Anchor Theory, Rebar Theory and the Missing Bridge

A map of the design methods for post-installed bonded steel in concrete — why a reinforcing bar may ignore the concrete cone, why a threaded rod may not, and a rule for when the cone is relevant

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Abstract

Post-installed bonded steel in concrete is designed today by at least six methods: the concrete capacity method of EN 1992-4, the anchorage and lap rules of EN 1992-1-1 with EAD 330087, strut-and-tie models, EOTA TR 069 with EAD 332402, the cover-dependent anchorage of EN 1992-1-1:2023 with its new provisions for post-installed bars, and manufacturer methods; in North America, ACI 318 offers the same split between anchoring (Chapter 17) and development length (Chapter 25). The methods rest on different mechanical models and reach opposite conclusions on the same question. The anchor methods verify the concrete cone for every fastener up to 20 diameters; the reinforcement methods never verify it. A ribbed bar and a threaded rod of equal strength, in the same hole and the same mortar, may therefore be designed to differ by a factor of two to ten, and the boundary between the two treatments is drawn by the name of the steel element rather than by any stated criterion.

This paper sets out each method with its rationale, its qualification basis, its field of application and its limits, and identifies the common mechanics beneath them. The concrete cone is a property of the load path: it forms where the tension of the element must return through concrete in tension, and it is absent where that tension is closed by a lap with existing reinforcement, by a compression strut to a proven node, or by hanger reinforcement. The reinforcement methods may ignore the cone because their field of application consists of closed load paths; they are misused, and the cone returns, when they are applied to open ones such as beam-to-column moment connections with straight bars, for which a worked example gives a cone resistance of 18 % of the yield force of the bars. Independently of closure, the cone ceases to govern a single fastener at 11 to 18 diameters against steel and 4 to 18 against bond, but never ceases to govern a dense row by depth alone.

The paper identifies the bridges that already exist between the two families (TR 069 with $\psi_{M,N}$, EN 1992-4 7.2.1.2(2)e, supplementary reinforcement, rebars designed as fasteners, strut-and-tie proof of nodes) and proposes the one that is missing: an element-neutral rule built on a closure ratio λ and a dominance ratio η, written as a single verification $N_{Ed} \le \min[N_{Rd,s};\ N_{Rd,b};\ N_{Rd,c}\ \psi_{M,N}/(1-\lambda)]$ whose end points are EN 1992-4 ($\lambda = 0$) and EN 1992-1-1 ($\lambda \ge 1$). Under it a threaded rod and a bar in the same position give the same result; the steel element enters only through bond qualification and, for moment and seismic connections, a ductility requirement. A decision schema summarises the use of every method. A seismic example computed with the author's software (AAS, ARS) shows the stakes: for one metre of Ø12 bars at 150 mm the anchor route gives 161 kN, 39 % of the capacity-design force, while the rebar route anchors the bars for that force with 651 mm of embedment.

Keywords: post-installed rebar; bonded anchor; threaded rod; concrete cone failure; design methods; EN 1992-4; EN 1992-1-1; EN 1992-1-1:2023; EAD 330087; EOTA TR 069; strut-and-tie; ACI 318; load path; closure ratio; design schema; seismic design

1. Introduction

Anyone who designs post-installed connections in concrete eventually meets the following situation. A new slab is to be connected to an existing one, or a new wall to an existing foundation, and two steel elements are available that look almost identical once they are in the hole: a ribbed reinforcing bar and a threaded rod, both bonded with the same injection mortar. Designed as a reinforcing bar, the connection is a matter of anchorage and lap lengths. The bars may be spaced at 100 or 150 mm, or closer, and the calculation never mentions a

concrete cone. Designed as a group of bonded anchors, the same connection runs into the concrete capacity method of EN 1992-4, whose projected-area rule treats any two fasteners closer than three times the embedment depth as sharing one breakout body. For a row at ordinary reinforcement spacing the cone governs, often by a wide margin.

The difference is not explained by the steel or the mortar. The mortar is frequently the same product, assessed for bars under EAD 330087 [3] and for rods under EAD 330499 [4]. If anything, the threaded rod is credited with the higher bond: its characteristic bond resistance τ_{Rk} in the product assessment is typically 7 to 15 N/mm², while the design bond stress f_{bd} allowed for a post-installed bar under EN 1992-1-1 is 2.3 to 4.3 N/mm² across the usual strength classes. The element credited with more adhesion is treated as the more vulnerable to a concrete failure.

Behind this asymmetry lies a gap that neither standard addresses. EN 1992-1-1 contains no concrete cone verification at all; the rebar route therefore assumes, without saying so, that the cone is never relevant. EN 1992-4 verifies the cone for every fastener, at every depth up to its limit of 20 diameters, and therefore assumes that it is always relevant unless purpose-made hanger reinforcement is provided. There is no rule, in either document, that states when the concrete cone is a relevant failure mode and when it stops being one. The boundary between the two positions is drawn by the name of the steel element.

The paper is organised as a map. Section 2 presents the design methods one by one, with their rationale and limits, and compares them. Section 3 identifies the mechanics they share. Section 4 shows where each is used and where it is stretched beyond its premise. Section 5 derives the geometric conditions under which the cone ceases to govern. Section 6 collects the bridges that already join the two families, and Section 7 proposes the one that is missing, together with the conditions under which threaded rods may use it. Section 8 gives a schema of use, Section 9 worked examples computed with the author's software, and Section 10 the discussion and conclusions.

The paper belongs to a series of critical examinations of EN 1992-4 provisions by the author, on the cracked-concrete classification [17], the pry-out factor [18] and concrete edge failure of multi-row groups [19]. Like those, it does not argue that the provision is wrong in its own domain. It argues that the domain has been drawn by the name of the product rather than by the mechanism, and proposes a criterion that draws it by the mechanism.

2. The design methods

Six methods are in use in Europe for bonded steel elements in hardened concrete, and a seventh in North America. Each answers a slightly different question, and the differences between their answers are the subject of this paper. For each method the rationale (the mechanical model it assumes), what it verifies, what qualifies a product for it, its field of application and its principal limits are stated. Table 1 compares them.

2.1 Anchor theory: EN 1992-4 with EAD 330499

EN 1992-4 [2] designs fastenings that transfer actions from an attached element, usually through a steel fixture, into a concrete member. Its tension verification comprises steel failure, pull-out (or, for bonded fasteners, combined pull-out and concrete failure), concrete cone failure, splitting and blow-out. The concrete cone resistance of a single fastener, not influenced by edges or neighbours, is

$$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5} \qquad (1)$$

with indicative values k_1 = 7.7 for post-installed fasteners in cracked concrete and 11.0 in uncracked concrete (EN 1992-4, 7.2.1.4). The exponent 1.5 rather than 2 is the size effect of the concrete capacity design method [8, 20]: the failure surface grows with the square of the embedment, but the average tensile stress it can sustain at failure falls as the embedment grows. Groups and edges are handled by the ratio of projected areas $A_{c,N}/A^0_{c,N}$, with a characteristic spacing $s_{cr,N} = 3\,h_{ef}$ and edge distance $c_{cr,N} = 1.5\,h_{ef}$. Two fasteners closer than $3\,h_{ef}$ share part of the same breakout body; a row of fasteners at close spacing behaves, for this failure mode, as a single strip.

Bonded fasteners have, in addition, the combined pull-out and concrete failure, whose group effect is governed by a separate characteristic spacing $s_{cr,Np} = 7.3\, d\, (\psi_{sus}\, \tau_{Rk,ucr})^{0.5} \le 3\, h_{ef}$. EN 1992-4 covers bonded fasteners only for 40 mm ≤ h_{ef} ≤ 20 d. Beyond 20 diameters the standard does not apply at all.

Two further provisions matter for this paper. First, EN 1992-4 allows the concrete cone verification to be replaced by a verification of supplementary reinforcement designed for the total load (7.2.1.2(1) and 7.2.1.9). The detailing rules of 7.2.1.2(2) are narrow: ribbed bars with $f_{yk,re} \le 600$ N/mm² and $\varphi \le 16$ mm, detailed as stirrups or loops, placed within 0.75 h_{ef} of the fastener, with an anchorage length inside the breakout body of at least 4 φ for bends, hooks or loops or 10 φ for straight bars, and anchored beyond it with l_{bd}. The same paragraph ends with a sentence that is central to the present argument: the cone verification at the end of the supplementary reinforcement may be omitted where, in reinforced members, the tension in the anchored bar is transferred to the reinforcement of the member *by adequate lapping* (7.2.1.2(2)e). Second, the standard leaves the transmission of fastener loads within the member to its supports to EN 1992-1-1 and its Annex A. The anchor model therefore stops at the breakout body; what happens beyond it is assumed to be somebody else's verification.

2.2 Rebar theory: EN 1992-1-1:2004 with EAD 330087

A post-installed reinforcing bar assessed to EAD 330087 [3] is designed as if it were a cast-in straight bar, with the anchorage and lap rules of EN 1992-1-1 §8.4 and §8.7 [1]. EN 1992-4 acknowledges the separate family only briefly: its scope notes that post-installed ribbed bars used to connect concrete members are covered by a European Technical Product Specification (1.2(7)), and it says nothing further about them. The basic required anchorage length is

$$l_{b,rqd} = (\varphi / 4) \cdot (\sigma_{sd} / f_{bd}) \qquad (2)$$

with $f_{bd} = 2.25\, \eta_1\, \eta_2\, f_{ctd}$. For C25/30 and good bond conditions $f_{bd} = 2.7$ N/mm², and a bar stressed to its design yield strength needs $l_{b,rqd} \approx 40\, \varphi$, independently of the diameter up to 32 mm. Lap lengths are 1.0 to 1.5 times longer.

Three features of the assessment deserve attention, because the rest of the argument depends on them.

- **The mortar is required to match a cast-in bar, not to exceed it.** EAD 330087 requires a mean bond resistance in confined tests of 10.0 N/mm² in C20/25 and 18.4 N/mm² in C50/60. If those values are reached the bar is designed with the ordinary f_{bd} of EN 1992-1-1 (factor $k_b = 1.0$); if not, f_{bd} is reduced. Bond strength above the cast-in reference earns nothing.
- **The design bond stress already contains an allowance for close spacing and small cover.** The note to Table A.4 of EAD 330087 explains how the required test bond strength is built up from f_{bd}: by the partial factor, the ratio of mean to 5 % fractile, the effect of cracking, the effect of short test embedment, and a factor 1/0.7 for *the effect of large edge distance and spacing* in the tests, following the background work of Spieth [16]. The low f_{bd} is low partly because it is meant to cover bars at small spacing and cover.
- **All tension tests are confined.** The test programme of EAD 330087 is run with a confined set-up so that splitting and cone failure cannot occur. The qualification of a post-installed bar never produces a concrete cone, because the method it feeds never asks for one.

The field of application is listed in EAD 330087 §1.2.1 and its Figures 1.1 to 1.5: overlap joints with existing reinforcement in slabs and beams; overlap joints at the foundation of a column or wall; end anchorage of slabs or beams designed as simply supported; anchorage of reinforcement in members stressed mainly in compression; and anchorage of reinforcement to cover the line of acting tensile force. The document adds that detailing and load transfer are to be accounted for as given in EN 1992-1-1, and that the transverse reinforcement required by EN 1992-1-1 shall be present. Geometric limits are a clear spacing of at least 40 mm and 4 φ between post-installed bars (2 φ with a drilling aid), and a minimum cover of 30 mm + 0.06 l_v for hammer drilling below 25 mm diameter. Nothing in this list is a free tensile load pulled out of an otherwise unreinforced block of concrete.

2.3 Strut-and-tie models: EN 1992-1-1 §6.5

Rationale. The member is idealised as a truss of concrete compression struts and steel ties meeting in nodes; concrete tension is not relied upon anywhere. A post-installed bar is a tie, and its anchorage is verified at the node where it meets a strut. *What it verifies:* the forces in struts, ties and nodes, and the anchorage of every tie beyond its node. *Qualification:* none specific; the bar must be assessed for anchorage (EAD 330087 or equivalent). *Field:* frame nodes, wall-to-slab and column-to-foundation joints, corbels, any configuration whose load path can be drawn. *Limits:* the designer must construct and justify the model; the node must physically exist, which for a straight post-installed bar means that the bar reaches the zone where the strut can bear on it, usually beyond the far reinforcement of the existing member. The method is where 'enough depth' acquires its real meaning: not depth against a cone, but depth to reach the node.

2.4 EOTA TR 069 with EAD 332402: the first bridge

The limitation of EAD 330087 to splices and simply supported end anchorages excluded the most useful application, the moment-resisting connection of a new member to an existing one without a lap. EOTA TR 069 [5], used with products assessed to EAD 332402 [6], fills that gap, and the way it does so is revealing. As soon as the post-installed bar is no longer lapped with existing reinforcement, the concrete cone returns: TR 069 verifies yielding, bond-splitting and concrete cone failure, the last with equation (1) above, $h$ef replaced by the embedment lb, and the same projected-area rule with $s$cr,N = 3 lb. It adds a factor ψM,N = 2.0 − z/(1.5 lb) ≥ 1.0 that raises the cone resistance when the compression zone of the connected member lies close to the tensioned bars, and it states in §4.1(3) that the cone need not be verified when the design relies on supplementary reinforcement following EN 1992-4. Its §8 asks, separately, that the local transfer of forces from the post-installed bars to the main reinforcement of the existing element be verified, for instance by a strut-and-tie model.

A bar does not stop being a bar when it is used without a lap, and a cone check does not become necessary because the code changed. What changed is the load path. TR 069 is the code's own admission that the cone is suppressed by the lap and the struts, not by the bar.

2.5 EN 1992-1-1:2023: post-installed reinforcement in the Eurocode itself

Rationale. The second-generation Eurocode 2 abandons the constant design bond stress. The anchorage length follows formula (11.3), $l$bd = $k$lb φ (σsd/435)^nσ (25/$f$ck)^0.5 (φ/20)^(1/3) (1.5 φ/cd)^0.5 ≥ 10 φ, so that cover and spacing enter directly; for the first time a Eurocode contains rules of its own for post-installed bars (11.4.8 and Annex C.8), $l$bd,pi = $l$bd/kb,pi ≥ 10 φ αlb, with bond efficiency classes kb,pi = 1.0 to 0.7 derived from the product's assessed bond (Table C.9), and laps $l$sd,pi = $k$ls $l$bd,pi with $k$ls = 1.2. *Verifies:* anchorage and lap, as for cast-in bars. *Field:* the same as EN 1992-1-1:2004. *Limits:* like its predecessor it contains no cone verification, and therefore inherits the same unstated premise of a closed load path, now with shorter bars. For the row of Ø12 at 150 mm used in Section 9, with cd = 45 mm and class 1.0, ARS gives $l$bd,pi = 320 mm and a lap of 384 mm, against 484 mm and 509 mm under the 2004 edition.

2.6 Manufacturer methods

Rationale. Manufacturers have developed design methods that credit part of the mortar's bond above the cast-in reference. The HIT-Rebar method of one manufacturer [25] extends the cover factor α_2 of EN 1992-1-1 below 0.7 when cd exceeds 3 φ, down to 0.25, quoting anchorage reductions of up to 70 % for adequate cover; the same manufacturer developed strut-and-tie models for frame nodes with straight bars (slab to wall, beam to slab, column to foundation). *Limits:* these methods are product-specific and outside the harmonised framework; their strut-and-tie variants make the closure of the load path explicit, which is precisely the verification the plain EN 1992-1-1 route omits.

These methods sharpen the argument of this paper rather than weaken it. Every one of them shortens the bar, and Section 5 shows that a shorter bar is closer to the range in which the cone governs: a row of Ø12 bars at 150 mm anchored over 20 φ would reach, on equation (5), only 40 % of its yield force in cone resistance. Where the shortened bar is still lapped, or still sits in a node whose strut closes its tension, that does not matter, and the

2023 Eurocode rightly treats it as reinforcement. Where it is not, the cone is back, which is why TR 069 checks it and why the manufacturer's frame-node method rests on an explicit strut. Higher bond is safe in the rebar route for the same reason the low bond of the 2004 edition was: because the load path, not the bond, removes the cone.

2.7 ACI 318: anchoring and development length

North American practice reproduces the same division. Chapter 17 of ACI 318 [27] designs anchors, with concrete breakout, for adhesive anchors qualified to ACI 355.4; Chapter 25 designs reinforcement by development length. Since 2013 the ICC-ES acceptance criteria AC308 qualify post-installed bars for design as reinforcement, by demonstrating equivalence with cast-in bars [28], and limit their embedment to 60 diameters [29]. The justification given in the practice literature for omitting the breakout check in that route is geometric: the embedment needed to yield the bar is deep enough to preclude other failures [29]. Section 5 shows that this is true for a single bar and false for a dense row; the North American route therefore rests on the same unstated load-path premise as the European one.

2.8 Comparison

Table 1 shows the essential point at a glance: whether the cone is verified depends on the family to which the method belongs, not on any property of the connection.

Table 1. The design methods for post-installed bonded steel in concrete.

Method	Mechanical rationale	Cone verified	Steel element	Length	Seismic	Typical use
EN 1992-4 (EAD 330499)	Force returns to the surface through concrete in tension; concrete capacity method	Always (unless hanger reinf.)	Rod, bar, sleeve	40 mm ≤ h_ef ≤ 20 d	Annex C, C1/C2, α_eq	Steel-to-concrete fixings
EN 1992-1-1:2004 + EAD 330087	Bar equivalent to cast-in; tension closed by lap or strut	Never	Ribbed bar (Annex C) only	≥ l_b,min·α_lb, to ETA max.	EAD -01: k_b,seis; EN 1998-1	Laps, simple supports, compression
Strut-and-tie, EN 1992-1-1 §6.5	Truss of struts and ties; concrete tension never used	No; node verified instead	Bar (assessed)	Anchorage beyond node	EN 1998-1 detailing	Frame nodes, joints, corbels
EOTA TR 069 + EAD 332402	Bar without lap; bond-splitting model with cone check	Yes, with ψM,N	Ribbed bar only	Product-specific, ≥ l_b,min	EAD 332402-v02	Moment connections without lap
EN 1992-1-1:2023, 11.4.8 + Annex C.8	Cover-dependent anchorage; bond class k_b,pi from assessment	Never	Ribbed bar	≥ 10 φ α_lb	EN 1998-1	As 2004, shorter bars
Manufacturer methods (e.g. HIT-Rebar)	Credit of mortar bond with large cover; frame-node STM	No (STM variant explicit)	Ribbed bar	Up to 70 % shorter	Product-specific	Slab-wall, frame nodes
ACI 318 Ch. 17 / Ch. 25 (+ AC308)	Anchoring (breakout) / development length	Ch. 17 yes / Ch. 25 no	Rod or bar / bar	Ch. 25: ≤ 60 d	ACI 318 Ch. 17/18	As the two European families

"Cone verified" refers to the concrete cone (breakout) failure under tension. The reinforcement family never verifies it; the anchor family always does unless purpose-made hanger reinforcement is provided.

3. The common mechanics: load path and closure

3.1 The cone is a statement about equilibrium

Consider any steel element that introduces a tensile force N into a concrete member by bond along a length l. Equilibrium requires that N leave the region again, either to the surface on which the fixture bears, or to the supports of the member, or into other reinforcement. In the anchor model the fixture bears on the concrete surface around the fastener and nothing else is assumed to be present. The force therefore has to travel from the embedded part of the fastener back to the surface through a body of concrete in tension. When the tensile

capacity of that body is exhausted, it separates as a cone. Concrete cone failure is the failure of the only load path the model allows.

In a lap splice the situation is different in kind. The post-installed bar and the existing bar run side by side, and the force passes from one to the other through a field of inclined compression struts, the classical mechanism of EN 1992-1-1 §8.7.4 and Figure 8.9. The tension that in the anchor model must be carried by concrete is carried here by the existing bar, and the transverse tension generated by the struts is carried by the transverse reinforcement EN 1992-1-1 requires. There is no unreinforced concrete body loaded in tension between the force and its destination, and therefore nothing that could separate as a cone. The governing concrete failure in a lap is splitting along the bars, and that is exactly what the cover, spacing and transverse reinforcement rules of EN 1992-1-1, and the 1/0.7 allowance inside f_{bd}, are there to control.

The other applications of EAD 330087 follow the same logic. At a simply supported end support the bar is anchored inside the node where the support reaction arrives as a compression strut; the strut and the bar meet and equilibrate each other. In a member mainly in compression the bar is pushed, not pulled. A bar covering the line of tensile force is part of a truss whose compression chord and struts already exist. Each of the five figures shows a configuration in which the tension in the bar is closed within reinforced concrete. A manufacturer's technical note puts it plainly: the restriction to splices exists because the bond forces of the bar must be balanced by local or global compression struts, and it is precisely because this failure mode is prevented by such struts that it does not appear in the concrete design rules [21]. EN 1992-4 states the same principle in its own words, in the one place where it deals with reinforcing bars anchored in a member: the cone at the end of supplementary reinforcement need not be checked when the tension in the bar is transferred to the member's reinforcement by adequate lapping (7.2.1.2(2)e). The anchor standard therefore already accepts that a lap removes the cone. It accepts it for the hanger bar that serves the anchor, not for the anchor itself.

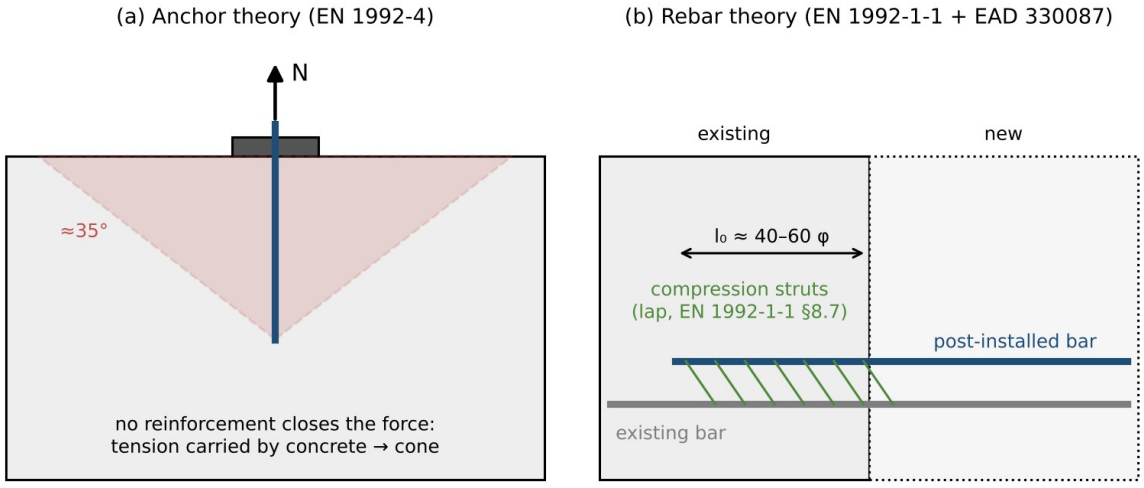


Figure 1. The same steel element in two models. (a) Anchor theory: the force returns to the surface through concrete in tension and the cone is the only failure surface the model allows. (b) Rebar theory: the force passes to an existing bar through compression struts; there is no concrete body loaded in tension that could separate.

3.2 What depth actually does

The question as it is usually put, why the cone may be ignored *as long as the bar is installed deep enough*, contains an assumption that needs correcting. The depth required by the rebar method is not a depth chosen to defeat the cone. It is the length over which the strut field must develop for the force to pass completely to the lapped bar, or the length the bar needs beyond the node to be anchored by bond. The cone is not beaten by depth; it is bypassed by the load path. Depth is the means by which the load path is provided.

Depth does, however, have a second effect, and it explains why the omission is rarely dangerous even when the load path is less clean than the figures suggest. Section 5 shows that, for a single bar, the cone resistance

overtakes the yield force of the bar at around 11 to 15 diameters. The rebar method demands about 40 diameters. A single bar anchored to the rebar rules is therefore, by the anchor model's own formula, about three times deeper than the depth at which its cone would cease to matter. For a single bar the rebar method is safe against the cone even on the anchor model's terms. For a row of bars it is not, and that is where the load-path argument stops being a nicety and becomes the whole justification.

3.3 The evidence that the cone is real when the load path is open

That the cone is a real failure mode for post-installed bars when they are short and not lapped is not in doubt. Column-to-foundation tests at the University of Stuttgart [10, 11], building on earlier work on post-installed starter bars [13–15], used four Ø25 post-installed bars anchored 250 mm (10 φ) into a 500 mm foundation reinforced with Ø12 bars at 150 mm top and bottom. Every specimen failed by concrete breakout in the foundation, and no bar yielded. The authors report that the EN 1992-4 expression gives a reasonable estimate of the breakout capacity in such joints, and that the compression from the column's bending raises it, often to the level that ψM,N predicts. These tests were designed to produce breakout, at an embedment below the 13.8 φ that Table 3 gives for a single Ø25 bar, and with no lap to existing reinforcement: the foundation mesh was horizontal, perpendicular to the force, and was not lapped with the column bars. They confirm the argument of this section from the other side. Remove the lap, shorten the bar, and the cone appears, exactly as the anchor model says it will.

4. Where each method is used, and where it is stretched

Table 2 maps the usual applications to the method that fits their load path. In most of them the choice is clear, and the methods are used within their premise. Three uses deserve attention because they stretch a method beyond its premise, and one because it is excluded without physical reason.

Table 2. Applications, their load path, and the method that fits it.

Application	How the tension is closed	Closed?	Method that fits	Common misuse
Slab or beam extension (lap with existing bars)	Lap with parallel existing bars	Yes	EN 1992-1-1 + EAD 330087; 2023 rules	Rods excluded although closure is identical
End support of a simply supported slab or beam	Strut from the support reaction meets the bar in the node	Yes	EN 1992-1-1 + EAD 330087	–
Wall or column starter in a foundation	Strut to the bottom reinforcement, if the bar reaches it	If reached	EAD 330087 (lap at foundation), STM	Bar stops at mid-depth: cone relevant
Slab-to-wall or beam-to-column moment connection, no lap	Only if a node is proven; otherwise partial (ψM,N)	Usually no	TR 069 + EAD 332402, or STM	Plain EN 1992-1-1 route with straight bars
Member stressed mainly in compression	Bar in compression	Yes	EN 1992-1-1 + EAD 330087	–
Hanger from a slab soffit	None	No	EN 1992-4	Bar designed by the rebar route
Anchor plate on a member face (steel fixture)	None (orthogonal mesh only); compression under moment (ψM,N)	No	EN 1992-4	–

4.1 Beam-to-column moment connections with straight bars

The moment of the beam is a couple: tension in the top bars and an equal compression at the bottom, pressing on the face of the column. In a cast-in frame node the top bars are bent down into the column beyond its far vertical bars, and the bottom compression reaches them through a diagonal strut across the joint; the node is closed and no cone is checked. Straight post-installed bars of limited length do not reach that zone, and the strut has nothing to bear on. EAD 330087 does not cover a moment connection without a lap, and in a beam-column joint the column bars are perpendicular to the beam bars, so no lap is possible. The plain EN 1992-1-1 route is nevertheless widely applied to such joints, because nothing in the calculation prevents it. EOTA TR 069 was

written for exactly this case and verifies the cone in the column, crediting the compression of the beam through $\psi M,N = 2 - z/(1.5\,l_b) \geq 1$ only when the compression lies close to the tensioned bars and away from edges. §9.4 shows that for an ordinary exterior joint the cone then provides 18 % of the yield force of the bars.

4.2 Starter bars that do not reach the node

A starter bar for a new wall or column, drilled into a foundation, is closed when it reaches the zone of the bottom reinforcement, where the compression strut from the column base meets it (EAD 330087, Figure 1.2, and the node of a strut-and-tie model). A bar that stops at mid-depth, because the drilling depth was limited or because the anchorage length came out short, is not closed; the cone is relevant, as the Stuttgart tests on Ø25 bars at 10 φ demonstrated [10, 11].

4.3 Reinforcing bars used as hangers

A post-installed bar used to suspend a load from a slab soffit, or as a starter in a thin member without reinforcement parallel to the force, has neither lap nor strut. Whatever its name, it is a fastener, and EN 1992-4 correctly treats rebars used as fasteners as anchors, with the cone. Using the rebar route because the steel element is a bar applies a method outside its premise.

4.4 Threaded rods in closed load paths

The converse misallocation is the exclusion of threaded rods from configurations whose load path is closed. A rod lapped with existing bars, or anchored in a proven node, has the same closure as a bar in the same position, but no method allows it to be designed as such. Section 7 examines why, and on what conditions it could be.

5. When does the cone stop governing?

The question has three different answers depending on whether one considers a single fastener against its steel, a single bonded fastener against its bond, or a group. In all three the reason is the same: the cone resistance of equation (1) grows with $h_{ef}^{1.5}$, faster than anything else in the problem, but the group rule takes most of that growth away again.

5.1 Single fastener: cone against steel

The steel resistance of a bar or rod does not depend on embedment. Setting equation (1) equal to it gives the depth beyond which the cone of a single fastener can no longer govern:

$$h^*_{ef} = \left[N_{Rk,s} \,/\, (k_1 \cdot \sqrt{f_{ck}}) \right]^{(2/3)} \qquad (3)$$

Table 3 evaluates equation (3) for B500 bars at yield and for threaded rods at their ultimate steel resistance, in cracked C25/30. In characteristic terms the cone stops governing at 10 to 15 diameters; on design values, with $\gamma_{Mc} = 1.5$ against $\gamma_{Ms} = 1.15$, at 12 to 18 diameters. The ratio h^*_{ef}/φ grows slowly with diameter (as $\varphi^{(1/3)}$), because the steel force grows with φ^2 while the cone depth needed to match it grows with $\varphi^{(4/3)}$. Figure 2 shows the four resistances of a single Ø16 bar side by side.

Table 3. Embedment at which the concrete cone of a single fastener equals its steel resistance (C25/30, cracked, $k_1 = 7.7$), equation (3).

Element	Steel force [kN]	h^*_{ef}, characteristic [mm]	h^*_{ef} / d	h^*_{ef} / d, design
B500 bar Ø10	39.3 (yield)	101	10.1	12.1
B500 bar Ø12	56.5 (yield)	129	10.8	12.9
B500 bar Ø16	100.5 (yield)	190	11.9	14.1
B500 bar Ø20	157.1 (yield)	255	12.8	15.2
B500 bar Ø25	245.4 (yield)	344	13.8	16.4
B500 bar Ø32	402.1 (yield)	478	14.9	17.8
Rod M12 8.8	67.4 (As·fuk)	145	12.1	–
Rod M16 8.8	125.6 (As·fuk)	220	13.7	–

Element	Steel force [kN]	h*ef, characteristic [mm]	h*ef / d	h*ef / d, design
Rod M20 8.8	196.0 (As·fuk)	296	14.8	–
Rod M24 8.8	282.4 (As·fuk)	378	15.7	–
Rod M16 5.8	78.5 (As·fuk)	161	10.0	–

Design column: cone with γMc = 1.5 against yield with γMs = 1.15. For comparison, the rebar method requires lb,rqd ≈ 40.3 φ for every diameter (C25/30, good bond, σsd = fyd). In uncracked concrete (k₁ = 11.0) the characteristic values fall to 8.0–11.8 φ for the bars.

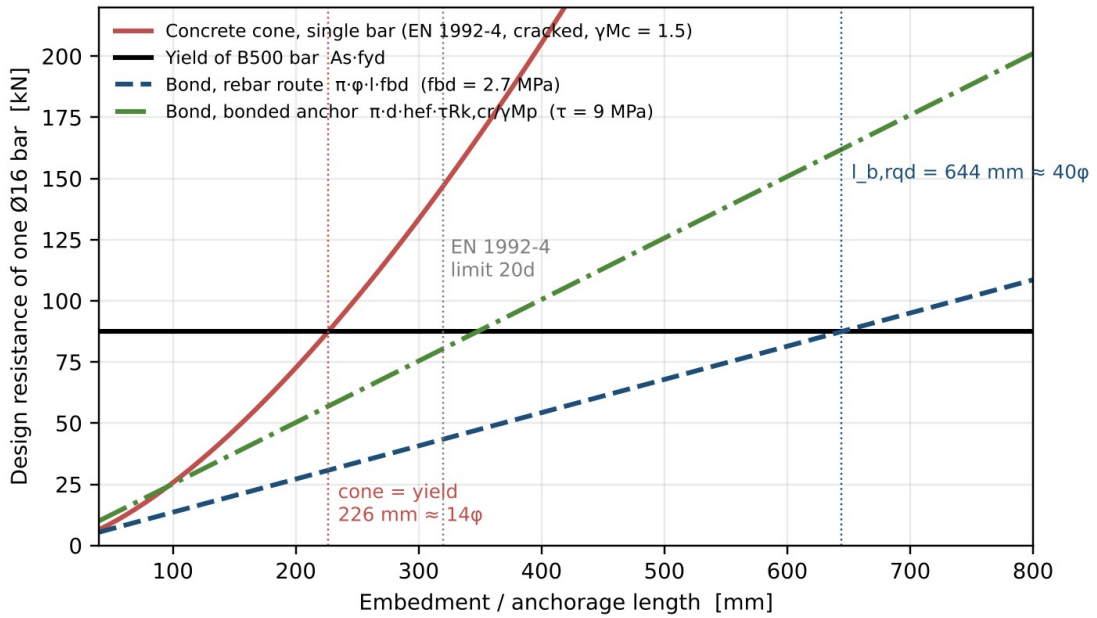


Figure 2. Design resistances of one Ø16 bar against embedment, C25/30 cracked. The cone overtakes yield at about 14 φ, long before the 40 φ the rebar method requires. The bond line of the rebar route is deliberately low; the bonded-anchor bond line is two to three times higher.

5.2 Single bonded fastener: cone against bond

For a bonded anchor the bond resistance π *d* hef τ grows linearly with embedment, the cone with *h*ef^1.5. The two meet at

$$h^*_{ef} = [\ \pi \cdot d \cdot \tau_{Rk} \ /\ (k_1 \cdot \sqrt{f_{ck}})\ ]^2 \qquad (4)$$

beyond which, for a single anchor, bond governs and the cone does not. Table 4 shows that this point lies at 4 to 18 diameters depending on diameter and bond strength. It also shows that, within the anchor model, a higher bond strength moves this point deeper: the force enters the concrete over a shorter length, and the cone remains relevant for longer. Bond strength is a choice of length; §7.8 returns to this.

Table 4. Embedment at which the concrete cone of a single bonded fastener equals its bond resistance, equation (4), expressed as h*ef / d (C25/30).

d [mm]	cracked, τ = 7	cracked, τ = 9	uncracked, τ = 12	uncracked, τ = 15
12	3.9	6.5	5.6	8.8
16	5.2	8.6	7.5	11.7
20	6.5	10.8	9.4	14.7
24	7.8	12.9	11.3	17.6

*τ in N/mm², characteristic; k₁ = 7.7 cracked, 11.0 uncracked. Beyond h*ef bond governs the single fastener. The stronger the bond, the deeper the cone stays relevant.*

5.3 Groups and rows: never by depth alone

For a group the answer changes completely. Consider a long row of fasteners at spacing *s* < 3 *h*ef, far from edges. Each fastener's share of the projected area is *s* · 3 *h*ef, and the cone resistance per metre of row becomes

$$N'Rk,c = (1000 / 3) \cdot k_1 \cdot \sqrt{fck} \cdot hef^{0.5} \quad [\text{per metre}] \qquad (5)$$

independent of the spacing. The *h*ef^1.5 of the single fastener has become *h*ef^0.5. The steel force per metre, however, grows in inverse proportion to the spacing. Requiring the cone to exceed the steel gives either a minimum spacing for a given depth or a minimum depth for a given spacing:

$$s \geq 3 \cdot As \cdot fy \,/\, (k_1 \cdot \sqrt{fck} \cdot \sqrt{hef}) \qquad \text{or} \qquad hef \geq [\, 3 \cdot As \cdot fy \,/\, (k_1 \cdot \sqrt{fck} \cdot s)\,]^2 \qquad (6)$$

Table 5 evaluates the design check for rows of bars stressed to yield, at the anchorage length the rebar method would give. The cone, checked as the anchor model checks it, reaches between 18 % and 126 % of the force; only the two lightest rows, Ø10 at 200 and 250 mm, pass. To make a row of Ø12 bars at 150 mm satisfy it one would need 1.5 m of embedment, 122 diameters; for Ø16 at 150 mm, 4.6 m. Figure 3 shows the same thing graphically: the cone line flattens with depth and never reaches the force of a dense row within any embedment that could be drilled.

Table 5. Long rows of B500 bars stressed to yield, checked against the concrete cone of EN 1992-4 at the anchorage length of the rebar method (design values, C25/30 cracked, far from edges).

Row	lb,rqd [mm]	Yield force [kN/m]	Cone resistance [kN/m]	Cone / force	l needed for cone [mm]	s needed at lb,rqd [mm]
Ø10 @ 100	403	341	172	0.50	1593	199
Ø10 @ 150	403	228	172	0.75	708	199
Ø10 @ 200	403	171	172	1.01	398	199
Ø10 @ 250	403	137	172	1.26	255	199
Ø12 @ 100	483	492	188	0.38	3303	261
Ø12 @ 150	483	328	188	0.57	1468	261
Ø12 @ 200	483	246	188	0.76	826	261
Ø16 @ 150	644	583	217	0.37	4640	403
Ø16 @ 200	644	437	217	0.50	2610	403
Ø20 @ 150	805	911	243	0.27	11328	563
Ø20 @ 200	805	683	243	0.36	6372	563

Cone per metre from equation (5) with γMc = 1.5; force Asfyd per metre. Member thickness, edges and ψM,N are not considered; in a real wall or slab the edges reduce the cone resistance further.

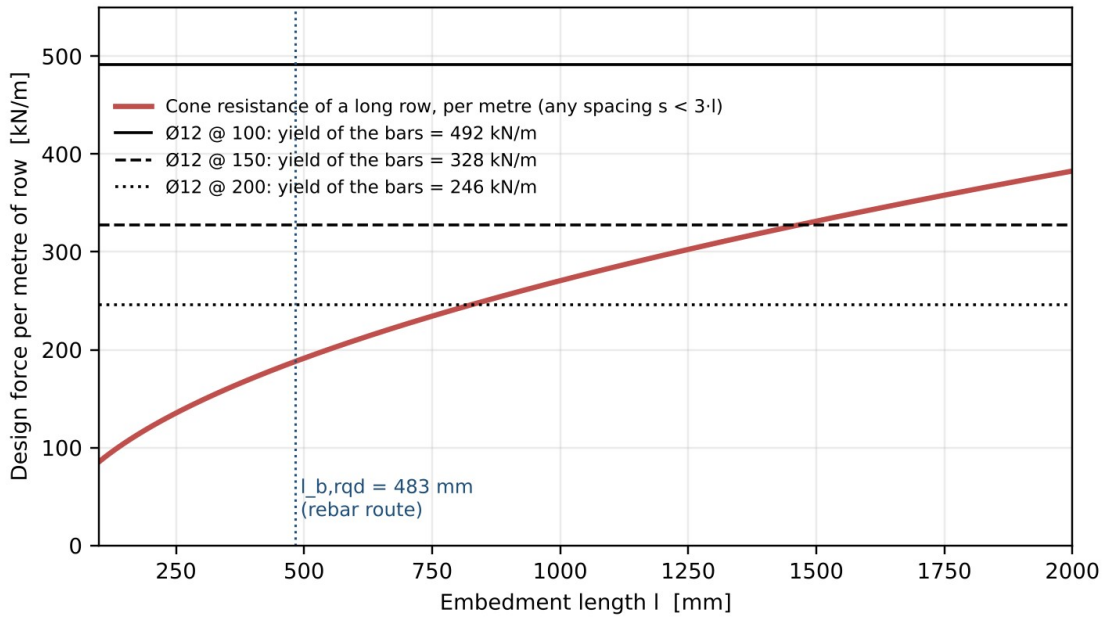


Figure 3. Cone resistance of a long row per metre (design, C25/30 cracked) against the yield force of rows of Ø12 bars. The cone grows only with the square root of the embedment; at the 483 mm anchorage length of the rebar method it reaches 57 % of the force of a row at 150 mm.

Connections of this kind, rows of Ø12 to Ø16 bars at 100 to 200 mm lapped with existing reinforcement, are built every day and have a long record of satisfactory service. If the cone model described them, they would be failing. The conclusion is not that the cone model is wrong, but that it is the wrong model for them: for a lapped row the breakout surface it postulates is crossed, along its whole width, by the existing bars to which the force is being transferred.

5.4 A case that exposes the model: the slab extension

The point can be made more sharply. A 200 mm slab is extended with Ø12 bars at 150 mm, set 40 mm above the soffit and lapped with the existing bottom bars (EAD 330087, Figure 1.1). Designed to the rebar rules the bars develop their full yield force, 49.2 kN each, with a lap of 1.5 lb,rqd = 725 mm. Designed as bonded anchors, drilled horizontally into the slab edge, each bar's breakout body is cut off by both faces of the slab: the projected area is fixed at $s \times h$ = 150 × 200 mm while the reference area $(3\ h\text{ef})^2$ grows with the square of the depth. Per bar,

$$\mathrm{NRk,c} = \mathrm{k_1} \cdot \sqrt{\mathrm{fck}} \cdot \mathrm{s} \cdot \mathrm{h} \cdot \psi\mathrm{s,N} \;/\; (9 \cdot \sqrt{\mathrm{hef}}) \qquad (7)$$

which *falls* as the embedment increases. At the 20 d limit of EN 1992-4 (240 mm) the design cone resistance is 4.1 kN per bar, 8 % of its yield force; at 725 mm it would be 2.3 kN (Figure 4). A model that predicts a smaller resistance for a longer anchorage is not describing what happens in a slab extension. It is describing a mechanism that cannot occur there, because the only way for the postulated breakout body to separate is for the slab to break across its full depth, through the very bottom reinforcement the bars are lapped with.

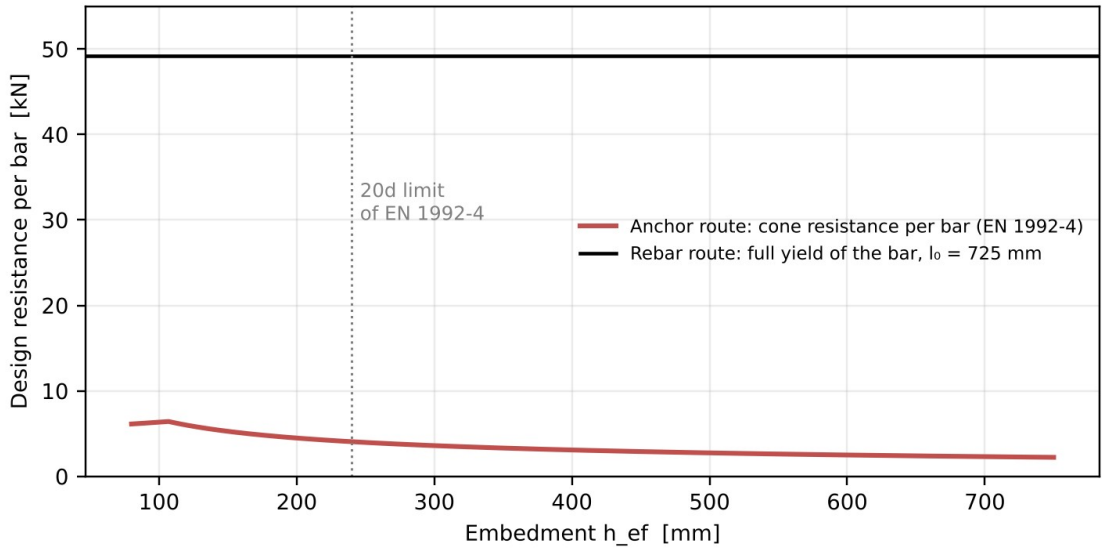


Figure 4. Slab extension, 200 mm slab, Ø12 at 150 mm, 40 mm above the soffit, C25/30 cracked. The anchor model gives a cone resistance that decreases with embedment; the rebar model gives full yield of the bar with a 725 mm lap.

5.5 The answer, stated generally

The concrete cone ceases to be relevant in three distinct situations, for three distinct reasons:

- **For a single fastener, beyond about 11 to 18 diameters**, because the cone resistance, growing with *h*ef^1.5, overtakes the steel (equation (3), Table 3) and, for bonded fasteners, beyond 4 to 18 diameters where it overtakes bond (equation (4), Table 4). This is the anchor model's own result and needs no outside argument.
- **For a group or a row, never by depth alone**, because overlapping breakout bodies reduce the growth to *h*ef^0.5 per unit length (equation (5)). Only spacing can help (equation (6)), and at reinforcement spacings it does not help enough.
- **For any fastener or group whose tension is closed by reinforcement or compression crossing the potential failure surface**, regardless of depth, spacing and the name of the steel element. This is the

situation of laps, supports and compression members in the rebar method, of supplementary reinforcement in EN 1992-4, and, partially, of the bending compression that ψM,N credits in TR 069. Here the cone is not overtaken; it is replaced by the verification of the elements that carry its tension.

Only the third explains the rebar method. The first explains why the rebar method is rarely unsafe even when its load-path premise is loosely applied to single bars. The second explains why that premise is indispensable for rows.

6. The bridges that already exist

Although the two families are presented as separate, the standards already contain several provisions that cross from one to the other. Each is partial; together they show that the principle on which a general bridge can be built is already accepted.

- **EOTA TR 069 with ψM,N.** The first explicit bridge: a reinforcement application designed with the anchor model's cone (TR 069 §4.3), and a credit, ψM,N, for the compression of the connected member when it lies close to the tensioned bars. It bridges in one direction only, from rebar to anchor, and only for products assessed to EAD 332402. It also shows that the cone is not suppressed by the bar but by the load path: remove the lap and the cone returns for bars.
- **EN 1992-4 7.2.1.2(2)e.** The cone at the end of hanger reinforcement may be omitted when the tension in the bar is transferred to the member's reinforcement by adequate lapping. This is the rebar route's principle written into the anchor standard, but applied to the hanger bar that serves the anchor, not to the anchor itself.
- **Supplementary reinforcement, EN 1992-4 7.2.1.2 and 7.2.1.9.** The cone is replaced by the verification of reinforcement designed for the total load. The bridge is narrow: stirrups or loops of at most 16 mm within 0.75 *h*ef, so that the ordinary straight bars of an existing member never qualify.
- **Rebars as fasteners.** Bonded fasteners made of reinforcing bar are assessed under EAD 330499 and designed to EN 1992-4 as anchors, with the cone. The steel element changes route according to its application, in this direction. The opposite direction, a threaded rod used as reinforcement, does not exist.
- **Strut-and-tie proof of the node.** EN 1992-1-1 §6.5 allows any connection to be justified by a truss model, and TR 069 §8 requires the local transfer to the existing reinforcement to be verified by one. A proven node replaces the cone because it shows where the tension goes.
- **EN 1992-1-1:2023 Annex C.8.** For the first time the qualification of a post-installed product (its assessed bond) feeds directly into a Eurocode design formula through the bond efficiency class. It bridges qualification and design, but not the cone question.
- **ACI 318 with AC308.** The same element may be designed by Chapter 17 or by Chapter 25 according to its qualification, with a 60-diameter limit on the reinforcement route; the bridge is a choice between routes, not a criterion.

What is missing is not a mechanism but a criterion: none of these provisions states, in general terms and for any steel element, when the tension is closed and the cone may therefore be omitted. Section 7 proposes one.

7. The missing bridge: a rule and a single verification

7.1 What a rule must do

Sections 3 to 5 identify two independent reasons why the cone can cease to matter: the tension of the fastener is closed by reinforcement or compression before it can load the concrete in tension, or the cone, even where it can form, is stronger than the weaker of the steel and the bond. A rule for the relevance of the cone should express both, and it should satisfy four requirements. It must be **element-neutral**: the same rule for a bar, a rod or any other qualified bonded element. It must be **verifiable** from quantities the designer holds: the position, diameter and anchorage of existing reinforcement, the geometry of the fastening and the resistances

already computed. It must **reproduce the existing provisions** as limiting cases, so that it extends rather than replaces them. And it must be **conservative where evidence is missing**, which in this field means that a partial closure of the load path is not credited until tests show how steel and concrete share the force.

7.2 The closure ratio λ

Let NEd be the design tension of a fastener (or, for a row, per unit length). The closure ratio is the share of that force which existing reinforcement can take over without passing through concrete in tension:

$$\lambda = T_cl \;/\; N_Ed\ , \qquad T_cl = \Sigma\ F_lap,i + F_node + F_re \tag{8}$$

Three contributions are admitted, each already defined in a standard:

- **Lap transfer, F_lap,i**, from each existing bar i parallel to the fastener and overlapping it over a length $l$ov,i: F_lap,i = min[As,i $f$yd ; As,f $f$yd · $l$ov,i / lo,i], where lo,i is the design lap length of EN 1992-1-1 §8.7.3 for the force in question, increased by the clear distance in excess of 4 φ or 50 mm as §8.7.2(3) requires. The transverse reinforcement of §8.7.4 must be present. As a limit on the strut field it is proposed that the clear distance ai not exceed $l$ov,i / 2, which keeps the strut inclination above about 27°.
- **Node transfer, F_node**, where the fastener is anchored in a node whose tension is equilibrated by a compression strut to reinforcement at the far face (a foundation, a wall-to-slab joint, a frame node). F_node is the force the strut-and-tie model of EN 1992-1-1 §6.5 can carry with the fastener anchored by $l$bd beyond the node. This is the contribution in which the depth of the fastener genuinely matters: the bar must reach the zone of the far reinforcement for the node to exist.
- **Purpose-made hanger reinforcement, F_re**, as EN 1992-4 7.2.1.2 and 7.2.1.9 already define it.

Reinforcement that crosses the potential breakout surface without being parallel to the force and anchored beyond it, such as the orthogonal surface mesh of a wall into which an anchor plate is fixed, does not close the load path and contributes nothing to λ. It does raise the cone resistance [12], and a future refinement could credit that in η; it is not a closure.

7.3 The dominance ratio η

The second ratio compares the cone with the failure modes that cannot be avoided:

$$\eta = N_Rd,c \;/\; \min(\ N_Rd,s\ ;\ N_Rd,p\ ) \tag{9}$$

with all three resistances for the same fastener or group, including the group and edge effects of EN 1992-4 and, under seismic action, the factors of Annex C. For a single fastener η ≥ 1 is reached at the embedments of equations (3) and (4), roughly 11 to 18 diameters against steel and 4 to 18 against bond (Tables 3 and 4). For a dense row it is generally not reached (Table 5). η ≥ 1 does not mean the cone cannot form; it means that if it formed it would not be the governing failure, so the design is decided by steel or bond whichever cone the concrete could produce.

7.4 The rule

The proposed rule is:

- **R1 (closure).** If λ ≥ 1, the concrete cone is not a relevant failure mode. The design verifies the lap, the node or the hanger reinforcement, together with splitting, as EN 1992-1-1 requires. For moment-resisting or seismic connections the fastener must, in addition, satisfy the ductility requirements of reinforcing steel.
- **R2 (dominance).** If λ < 1 but η ≥ 1, the cone is not governing and its verification is satisfied by the steel or bond verification already made.
- **R3 (relevance).** If λ < 1 and η < 1, the cone is relevant and shall be verified: NEd ≤ NRd,c, with the ψM,N credit of EN 1992-4 and TR 069 for compression near the tensioned fasteners. Partial closure is not credited at this level.

A second level, offered as a research proposal and not for design, would credit partial closure by verifying only the unclosed share against the cone, $(1 - \lambda)\, N_{Ed} \le N_{Rd,c}$. Whether the stiffer cone and the slipping lap share the force in that way, or whether the cone fails before the lap is mobilised, is a question for tests; EN 1992-4 7.2.1.2(1) takes the second view for hanger reinforcement, which designs it for the total load, and Level 1 follows it.

7.5 The rule contains the existing provisions

Table 6 shows that the rule returns, for each configuration the standards already treat, the answer the standards give, and that it gives an answer, by the same criterion, where they give none.

Table 6. The rule applied to configurations the standards already treat.

Configuration	Present provision	λ	Rule	Agreement
Lap with existing bars (EAD 330087 Fig. 1.1, 1.2)	EN 1992-1-1 §8.7; no cone	1	R1	Same result
End support, bar covering the tensile force line (Fig. 1.3, 1.5)	EN 1992-1-1 §9.2; no cone	1 (node)	R1	Same result
Hanger bar lapped with member reinforcement	EN 1992-4 7.2.1.2(2)e; cone omitted	1	R1	Same result
Fastener with stirrup hanger reinforcement	EN 1992-4 7.2.1.9; cone replaced	1 (F_re)	R1	Same result
Moment connection without lap	TR 069 §4.3; cone with ψM,N	< 1	R3 (R2 if η ≥ 1)	Same result
Anchor plate on a member face	EN 1992-4 7.2.1.4; cone always	0	R3, or R2 if η ≥ 1	Same, and states when the cone cannot govern
Threaded rod lapped like a bar	Not covered by either standard	1	R1 + ductility condition	New: same as the bar
Short bar without lap designed by the EC2 route	No cone checked	< 1	R3 if η < 1	Corrects an omission

7.6 Applications

Table 7 applies the rule to six configurations, all in cracked C25/30 with Ø12 B500 bars or M12 class 8.8 rods (the design forces differ by 5 %: 49.2 kN and 47.0 kN). The results are the same for the bar and the rod in every case; where the rule rejects the rod for the rebar route it does so because of R1's ductility condition, not because of the cone.

Table 7. Six applications of the rule (C25/30 cracked; Ø12 B500 bar or M12 8.8 rod; resistances printed by AAS, design values).

Case	Configuration	λ	η	Rule	Cone
A	Row @ 150 mm lapped with existing Ø12 @ 150, overlap 509 mm (= l_0)	1.00	–	R1	Not relevant
B	Same row, overlap 240 mm (20 d), 7 elements	0.47	0.96 (214.7 / 222.9 kN)	R3	Relevant and governing
C	Starter bars @ 150 into 600 mm foundation, l_v = 500 mm reaching the bottom mesh, node verified (EN 1992-1-1 §6.5)	≥ 1	–	R1	Not relevant
D	Same, l_v = 240 mm, ending at mid-depth	0	0.96	R3	Relevant and governing
E	Single hanger in a slab soffit, h_{ef} = 150 mm	0	1.85 (47.2 / 25.5 kN)	R2	Not governing (bond governs)
F	Anchor plate 2 × 2 at 150 mm, h_{ef} = 120 mm, wall face with orthogonal mesh	0	1.10 (67.7 / 61.7 kN, rod)	R2	Not governing (bond governs)

λ for case B: $F_{lap} = A_{sf}\, f_{yd}$ 240/509. η = $N_{Rd,c}$ / min($N_{Rd,s}$; $N_{Rd,p}$) for the group. Case D uses the group values of case B (same geometry, infinite concrete). In every case the result is the same for the bar and the rod; for moment or seismic connections R1 additionally requires a ductile steel.

Cases A and B mark the essential point. The same row, of bars or of rods, is cone-free with a 509 mm lap and cone-governed with a 240 mm overlap, because at 240 mm less than half of the force has a path through

reinforcement. Depth enters exactly where it should, as the length of the lap, and nowhere else. Cases C and D make the same point for the strut: a starter bar into a 600 mm foundation that reaches the bottom mesh is cone-free, one that stops at 240 mm is not. Cases E and F are the anchor problems of EN 1992-4 and remain there, whatever the steel element: a hanger in a soffit has no path but through concrete in tension ($\lambda = 0$), and an anchor plate on a wall face has only orthogonal reinforcement, which strengthens the cone but does not close it. In both, however, η exceeds 1: the cone could form, but the bond would fail first, so rule R2 applies and the cone verification EN 1992-4 performs is satisfied automatically. They move to R3 at shallower embedment or closer spacing, where Table 4 and equation (6) show the cone overtaking the bond.

7.7 The bridge between the two methods

The rule of §7.4 decides whether the cone is verified. It can also be written as a single verification that covers both methods and passes continuously from one to the other. For any bonded steel element, or group of them, with closure ratio λ:

$$N_{Ed} \leq \min[\, N_{Rd,s} \;;\; N_{Rd,b} \;;\; N_{Rd,c} \cdot \psi_{M,N} \,/\, (1 - \lambda)\,] \qquad (10)$$

where $N_{Rd,s}$ is the steel resistance, $N_{Rd,b}$ the bond resistance and $N_{Rd,c}$ the cone resistance of EN 1992-4, the last term being omitted when $\lambda \geq 1$. The bond term is taken from whichever qualification the system holds: the bond resistance of EN 1992-4 (7.2.1.6) with τ_{Rk} from an EAD 330499 assessment, limited to $h_{ef} \leq 20\,d$; or the anchorage of EN 1992-1-1, $\pi\, d\, l\, f_{bd}\, k_b$, with $f_{bd}\, k_b$ from an EAD 330087 assessment, valid at any length up to the assessed maximum and at the minimum clear spacing of that assessment. Equation (10) has the two present methods as its end points and nothing else in between:

- **$\lambda = 0$** gives exactly the EN 1992-4 tension verification (steel, bond, cone), and with $\psi_{M,N}$ exactly the verification of TR 069.
- **$\lambda \geq 1$** gives exactly the EN 1992-1-1 verification (steel and anchorage or lap), with no cone, and in the hanger case exactly EN 1992-4 7.2.1.2(2)e.
- **$0 < \lambda < 1$** is the region neither standard covers: a fastener partly lapped, a starter bar that reaches part of the way to the far reinforcement, an anchor group beside existing bars.

Two levels are proposed for the intermediate region. **Level 1**, for design now, verifies the full cone until λ reaches 1 (the step in Figure 5); it is conservative and needs no new evidence, and it is the rule of §7.4. **Level 2**, for validation, verifies the cone only for the share $(1 - \lambda)$ of the force that has no path through reinforcement (the curve in Figure 5). For the row of Table 7, cases A and B, Level 2 would reach the yield of the bars with an overlap of 192 mm ($\lambda = 0.38$), Level 1 only at the full lap of 509 mm. The distance between the two curves is the size of the question tests have to answer: whether a partial lap and a cone share the force, or whether the stiffer cone fails before the lap is mobilised.

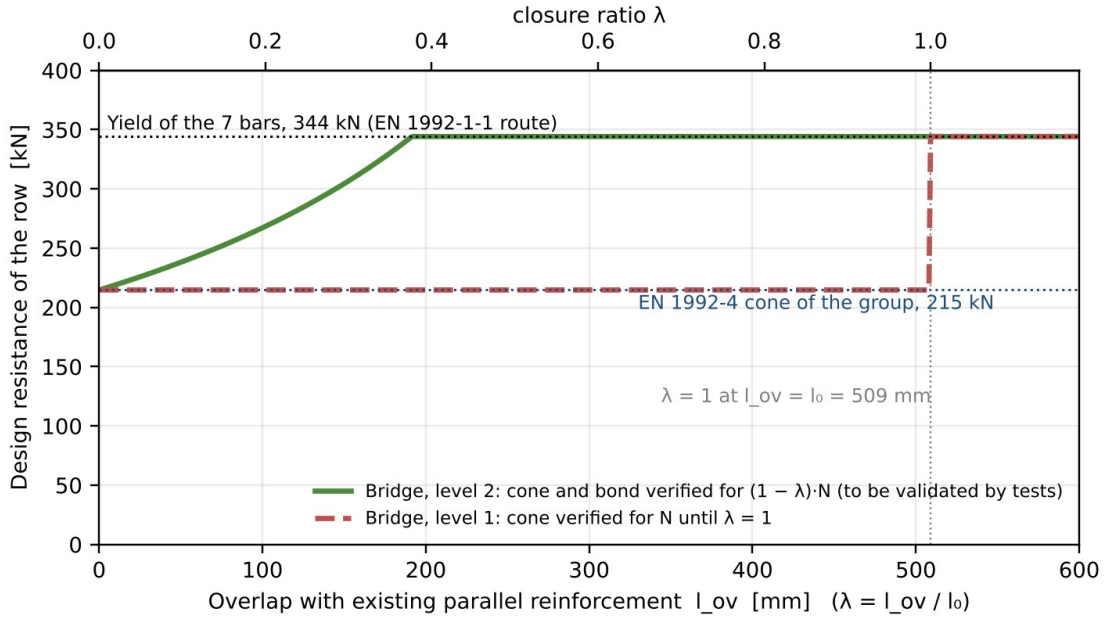


Figure 5. The bridge, equation (10), for the row of seven Ø12 at 150 mm of Table 7 (C25/30 cracked, design values). At $\lambda = 0$ it is the EN 1992-4 verification, at $\lambda = 1$ the EN 1992-1-1 verification. Level 1 (step) is the design rule proposed here; Level 2 (curve) is the hypothesis to be tested. For M12 8.8 rods the yield plateau is 329 kN instead of 344 kN; nothing else changes.

7.8 Threaded rods on the bridge: bond is not the variable

The question is sharper than it first appears. A rebar route that accepts a mortar with a bond strength several times that of a cast-in bar, and in its newer forms (EAD 332402 with TR 069, the HIT-Rebar method, EN 1992-1-1:2023) even credits part of that bond, cannot consistently refuse a threaded rod on the ground that its bond is too good. Nor does it. The bond of the steel element plays no part in deciding whether the cone is verified, in either route, and the comparison must be made with that in view.

In the EN 1992-1-1:2004 route the mortar's bond is not used at all. EAD 330087 asks the mortar only to equal a cast-in bar; any excess earns nothing, and the bar is designed with the cast-in $f$bd. The high-performance mortar is a guarantee of reliability (robust installation, sustained load, cracks, temperature), not a source of resistance. A threaded rod designed with the same $f$bd on its outer diameter would be designed identically, and the result would be the same. For an M16 rod of class 8.8, $A_s f_{yd} = 157 \times 557 = 87.4$ kN, exactly the 87.4 kN of a Ø16 B500 bar, and $l_{b,rqd} = 87.4\ \text{kN} / (\pi \cdot 16 \cdot 2.7) = 644$ mm, the same length. Nothing in the mechanics of bond suggests that the rod would hold less: the thread interlocks with the mortar more positively than the ribs do, and in both cases the governing interface in a qualified system is normally the mortar-to-concrete surface of the drilled hole, which does not know what steel is inside it.

Where the higher bond is used, in TR 069 and the methods of §2.5–2.6, it shortens the anchorage, and a shorter anchorage is precisely what brings the cone back (Section 5). That is why TR 069 verifies the cone for bars, not for rods. The cone returns because the bar has become short and unlapped, not because the bond has become high, and it would return in exactly the same way for a rod. Within the anchor model, equation (4) expresses the same fact for a single fastener: the stronger the bond, the shorter the length over which the force enters the concrete and the deeper the fastener must be before bond rather than cone governs. Higher bond is therefore neither an argument against the rod nor one in its favour. It is a choice of length, and the length, together with the load path, decides the cone.

Physically, then, a threaded rod placed where the post-installed bar would be, lapped with the existing reinforcement over the same length and with the same transverse reinforcement, transfers its force to the existing bar through the same struts and needs no cone verification for the same reason the bar needs none. The rebar equation, with the bond taken at the value the system has demonstrated, applies to it as a matter of mechanics.

7.9 Threaded rods on the bridge: what distinguishes the rod is the steel

The differences that remain concern the rod as reinforcement of the new member, not as an anchorage in the existing one.

- **Ductility.** EN 1992-1-1 relies on reinforcement of class B or C, with a guaranteed uniform elongation ($A_{gt} \geq 5$ % for class B) and hardening ratio ($f_t/f_y)_k \geq 1.08$, so that a bar yields over a length at a crack or a joint and the section can rotate and redistribute. A threaded rod is notched along its full length; its plastic strain tends to localise at a thread root, and the property classes of ISO 898-1 do not specify a uniform elongation in the sense of EN 1992-1-1 Annex C. For a lap carrying static force this hardly matters. For a moment connection, a critical region or seismic action it is the decisive difference, and it lies entirely in the steel.
- **Area.** The stress area is about 78 % of the nominal section, which is a matter of bookkeeping (§7.8 already uses it), but the root section also governs dowel action across the joint and fatigue at the notch.
- **Splitting under small cover.** The 60° thread flanks wedge differently from rebar ribs. Through a mortar annulus most of that wedging is redistributed before it reaches the concrete, so the difference is probably small, but it has not been measured at 2 φ cover and 4 φ spacing, the conditions that the 1/0.7 factor inside f_{bd} covers for bars.
- **Crack control in the new member.** A bar crossing a crack in the new concrete must yield and slip in a controlled way; a notched rod with a stiffer bond gives different crack widths. This is a serviceability question about reinforcement, not anchorage.

None of these concerns the concrete cone, and none is a reason why the anchorage of a lapped rod should behave differently from that of a lapped bar. All of them are open to the same treatment that post-installed bars received: a comparison with the cast-in reference in confined tests, in cracked concrete and at minimum cover and spacing, as in EAD 330087, supplemented for moment and seismic use by a ductility requirement on the steel (for instance stainless rods with a specified elongation, or a uniform-elongation criterion added to the rod's specification). A rod that passed those tests would have earned, on the evidence, the treatment the bar receives today.

7.10 Threaded rods: what the codes require today

Under the present framework a threaded rod cannot be designed by the rebar route, for reasons that are administrative rather than physical.

- **It is not reinforcement.** EAD 330087 covers straight deformed bars with the properties of EN 1992-1-1 Annex C, and its mandatory tests are run with bars of $f_{yk} \geq 500$ N/mm² and a relative rib area f_R between 0.05 and 0.10. The rebar route is licensed by demonstrating equivalence to a cast-in bar of that geometry; a threaded rod has never been put through that comparison.
- **EN 1992-4 has no lap route.** Its only mechanism for recognising reinforcement crossing the breakout body is supplementary reinforcement (7.2.1.2, 7.2.1.9), which must be stirrups or loops of at most 16 mm within 0.75 h_{ef} of the fastener. The straight longitudinal bars of an existing member do not qualify, however close and well anchored, although 7.2.1.2(2)e itself accepts that a lap removes the cone for the hanger bar.
- **EN 1992-4 stops at 20 diameters.** A lap requires 40 to 60 diameters, so within its scope the anchor model cannot represent a rod long enough to act as a lap even if the designer wanted it to.

The assessment framework itself already treats the bond of the two steel elements as interchangeable where that suits it: EAD 330087 allows the sustained-load, freeze-thaw and durability results of a mortar to be taken from its EAD 330499 assessment with threaded rods, and allows the slice tests to be run with M12 rods. Eligehausen, Mahrenholtz, Akguzel and Pampanin [9] reached the related conclusion that, with similar bond, a straight bar and a bonded anchor should need about the same embedment whether the connection is designed as an anchorage or by a strut-and-tie model, and proposed bringing the two sets of provisions into agreement.

In the author's software, AAS offers both routes for the same reinforcing bar and ARS designs the connection to EN 1992-1-1 with EAD 330087 or with the strut-and-tie model of EN 1992-1-1 §6.5; running the same connection through both is the quickest way to see the difference this paper describes.

7.11 Conditions for threaded rods to use the bridge

Equation (10) contains no term that depends on whether the steel element is ribbed or threaded. The steel term uses the stress area of the rod, the bond term the qualification the mortar holds, and the cone term the geometry. What remains is to state the conditions under which a threaded rod may use the $\lambda \geq 1$ end of the bridge, the end that today belongs to bars alone. On the analysis of §7.8–7.9, they concern the qualification of the bond and the steel, not the cone:

- **Bond.** The mortar holds an EAD 330087 assessment for bars, with $k_b = 1.0$ in the concrete class concerned, and the rod is shown in the reference tests of that EAD (confined, C20/25 and C50/60, 7 to 10 diameters) to reach at least the required bond $f_{bm,rqd}$ on its outer diameter. The rod is then designed with f_{bd} k_b on its nominal diameter and its stress area in the steel term.
- **Splitting.** The rod passes the tests at minimum cover and minimum clear spacing that EAD 330087 implies for bars, in uncracked and cracked concrete ($\Delta w = 0.3$ mm), so that the 1/0.7 allowance contained in f_{bd} is shown to hold for a thread.
- **Ductility, for static and quasi-static tension.** No requirement beyond those of the anchor route: a lap carrying static tension does not rely on the rotation capacity of the element.
- **Ductility, for moment connections, critical regions and seismic action.** The rod satisfies the reinforcement requirements of EN 1992-1-1 Annex C for class B, $A_{gt} \geq 5$ % and $(f_t/f_y)_k \geq 1.08$, verified on the threaded element, or the connection is designed to remain elastic with the rod as the non-dissipative element (EN 1992-4 9.2(3) a1 or a2). For stainless rods the elongation is specified and can be checked against this criterion; for carbon-steel classes such as 8.8 the uniform elongation is not specified and would have to be demonstrated.
- **Geometry.** The lap distances, transverse reinforcement and minimum cover of EN 1992-1-1 and EAD 330087 apply unchanged, and the 20 d limit of EN 1992-4 does not, since that limit belongs to the cone and bond model the bridge leaves behind at $\lambda \geq 1$.

With these conditions the bridge gives a rod and a bar in the same position the same result, which is what the mechanics of §7.8–7.9 says it should be. Without them, the rod stays at $\lambda = 0$, in EN 1992-4, as today.

7.12 Further bridges that could be added

Beyond the general rule, four narrower provisions would close specific gaps between the families, each within reach of existing knowledge:

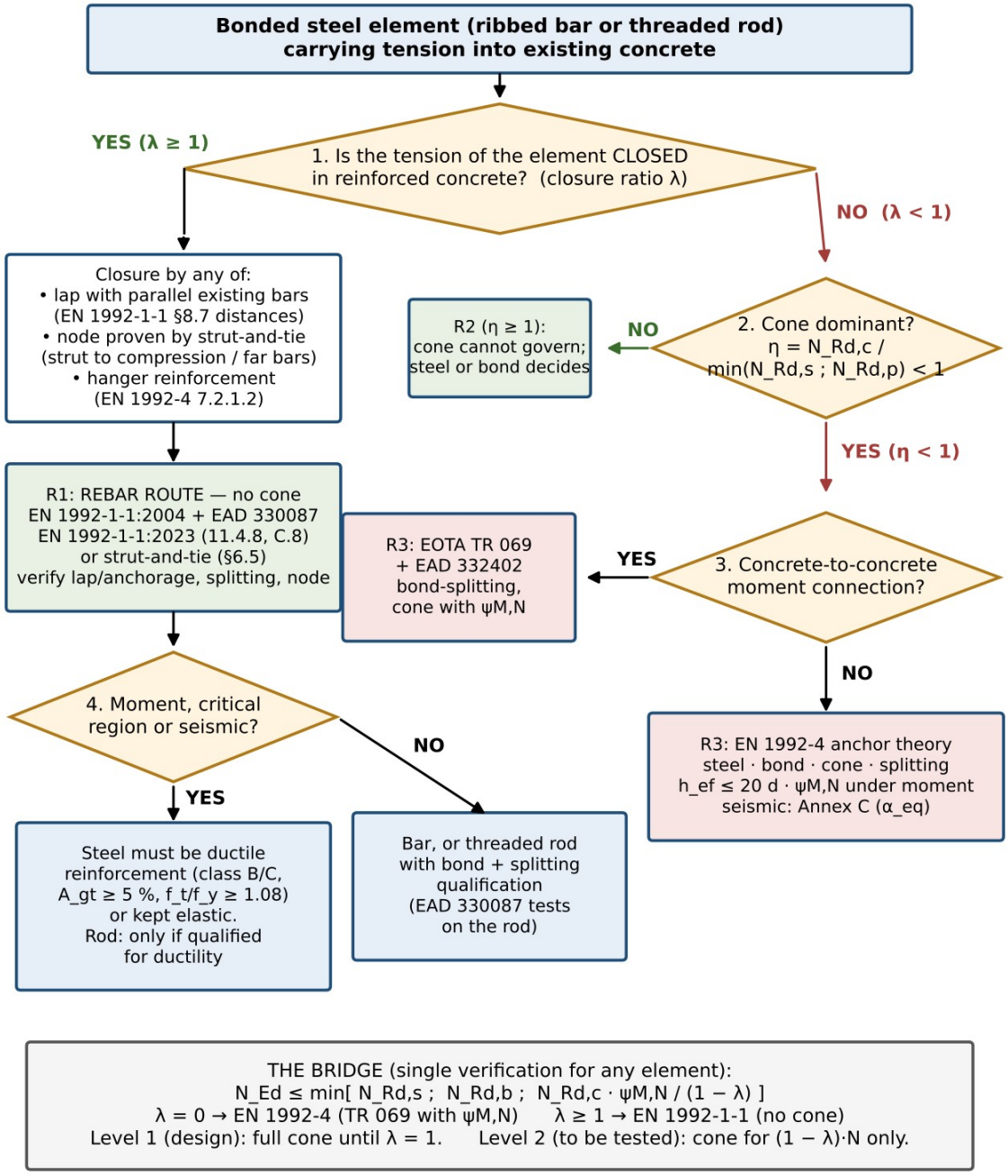
- **Credit for existing straight reinforcement.** Extend EN 1992-4 7.2.1.2 so that straight existing bars parallel to the fastener, within lap distance and anchored beyond the breakout body, count as closure (the F_lap term of equation (8)), and not only stirrups and loops of purpose-made hanger reinforcement.
- **Orthogonal reinforcement in the cone resistance.** Credit the measured increase of breakout resistance due to orthogonal surface reinforcement and member thickness [12] in $N_{Rd,c}$, and hence in η, without treating it as closure.
- **An explicit load-path check in the rebar route.** Require, in EN 1992-1-1 applications of post-installed bars outside laps and simple supports, a statement of how the tension is closed (lap, node or hanger), with the cone of TR 069 as the default when it is not. This makes explicit the premise the route already relies on.
- **Rods in the rebar route.** Admit threaded rods to the rebar route on the qualification conditions of §7.11.

7.13 What must still be established

The rule is built from provisions that already exist, but three of its elements require confirmation by test before it could enter a standard: the proposed limit $a \le l_{ov}/2$ on the distance between a fastener and the bar it laps, beyond the 4 φ / 50 mm of EN 1992-1-1; the Level 2 sharing of force between a partial lap and the cone; and, for threaded rods, the splitting behaviour at minimum cover and a ductility criterion for the steel (§7.9). None requires a new type of test: confined and unconfined pull-out tests with and without parallel existing bars, at varied overlap and distance, would settle the first two, and the EAD 330087 test series the third.

8. Schema of use

Figure 6 condenses the paper into a decision schema. The first question is not which product is used but whether the tension of the element is closed in reinforced concrete. If it is, the reinforcement route applies and the cone is not a failure mode; the only remaining question concerning the steel element is whether it must be ductile reinforcement, which depends on whether the connection resists moment, lies in a critical region or carries seismic action. If it is not closed, the cone is relevant unless $\eta \ge 1$, and the method is TR 069 for a moment connection between concrete members and EN 1992-4 otherwise. The bridge equation (10) runs underneath the whole schema. Table 8 gives the same decision in tabular form, with the method to be used and the checks it requires.



Green: cone not relevant. Red: cone relevant and verified. Blue: steel requirement.
The steel element (bar or rod) enters only at the steel requirement, never at the cone decision.

Figure 6. Schema of use for any bonded steel element (ribbed bar or threaded rod) carrying tension into existing concrete. The steel element enters the decision only at the steel requirement, never at the cone decision.

Table 8. Schema of use in tabular form.

Situation	Rule	Method	Checks
Tension closed by lap, proven node or hanger ($\lambda \geq 1$)	R1	EN 1992-1-1 (2004 + EAD 330087, or 2023), STM	Lap or anchorage, splitting, node; no cone. Steel: ductile reinforcement if moment, critical region or seismic
Not closed, cone cannot govern	R2	EN 1992-4 (or TR 069)	Steel and bond govern; cone satisfied

Situation	Rule	Method	Checks
(λ < 1, η ≥ 1)			automatically
Not closed, concrete-to-concrete moment connection (λ < 1, η < 1)	R3	TR 069 + EAD 332402	Yielding, bond-splitting, cone with ψM,N, local transfer (§8 of TR 069)
Not closed, steel fixture or hanger (λ < 1, η < 1)	R3	EN 1992-4	Steel, bond, cone, splitting; Annex C under seismic action
Partly closed (0 < λ < 1)	Level 1 / Level 2	Bridge, equation (10)	Level 1: full cone. Level 2 (research): cone for (1 − λ) N
Threaded rod in a closed load path	R1	Rebar route, on conditions of §7.11	Bond and splitting qualification; ductility for moment or seismic use

9. Worked examples

The difference between the two routes is largest where the stakes are highest, in seismic design. The example takes one metre of a typical connection, seven Ø12 B500 bars at 150 mm, bonded with an injection mortar that holds a European Technical Assessment both as a bonded anchor and as a post-installed rebar system (Chemfix 100, ETA-18/1157), in cracked C25/30, far from edges, loaded in tension. The structure is designed for ductility class DCM and the connection is treated as overdesigned in the sense of EN 1998-1 §5.11.2.1.2, so that it must be able to transmit $\gamma_{Rd}\, A_s f_{yd}$ with $\gamma_{Rd} = 1.2$ [22]. The rebar route was computed with ARS and the anchor route with AAS, both in the author's software family. All resistances in Table 9 are the values those programs print, except where the table states that a code factor has been applied by hand.

9.1 Seismic row of bars — Anchor route: EN 1992-4 with Annex C

The anchor route allows at most $h_{ef} = 20\, d = 240$ mm. At that depth AAS gives, for the group of seven, a design steel resistance of 7 × 44.3 = 310 kN, a combined pull-out and concrete resistance of 222.9 kN and a concrete cone resistance of 214.7 kN, the last being exactly equation (1) with the projected area $(6 \times 150 + 720) \times 720$ mm^2 against $(720\ \text{mm})^2$. Under seismic action EN 1992-4 Annex C (C.8 and Table C.3) multiplies the cone resistance of a group of post-installed fasteners other than headed-type ones by $\alpha_{eq} = 0.75$, and the combined pull-out resistance by 0.85, the latter computed with the seismic bond strength $\tau_{Rk,eq}$ of the product assessment. The seismic cone resistance is therefore 0.75 × 214.7 = 161.0 kN. For a continuous row rather than a group of seven, equation (5) gives 132.5 kN per metre statically and 99.4 kN per metre under seismic action.

None of the three design options of EN 1992-4 §9.2(3) can then be met in a useful way. Capacity design (a1) asks the fastening to carry the overstrength force of the bars, 1.2 × 344.2 = 413 kN; the cone provides 161 kN, 39 %. The ductile option (b) requires the steel to be weaker than every concrete failure mode; here the steel, at 310 kN, is almost twice as strong as the cone. Elastic design (a2) remains, at less than half of the yield force of the bars, which defeats the purpose of placing them. And §9.2(5) removes the question entirely in one important case: the seismic provisions of EN 1992-4 do not apply in critical regions of concrete members where spalling or yielding of the reinforcement may occur, such as plastic hinge zones. The base of a wall or a column, the most frequent location of a post-installed starter connection, is such a region.

9.2 Seismic row of bars — Rebar route: EN 1992-1-1, EAD 330087-01 and EN 1998-1

Designed as a lap with the existing Ø12 bars at 150 mm, ARS gives for the static case a basic anchorage length $l_{b,rqd} = 484$ mm, a lap length $l_0 = 509$ mm and an embedment of 543 mm, with the bars reaching their full design yield force, 7 × 49.2 = 344.2 kN. The 2018 edition of EAD 330087 excluded seismic action from its scope; the current edition (-01) [23] and the product assessment [24] provide a seismic bond factor $k_{b,seis}$, equal to 1.0 for Ø12 in C25/30 (ETA-18/1157, Table C4). Anchoring the overstrength force $\gamma_{Rd}\, A_s f_{yd} = 413$ kN raises the embedment to 651 mm. The connection develops the yield force of the bars, seismic or not, and no concrete cone appears anywhere in the verification.

The two programs also allow a like-for-like comparison at equal depth. AAS evaluates the rebar route as well, and at the 240 mm the anchor route allows it gives a bond-governed resistance of 7 × 30.3 = 212.1 kN, statically

almost identical to the anchor route's 214.7 kN. At equal depth the two routes nearly coincide in the static case. They separate for two reasons only. The rebar route is permitted to go deeper, to the length the strut field needs, while the anchor route stops at 20 diameters. And under seismic action the anchor route reduces the cone of the group by 25 % for uneven load sharing and crack interaction, while TR 069, for exactly the same row in exactly the same crack, states that no additional reduction is required for groups of rebars, because the crack usually runs along the layer and all the bars see the same width [5, §5.3].

Table 9. Seismic example: one metre of seven Ø12 B500 bars at 150 mm, Chemfix 100 (ETA-18/1157), C25/30 cracked, far from edges, tension, DCM (values printed by AAS and ARS).

Route	Program	Embedment [mm]	Static design resistance [kN]	Seismic design resistance [kN]	Governing
Anchor, EN 1992-4 (7 bars as a group)	AAS	240 (= 20 d, maximum)	214.7	161.0 *	Concrete cone
Anchor, continuous row, eq. (5)	–	240	132.5 / m	99.4 / m *	Concrete cone
Rebar, EN 1992-1-1 + EAD, same depth	AAS	240	212.1	212.1	Bond (kb,seis = 1.0)
Rebar, lap to EN 1992-1-1, designed to yield	ARS	543 (static); 651 (seismic, γRd = 1.2)	344.2	344.2 (anchored for 413)	Steel yield

** α_{eq} = 0.75 (EN 1992-4 Table C.3, group of post-installed fasteners) applied by the author to the printed static cone resistance. The combined pull-out resistance (222.9 kN static) is reduced by 0.85 and recomputed with $\tau_{Rk,eq}$ from the product assessment; it does not govern. Seismic capacity-design demand $\gamma_{Rd} A_s f_{yd}$ = 1.2 × 344.2 = 413 kN.*

9.3 What the example shows

The seismic case does not change the conclusion of Section 5; it sharpens it. Within the anchor model, the cone of a dense row cannot be raised to the yield force of the bars by any embedment the standard allows, the seismic reduction then takes away a further quarter, and the capacity design that EN 1998-1 expects of a structural connection becomes unattainable. Within the rebar model the same row, in the same holes with the same mortar, is designed to yield with a margin for overstrength. If the cone were the mechanism that governed these connections, the rebar route would be unconservative by a factor of about 2.6 under seismic action. The service record of lapped post-installed connections, and the Stuttgart tests in which breakout occurred when the lap was absent and the bars were short [10, 11], indicate that it is not the governing mechanism.

In the terms of Section 7, the rebar design of this example is case A of Table 7 ($\lambda = 1$, rule R1) and the anchor design is case B ($\lambda < 1$, $\eta < 1$, rule R3). The difference of a factor 2.6 between them is not a difference between a bar and a rod, nor between two bond strengths: it is the difference between a closed and an open load path.

9.4 Beam-to-column moment connection with straight bars

An exterior beam 300 × 500 mm is connected to an existing column 400 × 400 mm in cracked C25/30. The top reinforcement, 3 Ø16 B500 at 100 mm, is post-installed straight into the column; at yield it carries $T = 3 \times 87.4 = 262$ kN, with a lever arm $z \approx 405$ mm. The column depth limits the embedment to about 340 mm (21 φ).

- **Plain EN 1992-1-1 route.** The bars need $l_{b,rqd} = 644$ mm and cannot be anchored in 340 mm; even with the cone ignored, the anchorage develops 230 N/mm², 53 % of the yield force (138 kN). The route is outside the scope of EAD 330087 in any case, since no lap is possible.
- **TR 069 route ($\lambda = 0$).** The cone in the column, with $l_b = 340$ mm, $s_{cr,N} = 1020$ mm, the projected area limited to the 400 mm width of the column, $\psi_{s,N} = 0.76$ for the 100 mm edge distance, and $\psi_{M,N} = 1.0$ because the bars lie within 1.5 l_b of the column edges, is $N_{Rd,c} = 241.4 \times 0.392 \times 0.759 / 1.5 = 47.9$ kN, 18 % of the yield force (author's calculation to TR 069 §4.3).
- **Proven node ($\lambda = 1$).** In an interior joint the bars can be drilled through the column and lapped with the top reinforcement of the opposite beam, or anchored beyond a node verified by a strut-and-tie model; the tension is closed, no cone applies, and the bars develop their yield force of 262 kN.

The same three answers hold for threaded rods of equal strength in the same positions. What decides is not the element but the load path, and in the exterior joint with straight elements there is none that the plain rebar route can claim.

Table 10. Exterior beam-to-column moment connection, 3 Ø16 B500 (or M16 8.8), column 400 × 400 mm, C25/30 cracked (design values).

Route	λ	Resistance [kN]	Share of yield	Governing
Plain EN 1992-1-1, straight bars, 340 mm	–	138	53 %	Anchorage length; outside EAD 330087 scope
TR 069, cone in the column, ψM,N = 1.0	0	47.9	18 %	Concrete cone
Through the column, lapped or proven node (interior joint)	1	262	100 %	Steel yield

Yield of 3 Ø16: 262 kN; M16 8.8 rods give the same force (3 × 87.4 kN). Cone: author's calculation to TR 069 §4.3 with h_ef = l_b = 340 mm.

10. Discussion and conclusions

10.1 The label decides, not the mechanism

The present arrangement assigns a failure mode according to the name of the product. A ribbed bar is presumed to sit in a closed load path; a threaded rod is presumed to sit in an open one. Neither presumption is checked by the method that follows from it. The rebar route does not require the designer to show the struts, and the anchor route does not allow the designer to show them. In the overlap where the two methods meet, which is large in practice, the same connection can be found adequate or inadequate by a factor of two to more than ten depending on which element was drawn on the plan.

The rule of Section 7 removes the label from the decision. It asks of every bonded element the same two questions, whether its tension is closed by reinforcement and whether its cone could govern if it were not, and it answers them for a bar and a rod alike.

10.2 Existing reinforcement: all or nothing

The two routes take opposite extreme positions on the reinforcement already in the member. The rebar route assumes, without verification, that it carries everything. The anchor route ignores it entirely unless it satisfies the detailing rules for supplementary reinforcement, which were written for purpose-placed hanger bars. The author's earlier paper on cracked concrete [17] noted the second extreme in the context of ordinary flexural and distribution reinforcement crossing the cone, citing experimental evidence that such reinforcement raises the breakout capacity [12]. The truth lies between the two and is not modelled by either. A graded recognition of existing reinforcement, by its quantity, orientation and anchorage relative to the breakout body, would serve both routes better than the present switch.

10.3 The opposite risk

Criticism of the anchor model's severity must be matched by a warning in the other direction, because the rebar route is easy to misuse. A post-installed bar used as a hanger in the soffit of a slab, carrying a suspended load downward, has no lap and no strut to close its tension: its force must return to the slab through concrete in tension, and the cone is real. The same is true of a bar used as a starter in a thin member without reinforcement in the direction of the force, or of an end anchorage under a moment when the existing member is not designed as the node of a strut-and-tie model. Using the rebar route in those cases, because the steel element is a bar, applies a method outside the premise that makes it safe. The column-foundation tests discussed in §3.3 show what happens then, and §9 shows that under seismic action the anchor standard excludes the most common location of such connections altogether.

10.4 What the qualification never tests

The rebar assessment is run entirely in confined tests, which by design cannot produce a cone. The anchor assessment measures the cone in unreinforced concrete, which by design cannot show what reinforcement

does to it. Each qualification therefore confirms the premise of its own design method and is silent on the premise of the other. The breakout behaviour of rows of bonded steel elements in reinforced members, with and without a lap, at embedments between 20 and 60 diameters, lies in the gap between the two test programmes and has received little systematic attention outside the column-foundation work cited above.

10.5 Conclusions

1. Seven methods are used for post-installed bonded steel in concrete. They fall into two families resting on different premises. The anchor family (EN 1992-4, TR 069, ACI 318 Chapter 17) assumes an open load path and verifies the concrete cone; the reinforcement family (EN 1992-1-1:2004 with EAD 330087, EN 1992-1-1:2023, strut-and-tie, manufacturer methods, ACI 318 Chapter 25 with AC308) assumes a closed one and never verifies it. Neither family states the premise as a criterion, and the boundary between them is drawn by the name of the steel element.
2. The concrete cone is a property of the load path. It is absent where the tension is closed by a lap, a proven node or hanger reinforcement, and present where it must return through concrete in tension. Depth matters only as the length a lap or a strut requires; bond strength does not decide the cone in either family.
3. The reinforcement methods are safe within their premise and are stretched beyond it in practice: beam-to-column moment connections with straight bars, starter bars that do not reach the node, and bars used as hangers. In an ordinary exterior beam-column joint the cone provides 18 % of the yield force of the bars.
4. Without closure, the cone ceases to govern a single fastener at 11 to 18 diameters against steel and 4 to 18 against bond, but a dense row never by depth alone; a row of Ø12 at 150 mm would need 1.5 m of embedment.
5. Bridges already exist (TR 069 with $\psi_{M,N}$, EN 1992-4 7.2.1.2(2)e, supplementary reinforcement, rebars as fasteners, strut-and-tie proof, EN 1992-1-1:2023 Annex C.8), each partial. What is missing is a general criterion.
6. An element-neutral rule is proposed: the cone is irrelevant when the closure ratio λ reaches 1 or the dominance ratio η reaches 1, and verified otherwise. As one verification, $N_{Ed} \leq \min[N_{Rd,s}; N_{Rd,b}; N_{Rd,c}\, \psi_{M,N}/(1-\lambda)]$, it is a bridge whose end points are EN 1992-4 and EN 1992-1-1. Level 1 (full cone until $\lambda = 1$) is offered for design; Level 2 (cone for the unclosed share) is a hypothesis for testing.
7. Threaded rods can cross the bridge on the same terms as bars. A rod lapped like a bar has the same anchorage (for M16 8.8 and Ø16 B500, 87.4 kN and 644 mm). It needs bond and splitting qualification to EAD 330087 and, for moment, critical-region or seismic connections, the ductility of class B reinforcement or an elastic design. The present exclusion is administrative, not mechanical.
8. Under seismic action the stakes are largest: for one metre of Ø12 at 150 mm the anchor route gives 161 kN against a capacity-design demand of 413 kN, and EN 1992-4 does not apply in plastic hinge zones, while the rebar route anchors the bars for their overstrength with 651 mm. The schema of Figure 6 assigns the difference to its cause, the load path, and lets any qualified element use it.

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