefore, its long-term behavior is of interest. In case of verification of the failure mode "combined pull-out and concrete cone failure" of chemical fasteners, EN 1992-4 [18] contains an additional coefficient ψ_{sus} (not present in [1] and [4]), which is intended to take account of the effect of a tension load acting permanently on the fastener (sustained loading). It decreases the adhesive strength of the chemical fastener and therefore the resistance. The coefficient is product-specific and should be given in the product-related European Technical Assessment (ETA). It is included in the design by considering the ratio of the value of sustained loading related to the value of short-term loading. If no value is specified in the ETA for chemical anchors, a default coefficient of ψ_{sus} = 0,6 is assumed.

There is currently no qualification guideline to describe how this value must be derived. As long as this remains the case, the design in accordance with EN 1992-4 [18] for a specific product with the total effect of the sustained load results in a load reduction of 40% compared to [1] and [4].

2.4.2. Consideration of the excess force on the concrete breakout body subjected to a moment

When a fastening consisting of two anchors is subjected to a bending moment, a couple is set up consisting of a tensile force in the anchor and a compressive force beneath the fixture (Figure 6). If the tensile force in the anchor exceeds the concrete cone breakout capacity, then a concrete cone failure will occur. In this situation however the concrete cone failure load may be influenced by the adjacent compression stress block beneath the fixture. According to [10], the impact depends to a large extent on the lever arm between the resulting tension and compression forces (z) in relation to the radius of the expected breakout cone (r = 1.5 h_{ef}, with h_{ef}= anchoring depth of the fastener).

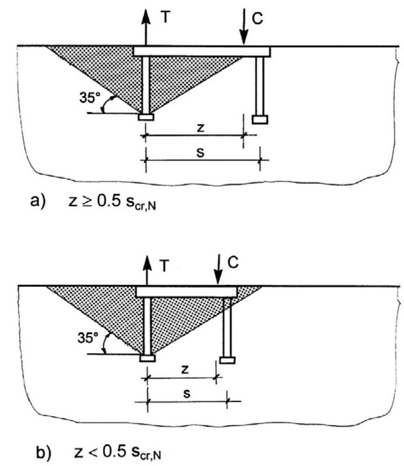


Figure 6. Impact of a bending moment acting on the anchor plate on the concrete breakout load of the tensioned fasteners [10].

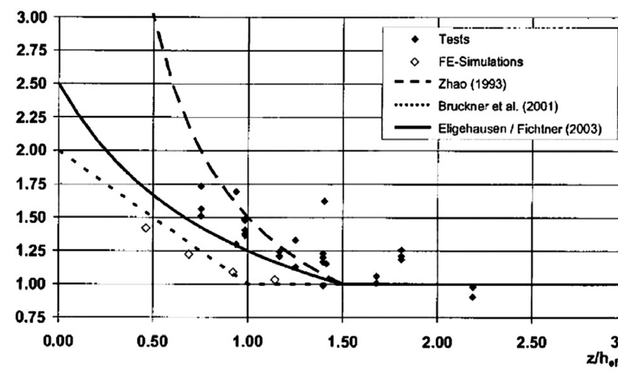


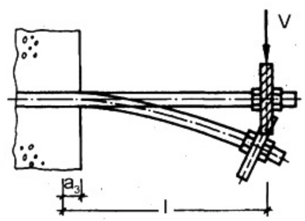
Figure 7. Impact of a compression force beneath the anchor plate on the concrete breakout load as a function of the ratio between the inner lever arm z and the anchoring depth hef due to an applied bending moment.

It is determined using the coefficient $\psi_{M,N}$ (= 2- z /1.5h_{ef}).The smaller the difference between the resulting compression and tension force, the greater the increase in the load required to precipitate concrete cone failure (Figure 7). The coefficient can be between 1.0 and 2.0 in accordance with EN 1992-4 [18]. This behavior can only be incorporated to a limited extent in the design and only in the cases of large edge distances, for example. Important studies have already been made in this regard in [8], [10] and [11].

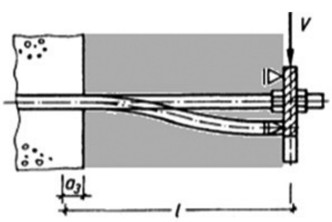
2.4.3. Consideration of the supporting effect of a mortar bed (shimming)

When designing a fastener or providing verification for steel failure under an acting shear load, a distinction must be made between a "shear load without lever arm" and a "shear load with lever arm". Until now, the design method for "shear load without lever arm" can only be used if the fixture is made of metal and positioned directly against the concrete. Compensation layers or shims were only covered up to t = 3mm while this value was already increased to d/2 in [1] and [4] (d = nominal diameter of the anchoring element [mm]). If this was not the case, the design had to be assumed as "shear load with lever arm", which results in significantly lower resistance values with respect to "steel failure" due to bending stresses.

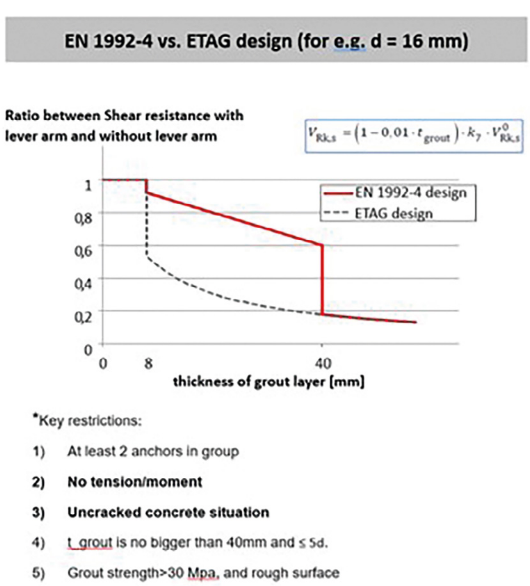
EN 1992-4 [18] provides the option of taking account of the supporting effect of a mortar bed under the fixture up to a maximum thickness of t = 40 mm. This only applies if it can be demonstrated that no cracks can be expected in the concrete (non-cracked concrete). In accordance with EN 1992-4 [18], verification will be provided within the limits of the layer thickness of 0.5d <t <40 mm as "shear load without lever arm" where the resistance value for this type of failure is linearly reduced within the said limits. For a mortar layer thickness of t = 40 mm, there will be a 40% reduction in the resistance value compared to a shear load without a lever arm and without shims. (Figure 8).



a) Fixture can be rotated freely.



b) Supporting effect of the mortar bed up to t = 40mm, schematic, non-cracked concrete.



c) Example for Anchor Diameter 16 mm.

Figure 8. Fastening under shear load with lever arm.

If the value of the characteristic cylinder compressive strength f_{ck} of the mortar being used is less than 30 N/mm² (MPa), the linear reduction is already within the limits of 0 < t < 40 mm.

For a ratio of embedment depth (h_{ef}) to diameter (d) h_{ef}/ d < 5 and a concrete strength class less than C20/25, a reduction in the resistance value for the failure type "steel failure without lever arm" of 20% is recommended.

2.4.4. Consideration of failure modes under combined tension and shear loads

The load-bearing behavior of fasteners under combined tension and shear loads lies somewhere between the behavior for centric tension and shear loads and depends on the angle of action. The same modes of failure occur as for tension or shear loads. The following failure combinations are possible:

a) Steel failure under tension and shear load
b) Concrete breakout failure under tension load and steel failure under shear load
c) Concrete breakout failure under tension and shear load
d) Steel failure under tension load and concrete failure under shear load.

Until now, the individual modes of failure under combined tension and shear loads have not been fully considered on the basis of a trilinear interaction equation (Figure 9). According to EN 1992-4, the combined action should be calculated separately, once for concrete-related failures and once for steel failures, with the smallest value of both interaction curves providing the design value. This technically correct approach results in significantly higher resistance values (Figure 10) than in the original equation ([1] and [4]).

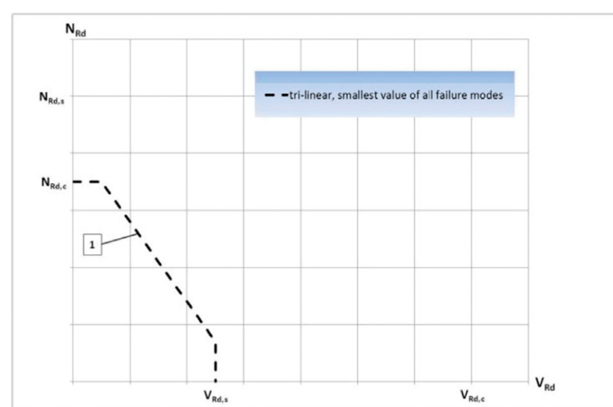


Figure 9. Trilinear interaction diagram for fasteners based on [1], taken from [13].

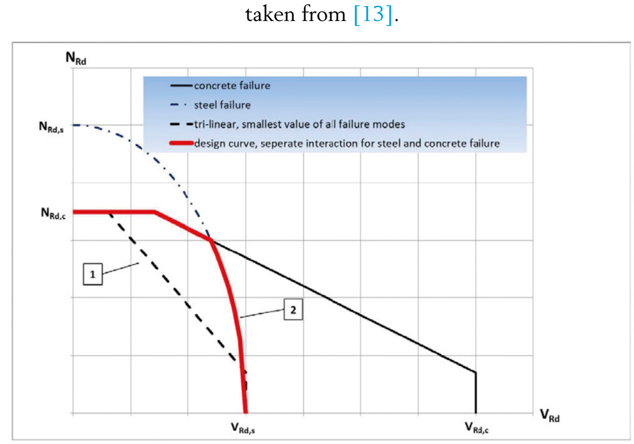
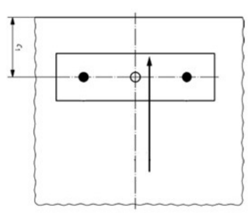


Figure 10. Interaction diagram in accordance with EN 1992-4 taking into account the different modes of failure, taken from [13].

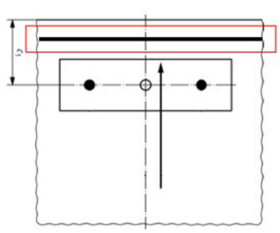
2.4.5. Consideration of edge reinforcement for the concrete edge failure

Fasteners close to the edge under shear load perpendicular to the edge can fail due to concrete breakage (concrete edge failure) before reaching the steel load-bearing capacity. Coefficient $\psi_{re,V}$ in EN 1992-4 takes into account the increase in the concrete edge failure load based on the type of edge reinforcement in place. If there is no available edge reinforcement or shear reinforcement, the coefficient is 1 (Figure 11a). The approach is identical to [1] and [4]. Whereas in [1] and [4], when edge reinforcement is provided, the basic characteristic resistance for the failure type "concrete edge failure" is increased by 20% ($\psi_{re,V}$= 1.2), in EN 1992-4 [18], the effect of edge reinforcement is ignored (Figure 11b) because there is no a clear strut & tie model to verify how it happens when a shear reinforcement is available (Figure 11c) . If staggered shear reinforcement is available (a ≤ 100mm and a ≤ $2c_1$ with c_1 = edge distance in [mm]) and verification is provided for cracked concrete, the basic value is increased by 40%. This corresponds to the approach of [1] and [4].



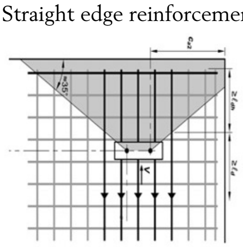
ψre,V		
	ETAG 001	1.0
	CEN/TS 1992-4	1.0
	EN 1992-4	1.0

a) Without edge, shear or hanger reinforcement.



ψre,V		
	ETAG 001	1.2
	CEN/TS 1992-4	1.2
	EN 1992-4	-

b) Straight edge reinforcement.



ψre,V		
	ETAG 001	1.4
	CEN/TS 1992-4	1.4
	EN 1992-4	1.4

c) Edge and close-meshed shear reinforcement.

Figure 11. Type of edge reinforcement and its impact on the concrete edge load.

2.4.6. Consideration of the concrete edge load for shear loads parallel to or at an angle to the edge

The coefficient ψ_α takes into account the angle α that the acting shear force forms with the direction perpendicular to the free edge. If the force acts parallel to the edge (α = 90°), the failure-inducing force acting perpendicular to the edge in accordance with [11] is approximately 50% of the load. This means that the shear force that can be absorbed when applied parallel to the edge with the same edge distance is approximately twice as great as the load applied perpendicular to the edge. To date, the approach in accordance with [1] and [4] resulted in a 2.5-fold shear force under the above-mentioned marginal conditions. In accordance with EN 1992-4 [18], the original value of 90 ° in [11] is reverted while the equation for the calculation of the coefficient ψ_α has been modified accordingly. Consequently, the concrete edge failure load for a shear force acting obliquely to the edge produces up to 20% (90°) less resistance values according to EN 1992-4 [18] compared to [1] and [4], and as the angle decreases, the difference becomes smaller.

2.4.7. Impact of the conversion of the original concrete compressive strength measured on cubes with an edge length of 200mm

The original equations for determining concrete-related failure loads, such as concrete cone failure and concrete edge failure, were determined by taking into account the concrete compressive strength measured on concrete cubes with an edge length of 200 mm. In the context of transferring the design concept to other fastening systems or guidelines, the corresponding equations were given with reference to a concrete compressive strength – measured on concrete cubes with an edge length of 150mm.

As part of the revisions made to the European Standard, the equations in question were adjusted to reflect the cylinder compressive strength (150mm x 300mm). Based on this adjustment, up to 4% lower resistance values are calculated than for [1] and [4] in accordance with EN 1992-4 [18] – using the equation referred to.

3
FASTENING DESIGN IN FPREN 1992-1-1:2023 [15]

There is a fastening application which is not covered by EN1992-4 [18]. This application is the rigid connection between structural concrete elements using post-installed reinforcement bars. This application is covered, as a novelty, in FprEN 1992-1-1:2023 [15] (Art. 11.4.8). These connections are made with deformed reinforcement bars (f_{yk} ≤ 500 MPa) and mortars (epoxies, vinylesters, etc) in existing concrete structures to resist mainly static loads. (Figure 12).

The reason for not covering these topics in EN1992-4 is that the approach, in relation to the classical theory of anchors on which EN1992-4 is based, is different. The two main differences are:

Post-installed reinforcement bars (Rebar) are stressed by tension-compression loads. Not shear loads as an anchor.

Concrete cone failure or combined pullout and concrete cone failure, which are typical failure mode in classical the-

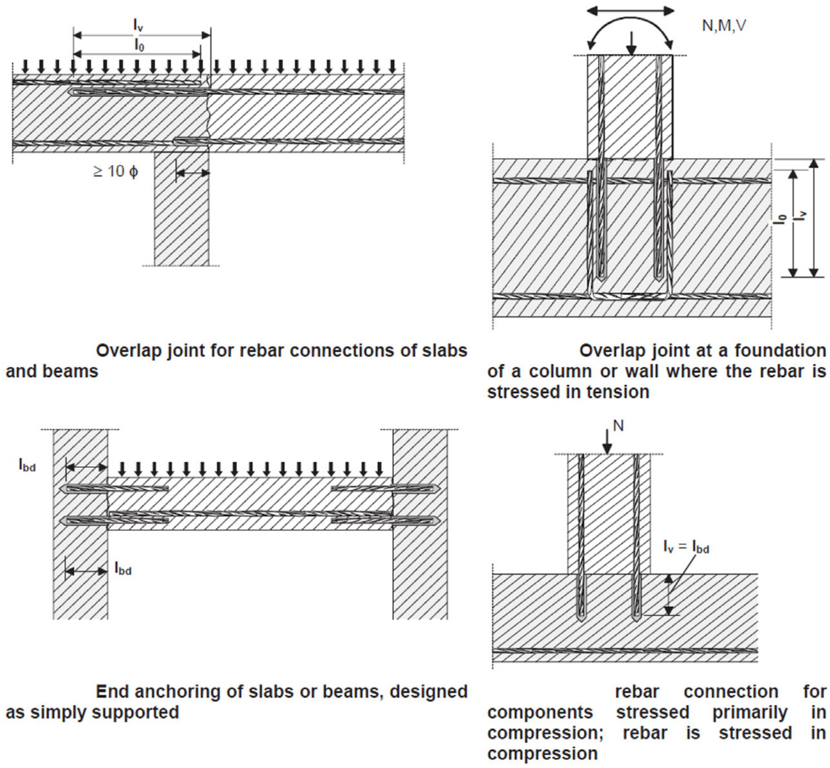
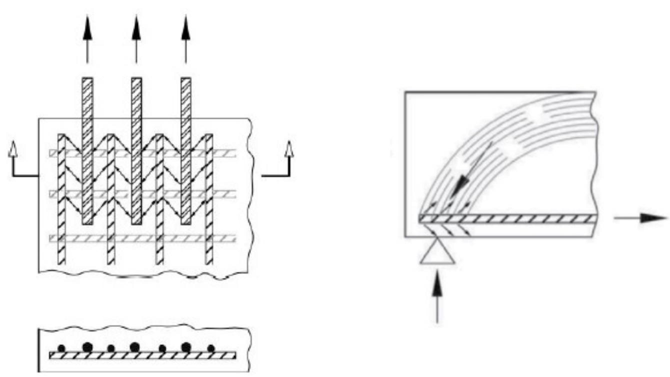


Figure 12. Examples of post-installed rebar connections include EAD 330087-00-0601"Systems for Post-Installed rebar connections with mortar". Source [16].



a) Overlap. b) Compression Strut.

Figure 13. Situations to avoid concrete cone failure or combined pullout and concrete cone failure with post installed rebar. Source [19].

ory of anchors, are prevented by the existing reinforcement, which takes tension loads as an overlap with post-installed rebar or by a compression strut. (Figure 13).

This sketch clarifies this last topic

Key
l_{bd} design anchorage length
1 start of achorage

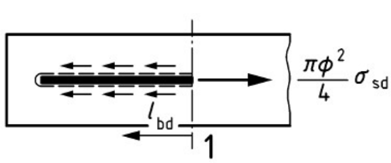


Figure 14. Sketch Anchorage of bonded post-installed reinforcement. Source [15].

The start of anchorage refers to the cross section where the reinforcement force is fully transferred to the concrete in compression. (Figure 14).

3.1. Design Anchorage length calculation

Calculation of design anchorage lenght for post-installed rebar is described in Art. 11.4.8 FprEN 1992-1-1:2023 [15].

Formula (1) is used according to [15]:

$$l_{bd,pi} = \frac{l_{bd}}{k_{b,pi}} \geq 10\phi\ \alpha_{lb} \quad (1)$$

Where:

$l_{bd,pi}$ is anchorage length for a post-installed rebar with ϕ diameter.

$k_{b,pi}$ is bond efficiency factor. This factor depends on bonding properties of mortar, which are evaluated with test regarding European Assessment Document EAD 330087-00-0601. This factor appears in European Technical Product Specification (European Technical

Table 11.1 (NDP) — Anchorage length of straight bars divided by diameter l_{bd}/ϕ

ϕ [mm]	Anchorage length l_{bd}/ϕ							
	f_{ck}							
	20	25	30	35	40	45	50	60
≤ 12	47	42	38	36	33	31	30	27
14	50	44	41	38	35	33	31	29
16	52	46	42	39	37	35	33	30
20	56	50	46	42	40	37	35	32
25	60	54	49	46	43	40	38	35
28	63	56	51	47	44	42	40	36
32	65	58	53	49	46	44	41	38
NOTE The values of Table 11.1 (NDP) are derived from Formula (11.3). This table is valid for $c_d = 1{,}5\phi$; $\sigma_{sd} = 435$ MPa and for bars in good bond conditions. For bars in poor bond conditions in concrete members the values should be multiplied by 1,2.								

Table 1.Anchorage length of straight bars. (It corresponds to Table 11.11 in [15]).

Approval) (ETA) of mortar. This factor could take values between 0.71 to 1.

α_{lb} factor accounting for cracks along the bar which may be taken as $\alpha_{lb} = 1{,}5$ in general or as given in the European Technical Product Specification of mortar.

l_{bd} is the anchorage length for a cast-in rebar with ϕ diameter. There are important changes regarding this topic in FprEN 1992-1-1:2023 [15]. There are two calculation methods:

Simplified Method: Using Table 1 based in f_{ck} of concrete and Table 1. Anchorage length of straight bars. (It corresponds to Table 11.11 in [15])

Detailed Method: Design anchorage length should be calculated with formula (2) according to [15].

$$l_{bd} = k_{lb}\, k_{cp}\, \phi \left(\frac{\sigma_{sd}}{435}\right)^{n_\sigma} \left(\frac{25}{f_{ck}}\right)^{1/2} \left(\frac{\phi}{20}\right)^{1/3} \left(\frac{1.5\phi}{c_d}\right)^{1/2} \geq 10\phi \qquad (2)$$

where:

c_d is the concrete cover. This is Min (0.5 cs, cx, cy) (Figure 15).

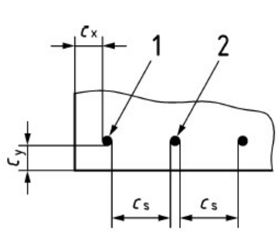


Figure 15. Concrete cover definition. Source [15].

σ_{sd} is the tension/compression stress in rebar in MPa.

f_{ck} is the characteristical concrete strength in MPa.

ϕ is the diameter rebar in mm.

k_{cp} is the coefficient accounting for casting effects on bond conditions.

k_{lb} is the factor depending design situation (50 for persistent and transient design situations. 35 for accidental design situations).

3.2. *Post Installed Rebar Installation*

It is important to note that design of post-installed reinforcing bars according to FprEN 1992-1-1:2023 [15] assumes that the installation is performed according to the manufacturer´s installation instructions by qualified personnel and inspection of the installation is carried out by appropriately qualified personnel.

Installation procedure of post-installed rebars involves the realization of drill holes in the concrete. The realization of drill holes close to each other or close to the concrete edge can cause cracks in the concrete that could significantly reduce the tension strength of post-installed rebars.

That is why Article 11.4.8 [15] indicates minimum distances at the concrete edge of the post-installed rebars depending on the drilling method used (rotary percussion drilling with electropneumatic hammer, rotary drilling with diamond coring, compressed air drilling), if drilling is guided with a drilling aid, etc. (Table 2 and Figure 16).

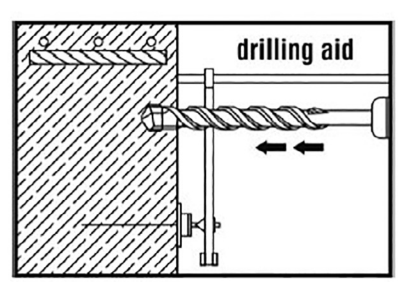


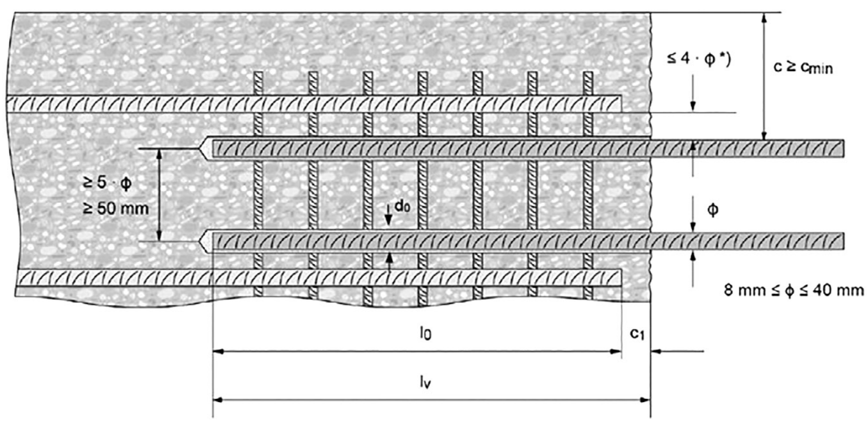
Figure 16. Example of drilling aid. Source [16].

There are also limitations with the minimum distance between post-installed rebars $c_{s,pir}$=max (4ϕ; 40 mm) and between post-installed and cast-in rebars c_s = max (2ϕ; 20 mm).

Table 11.2 — Minimum concrete cover $c_{min,b}$ for post-installed reinforcing steel bars

Drilling method	Bar diameter	$c_{min,b}$	
		without drilling aid	with drilling aid
Rotary percussion drilling / Hammer drilling and diamond coring/drilling	$\phi < 25$ mm	$30\text{ mm} + 0{,}06 l_{bd,pi} \geq 2\phi$	$30\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$
	$\phi \geq 25$ mm	$40\text{ mm} + 0{,}06\ l_{bd,pi} \geq 2\phi$	$40\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$
Compressed air drilling	$\phi < 25$ mm	$50\text{ mm} + 0{,}08 l_{bd,pi}$	$50\text{ mm} + 0{,}02 l_{bd,pi}$
	$\phi \geq 25$ mm	$60\text{ mm} + 0{,}08 l_{bd,pi} \geq 2\phi$	$60\text{ mm} + 0{,}02 l_{bd,pi} \geq 2\phi$

Table 2. Minimum concrete cover for post-installed rebar. (it corresponds to Table 11.1. in [15]).



*) If the clear distance between lapped bars exceeds $4 \cdot \phi$, then the lap length shall be increased by the difference between the clear bar distance and $4 \cdot \phi$.

- c concrete cover of post-installed rebar
- c_1 concrete cover at end-face of existing rebar
- c_{min} minimum concrete cover according to Table B3 and to EN 1992-1-1
- ϕ diameter of reinforcement bar
- l_0 lap length, according to EN 1992-1-1 for static loading and according to EN 1998-1, chapter 5.6.3 for seismic loading
- l_v embedment length $\geq l_0 + c_1$
- d_0 nominal drill bit diameter

Figure 17. General construction rules for post-installed rebars. Source [17].

These minimum distances could be specified in European Technical Product Specification of the mortar. (Figure 17)

CONCLUSIONS

EN1992-4 represents the state of **the art regarding the design of concrete fasteners**, being fully consistent with the rest of the Eurocodes series.

The design according to EN1992-4 [18] is only possible for those fasteners with an ETA approval, in which EN1992-4 [18] is specified as the design method.

At the technical level, EN1992-4 [18] does not introduce very significant changes in relation to ETAG 001 [1] or CEN/TS 1992-4 [4], which it replaces, however, the level of acceptance and mandatory compliance will necessarily be higher.

There are two new aspects to take account in design of fasteners in concrete:

- Consideration of the effect of sustainied tension loads for chemical anchors due to creep effect.
- Consideration of strenght contribution of reinforcement close to fasteners.

FprEN 1992-1-1:2023 [15] includes, as a novelty, anchorage lenght calculation of post-installed rebars, not included in EN1992-4 [18], which is used for design of rigid connections between concrete members.

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