

Seven Questions for EN 1992-4

A critical review of load-distribution, interaction and modification-factor provisions for fastenings in concrete whose formulae depart from observed or mechanically expected behaviour

Yves De Lathouwer

Adit Ltd · ORCID 0009-0005-8802-1686 · eng.adit.org.il (English) · www.adit.org.il (Hebrew)

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Abstract

EN 1992-4:2018 is the European standard for the design of fastenings in concrete. Its resistance models rest on an extensive experimental basis, but several of its load-distribution rules, interaction rules and modification factors are not derived from that basis, or apply it beyond the conditions in which it was obtained. This paper reviews seven such provisions. Three have been examined in detail in earlier studies by the author and are summarised here: the default assumption of cracked concrete and the undefined depth of its 0.3 mm reference crack; the pry-out factor k_8 , which links pry-out to tension resistance by a factor of 1 or 2 where mechanics and test databases indicate about 2.5 to 4; and the concrete edge verification of multi-row groups, in which only the row closest to the edge is effective, so that adding anchors can lower the verified resistance by 36 to 58 %. Four further provisions are examined here for the first time, with worked examples computed with the formulae of the standard: (i) the tension–shear interaction of Table 7.3, which combines the most utilised tension mode and the most utilised shear mode with one exponent whatever the mechanisms involved; (ii) the splitting provisions of §7.2.1.7, where the only exemption for uncracked concrete requires designing for cracked concrete, so that for an M12 wedge-anchor group the verified resistance falls from 63.1 kN to 32.2 kN with the splitting check, or to 40.0 kN plus 138 mm² of reinforcement without it; (iii) the constant factor $\psi_{90^\circ, V} = 2.0$ for shear parallel to an edge, which a resistance-dependent expression of the fib type places between 2.4 and 1.1 for the same anchor as c_1 grows from 60 to 200 mm, so that the constant is unconservative by up to 87 % at larger edge distances; and (iv) the shell-spalling factor $\psi_{re, N}$, which reduces cone, bond and, through k_8 , pry-out resistance by up to 30 % because reinforcement is present, and has no counterpart in ACI 318. The provisions are classified by the nature of the departure — contradiction of tests, inconsistency with a parallel code, internal logical inconsistency — and a research programme is proposed for each. The review refers to the first-generation text; the second-generation Eurocodes were not available to the author.

Keywords: EN 1992-4; fastenings in concrete; post-installed anchors; design codes; cracked concrete; pry-out; concrete edge failure; tension–shear interaction; splitting; shell spalling; code review

1 Introduction

EN 1992-4 [1] brought the European design of fastenings in concrete — headed studs, anchor channels, mechanical, bonded and screw anchors — into one Eurocode part, replacing the design

annexes of the European technical guidelines and the CEN/TS 1992-4 series. Its core, the Concrete Capacity (CC) method, is among the best-tested design models in structural engineering: the basic resistances of concrete cone, pull-out and concrete edge failure are regressions on thousands of tests, and each product enters the design through a European Technical Assessment (ETA) based on its own test programme [2, 5].

A design standard, however, is more than its basic resistances. Between the tested single-anchor resistance and the verification of a real fixture stand load-distribution rules, interaction rules and modification factors (ψ -factors) that adapt the basic value to the actual geometry, reinforcement and loading. Some of these are well supported; others are conventions, inherited from earlier guidelines, that were never derived from tests of the situation they now govern, or that follow from the tests only under conditions that the rule does not require. It is in these rules, rather than in the basic resistances, that a designer meets results that contradict mechanical intuition.

The author has worked on anchor design for many years, teaches it to students and design offices, and develops the AAS anchor-design software of Adit Ltd [18], in which every provision of EN 1992-4 has to be implemented literally and every result has to be explained to a user. That work has produced a list of provisions whose formulae appear to depart from the behaviour they describe. Three of them have been the subject of detailed studies [7, 8, 9]; this paper summarises those findings (Part A, Section 2) and examines four further provisions (Part B, Sections 3 to 6), using the text of I.S. EN 1992-4:2018 and worked examples computed with its formulae. Section 7 classifies the seven provisions, and Section 8 proposes a research programme.

The purpose is not to question the safety of the standard as a whole, nor the experimental basis of its resistance models. It is to identify, precisely and with numbers, the places where a formula and the physics part ways, so that they can be tested and, where necessary, corrected.

Part A — Provisions already examined

2 Summary of earlier findings

2.1 The definition of cracked concrete

EN 1992-4 requires fastenings to be designed for cracked concrete unless it is shown that the concrete remains uncracked, which for most anchor types reduces the characteristic concrete resistances by about 30 % ($k_1 = 7.7$ instead of 11.0 for post-installed anchors). Cracked concrete is characterised in the product qualification by a crack width of 0.3 mm, but neither EN 1992-1-1 nor EN 1992-4 attaches a depth or a geometry to that crack. A flexural crack is a wedge: 0.3 mm at the tension face is narrower at every depth along the anchorage, whereas the qualification specimen is cracked to a uniform width through its whole depth — a geometry that occurs in restrained walls and slabs on grade but not in the suspended slabs where most anchors are installed. A crack-width calculation to EN 1992-1-1 §7.3.4 shows that a 0.3 mm reference crack requires a reinforcement stress of about 300 to 350 N/mm², i.e. 70 to 80 % of f_{yd} , whereas a slab under quasi-permanent loads carries cracks of about 0.14 to 0.23 mm. The study [7] proposes a graded, criteria-based classification in place of the binary default.

2.2 The pry-out factor k_8

Pry-out is not verified on its own mechanical terms: the characteristic pry-out resistance is k_8 times the anchor's tension resistance (concrete cone or, for bonded anchors, combined pull-out and

concrete failure), with $k_8 = 1$ or 2 by default. The mechanics of a laterally loaded anchor give a ratio between tension resistance and resistible shear of about 4 to 7; the available test databases give an effective factor of about 2.5 for single anchors and 3.3 for groups; and product assessments already grant values up to 2.9. The rule is also internally inconsistent: the bond (pull-out) resistance of a bonded anchor enters its pry-out resistance, while the tested pull-out resistance of a mechanical anchor does not, so that the same concrete screw is treated differently when it is set with an injection mortar; and the group effect in pry-out is represented by overlap factors borrowed from tension [8].

2.3 Concrete edge failure of multi-row groups

For a fastening close to an edge and loaded towards it, §6.2.2.2 (1) b) and §7.2.2.5 (2) make only the row closest to the edge effective and assign it the whole shear load, whether or not the fixture has hole clearance. For a 3×3 group of M12 wedge anchors at $s = 150$ mm, the verified resistance at $c_1 = 100$ mm is 39.0 kN, but 77.9 kN if the holes of the front row are slotted so that those anchors carry nothing; adding a row near the edge lowers the verified resistance by 36 to 58 % for $c_1 = 150$ to 75 mm. Nonlinear finite-element analyses (Code_Aster) showed that on a rigid plate all rows are active up to failure: the group resisted 2.9 to 5.4 times the front row acting alone, removing the front row did not increase the resistance, and with a hole clearance that lets the front row fail first the group still reached 92 to 94 % of its resistance. The governing failure was a break-out body starting behind the back row. A verification combining an equal-share check of the front row with a check of the back-row body was proposed; it was conservative by a nearly constant factor of 1.4 to 1.6 against the normalised FE results, compared with 2.9 to 4.7 for the present rule [9].

Part B — Four further provisions

3 Tension–shear interaction (Table 7.3)

3.1 The provision

For failure modes other than steel failure, Table 7.3 of EN 1992-4 requires

$$(N_{Ed}/N_{Rd,i})^{1.5} + (V_{Ed}/V_{Rd,i})^{1.5} \leq 1 \quad (1)$$

or, alternatively, $N_{Ed}/N_{Rd,i} + V_{Ed}/V_{Rd,i} \leq 1.2$ with each ratio not greater than 1, and states that "the largest value of $N_{Ed}/N_{Rd,i}$ and $V_{Ed}/V_{Rd,i}$ for the different failure modes shall be taken". Steel failure is verified separately with an exponent of 2. The linear alternative is geometrically identical to the trilinear rule of ACI 318-19 §17.8, whose commentary presents it as a simplification of an interaction with the exponent 5/3 [3].

3.2 Why the provision is questionable

The rule is mode-blind. The tension ratio and the shear ratio are each taken as the maximum over all failure modes, and the pair is then combined with one exponent, irrespective of which mechanisms produced the two maxima. Three quite different situations are therefore treated alike:

- **Shared volume.** Concrete cone in tension and concrete edge failure in shear near an edge or a corner: the two failure bodies occupy much of the same concrete, and a strong interaction is mechanically plausible.

- **Partially shared mechanism.** Concrete cone in tension and pry-out in shear: both rely on the concrete behind the anchor, and pry-out resistance is itself defined as a multiple of the cone resistance.
- **Separate mechanisms.** Pull-out in tension (a product mechanism at the expansion or bond zone, deep in the hole) combined with concrete edge failure in shear (a body detaching at the surface between anchor and edge): the two mechanisms share little concrete and are resisted by different parts of the anchorage.

The exponent 1.5 is a convenient envelope of interaction tests in which these cases were not separated. The standard does not give its test basis, and the commentary literature presents it as a simplified rule [2, 5, 17]. Whether the same reduction is justified when the two maxima come from mechanisms that do not share a failure body has, to the author's knowledge, not been examined systematically.

3.3 Worked example

Consider a single MTP-X M12 wedge anchor ($h_{ef} = 70$ mm) at $c_1 = 100$ mm from an edge in uncracked C25/30. From its product assessment and the standard, the design pull-out resistance is $N_{Rd,p} = 28/1.5 = 18.7$ kN and the design concrete edge resistance is $V_{Rd,c} = 19.5/1.5 = 13.0$ kN; these two govern tension and shear respectively. An anchor loaded to 70 % of both — $N_{Ed} = 13.1$ kN and $V_{Ed} = 9.1$ kN — fails Eq. (1) with $0.70^{1.5} + 0.70^{1.5} = 1.17$, and also the linear alternative ($1.40 > 1.2$). If the two mechanisms were independent, the admissible region would be the full rectangle of Figure 1, and the anchor would be utilised at 70 %. The area between the curves in Figure 1 is the potential over-conservatism when the two governing modes do not interact, and the region in which a mode-specific rule would be needed.

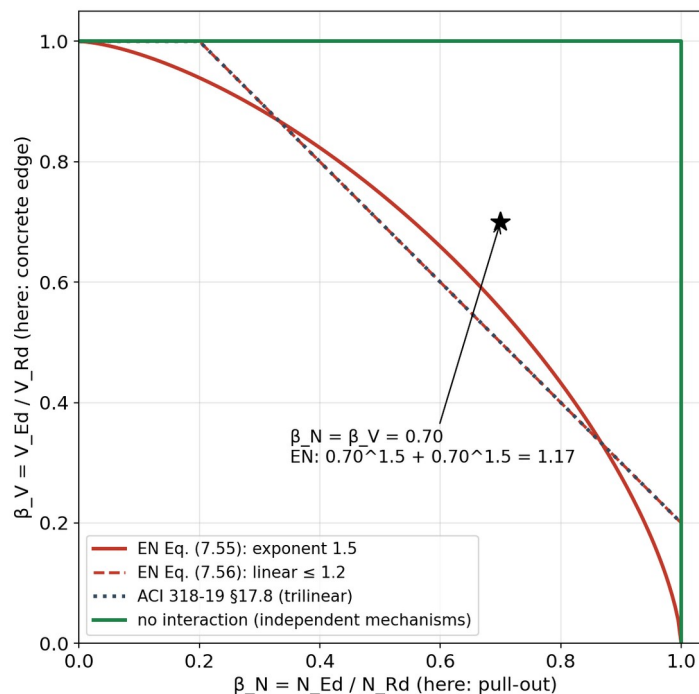


Figure 1. Admissible combinations of tension and shear utilisation: EN 1992-4 Eq. (7.55) and (7.56), ACI 318-19 §17.8, and the hypothesis of independent mechanisms (pull-out combined with concrete edge failure).

3.4 Open question

Is the interaction between two concrete-related failure modes a property of the pair of mechanisms, and should Table 7.3 distinguish at least the pairs that share a failure body (cone–edge, cone–pry-out) from those that do not (pull-out–edge, bond–edge)? The question can be answered with a limited test series on single anchors near an edge, loaded at several angles, with the anchor type chosen so that pull-out governs in tension; three-dimensional nonlinear analysis of the kind used in [9] can map the interaction beforehand.

4 Concrete splitting (§7.2.1.7)

4.1 The provision

Splitting under load must be verified unless (1) the edge distance in all directions is at least $c_{cr,sp}$ (1.2 $c_{cr,sp}$ for groups) and $h \geq h_{min}$, or (2) the characteristic resistances for concrete cone and pull-out are calculated for **cracked** concrete and reinforcement resists the splitting forces and limits the crack width to 0.3 mm. The reinforcement is

$$\Sigma A_{s,re} = k_4 \cdot \Sigma N_{Ed} / (f_{yk,re} / \gamma_{Ms,re}) \quad (2)$$

with $k_4 = 2.0$ for deformation-controlled expansion anchors, 1.5 for torque-controlled and bonded expansion anchors, 1.0 for undercut anchors and screws and 0.5 for bonded and headed fasteners. Otherwise the splitting resistance is computed with the area method of the cone, but with $c_{cr,sp}$ and $s_{cr,sp} = 2 c_{cr,sp}$ taken from the product assessment and a thickness factor $\psi_{h,sp} = (h/h_{min})^{2/3}$, limited to $\max\{1; ((h_{ef} + 1.5 c_1)/h_{min})^{2/3}\}$ and to 2.

4.2 Why the provision is questionable

The values of k_4 are defensible: they reflect the ratio of the radial splitting force to the tension in anchors of different types, and a wedge anchor can produce radial forces of the order of its tension. The difficulty lies elsewhere.

- **The only exemption for uncracked concrete is to design for cracked concrete.** A verification that exists because the concrete is uncracked can be avoided only by abandoning the uncracked resistances — for mechanical anchors typically 30 % on the cone and more on pull-out — even though reinforcement that limits the splitting crack to 0.3 mm is also required. There is no route in which the reinforcement is provided and the uncracked resistances are kept.
- **The characteristic distance is a product constant without a model.** $c_{cr,sp}$ and h_{min} are taken from the product assessment, often at 2 to 3 h_{ef} , and enter an area method whose geometry was calibrated for the concrete cone. The splitting resistance so obtained scales with the cone formula rather than with the splitting mechanism (radial force against the tensile capacity of the member cross-section).
- **The thickness law is empirical and capped.** The exponent 2/3 and the upper limit of 2 in $\psi_{h,sp}$ are not related in the standard to any mechanical quantity.

4.3 Worked example

A 2×2 group of MTP-X M12 anchors ($s = 150$ mm, $h_{ef} = 70$ mm) in uncracked C25/30, with its product assessment values $c_{cr,sp} = 175$ mm ($2.5 h_{ef}$) and $h_{min} = 140$ mm, is placed 120 mm from one

edge in a 150 mm slab. The values below were computed with the formulae of EN 1992-4 as implemented in the AAS engine and are design resistances.

Table 1. Design tension resistance of a 2×2 MTP-X M12 group ($s = 150$ mm, $c = 120$ mm, $h = 150$ mm, C25/30) under the three routes of §7.2.1.7.

Route	Governing resistance [kN]	Governing mode	Additional requirement
Uncracked, splitting not considered (reference)	63.1	concrete cone	—
Uncracked, splitting verified (7.2.1.7 (2) c)	32.2	splitting	—
Exemption (2) b) 2): cracked resistances + reinforcement	40.0	pull-out (cracked, $4 \times 15/1.5$)	$\Sigma A_{s, re} = 138 \text{ mm}^2$ for $\Sigma N_{Ed} = 40 \text{ kN}$
Exemption (2) b) 1): $c \geq 1.2$ $c_{cr, sp} = 210 \text{ mm}$, $h \geq 140 \text{ mm}$	63.1	concrete cone	geometry not available here

The splitting check halves the verified resistance of the group ($63.1 \rightarrow 32.2 \text{ kN}$). The route the standard offers to avoid it restores only part of the loss (40.0 kN), because the pull-out resistance in cracked concrete is 15 kN instead of 28 kN, and it adds 138 mm^2 of reinforcement that must be placed symmetrically close to the anchors — in an existing slab, usually impossible. The designer who cannot satisfy the geometric exemption therefore loses between 37 % and 49 % of the resistance, whatever the actual risk of splitting.

4.4 Open question

Should the standard offer an intermediate route — uncracked resistances with splitting reinforcement to Eq. (2) — and should $c_{cr, sp}$ be replaced by a mechanical model of the splitting force against the tensile capacity of the member cross-section? Splitting tests on members of controlled width and thickness, with and without reinforcement, would answer both questions.

5 Shear parallel to an edge ($\psi_{\alpha, V}$, Eq. 7.48)

5.1 The provision

The effect of a shear load inclined to the edge is taken into account by

$$\psi_{\alpha, V} = [\cos^2 \alpha_V + (0.5 \sin \alpha_V)^2]^{-0.5} \geq 1 \quad (3)$$

which reaches $\psi_{90^\circ, V} = 2.0$ for a load parallel to the edge, for every anchor diameter, embedment, concrete strength and edge distance. ACI 318-19 uses the same constant (a factor of 2 for the parallel direction).

5.2 Why the provision is questionable

A load parallel to the edge does not detach the same body as a load towards it: failure is initiated by local crushing and splitting of the concrete in front of the anchor in the direction of the load, followed by spalling towards the edge [5, 6]. The resistance to this mechanism is governed by local bearing, i.e. by the anchor diameter and the concrete strength, rather than by the size of the edge

break-out body that grows with $c_1^{1.5}$. A constant ratio between the two cannot hold over a range of edge distances.

An expression of this mechanical form is associated with fib Bulletin 58 [2] and is applied by at least one widely used commercial design program and by the AAS engine: $\psi_{90^\circ, V} = 4 \cdot (n \cdot d_{\text{nom}}^2 \cdot f_{ck} / V_{Rk, c, \perp})^{0.5} \leq 4$, where n is the number of loaded anchors and $V_{Rk, c, \perp}$ the resistance perpendicular to the edge (N, mm). The parallel resistance then grows with the square root of $V_{Rk, c, \perp}$ rather than in proportion to it. The author verified the values printed by the commercial program in ten of its design reports, which ranged from 1.9 to 4.0; the exact form should be checked against the text of fib Bulletin 58 by the reader.

5.3 Worked example

Figure 2 compares the two approaches for a single MTP-X M12 anchor in uncracked C25/30 ($h = 300$ mm) for $c_1 = 60$ to 200 mm. With the resistance-dependent factor, $\psi_{90^\circ, V}$ falls from 2.41 at $c_1 = 60$ mm to 1.99, 1.72, 1.31 and 1.07 at 80, 100, 150 and 200 mm. The characteristic parallel resistance is then 23.9, 28.9, 33.5, 44.1 and 53.7 kN, against 19.8, 29.0, 39.0, 67.5 and 100.2 kN with the constant 2.0. At small edge distances the constant is conservative (by 17 % at 60 mm); from about 80 mm it is **unconservative**, by 16 % at 100 mm, 53 % at 150 mm and 87 % at 200 mm.

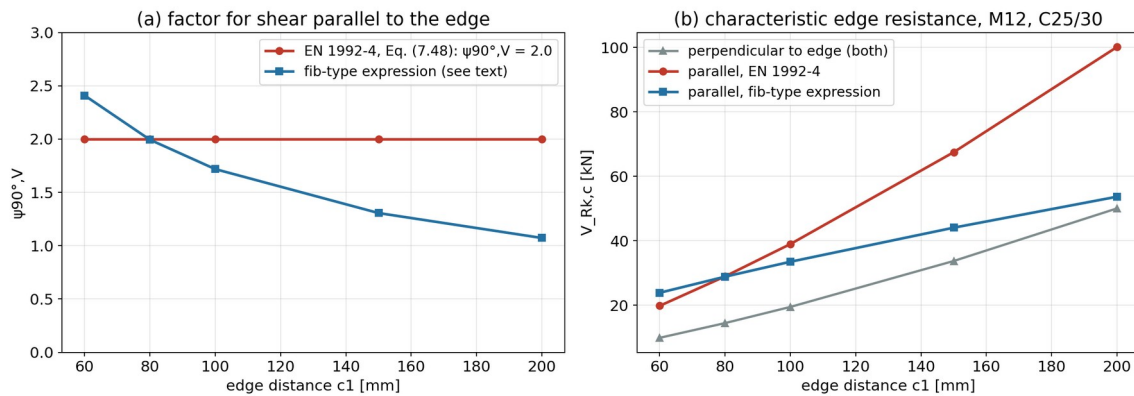


Figure 2. Shear parallel to the edge, single MTP-X M12, uncracked C25/30: (a) $\psi_{90^\circ, V}$ from EN 1992-4 and from the resistance-dependent expression; (b) the resulting characteristic edge resistances.

The finding reverses the usual assumption that the constant 2.0 is simply conservative: it is conservative where the edge resistance is small and unconservative where it is large, because it ties the parallel resistance to a failure body that the parallel load does not mobilise.

5.4 Open question

Which expression reproduces the test results for parallel shear over a wide range of c_1/d_{nom} ? The test databases on which the edge-failure model was calibrated [6, 10, 11] contain parallel-shear tests; a re-evaluation of those tests against both expressions, stratified by c_1/d_{nom} , would settle the question without new testing.

6 The shell-spalling factor ($\psi_{re, N}$, Eq. 7.5)

6.1 The provision

For $h_{ef} < 100$ mm the concrete cone resistance is multiplied by

$$\psi_{re,N} = 0.5 + h_{ef}/200 \leq 1 \quad (4)$$

unless the reinforcement, in both directions, is spaced at 150 mm or more (any diameter) or at 100 mm or more (diameters of 10 mm or less). The same factor applies to the combined pull-out and concrete resistance of bonded anchors (§7.2.1.6 (6)) and, because the pry-out resistance is k_8 times the cone or bond resistance, it propagates into pry-out.

6.2 Why the provision is questionable

- **The reduction is triggered by the presence of reinforcement.** Its physical justification is that dense bars close to the surface create a plane of weakness along which the concrete cover spalls before a full cone forms. The rule, however, is expressed only through bar spacing and diameter — not through the concrete cover, the depth of the bars relative to h_{ef} , or their position relative to the anchor — so it applies equally where the bars lie well below the anchor or far from it.
- **It is large where it applies.** At $h_{ef} = 40, 50$ and 70 mm the reduction is 30 %, 25 % and 15 % — comparable with the cracked-concrete reduction, and cumulative with it.
- **It has no counterpart in ACI 318.** The concrete breakout provisions of ACI 318-19 Chapter 17, calibrated on overlapping test databases, contain no shell-spalling factor.
- **Its test basis is not given.** The factor has been carried over from earlier European guidance; the standard gives no reference to the tests that justify its present form for today's anchors and today's reinforcement layouts.

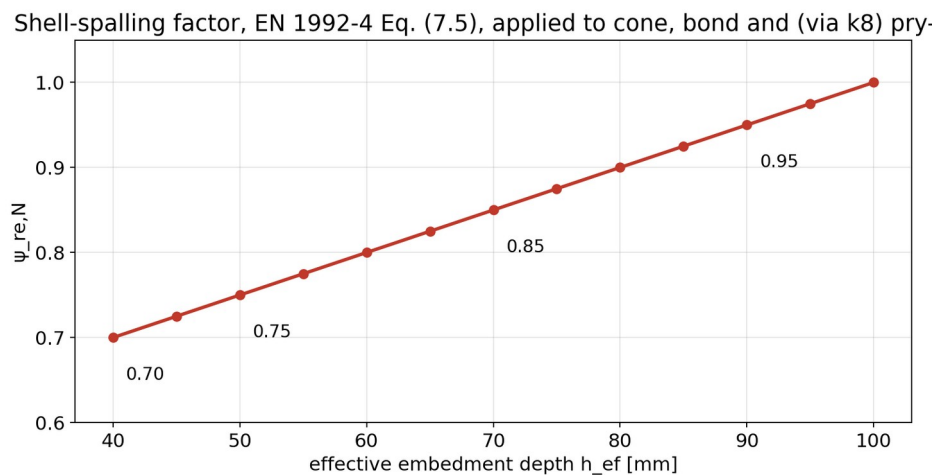


Figure 3. The shell-spalling factor of EN 1992-4 as a function of the effective embedment depth.

6.3 Worked example

For the MTP-X M12 at $h_{ef} = 70$ mm in a slab reinforced with $\varnothing 10$ bars at 125 mm — neither exemption of Eq. (4) is met — $\psi_{re,N} = 0.85$. The characteristic cone resistance of a single anchor in uncracked concrete falls from 32.2 to 27.4 kN, and its pry-out resistance, $k_8 \cdot N_{Rk,c}$ with $k_8 = 2.4$, from 77.3 to 65.7 kN. The same slab with $\varnothing 10$ bars at 100 mm, i.e. with **more** reinforcement, is exempt and keeps the full resistance.

6.4 Open question

Does dense surface reinforcement reduce the cone resistance of modern post-installed anchors at 40 to 100 mm embedment, and if so, is the governing parameter the bar spacing or the ratio of cover

to embedment depth? A small test series in slabs with controlled cover and spacing would answer it.

7 Synthesis

Table 2 classifies the seven provisions by the nature of their departure from observed or mechanically expected behaviour.

Table 2. Classification of the seven provisions.

Provision	Clause	Nature of the departure	Direction of error	Status
Cracked-concrete default	§4.4, 7.2	reference crack without depth; test geometry $\neq$ member geometry	conservative	studied [7]
Pry-out factor k_8	§7.2.2.4	contradicts mechanics and test databases; internal inconsistency	conservative	studied [8]
Front-row rule, edge failure	§6.2.2.2, 7.2.2.5	contradicts displacement compatibility; FE; paradox	conservative, non-monotonic	studied [9]
Tension–shear interaction	Table 7.3	mode-blind combination of different mechanisms	conservative (likely)	open
Splitting	§7.2.1.7	exemption requires cracked design; empirical $c_{cr,sp}$, $\psi_{h,sp}$	conservative	open
Parallel shear $\psi_{\alpha,V}$	Eq. (7.48)	constant where the mechanism implies a variable	both — unconservative at large c_1	open
Shell spalling $\psi_{re,N}$	Eq. (7.5)	triggered by reinforcement; no ACI counterpart; basis not given	conservative (likely)	open

Three patterns emerge. First, most of the provisions are conservative, and their cost is borne by the owner in anchors that are deeper, larger or more numerous than necessary. Second, two of them are **non-monotonic** in a way that can mislead a designer: the front-row rule makes a fixture weaker when anchors are added, and the splitting exemption makes the verified resistance of an uncracked member depend on assuming that it is cracked. Third, one provision — the constant parallel-shear factor — is conservative in some ranges and unconservative in others; this is the provision whose correction matters most for safety, not only for economy.

A common thread is that the provisions were introduced as simplifications at a time when design was done by hand. With design software now standard practice, the argument for a single constant exponent, a single constant angle factor or a single loaded row has weakened; the more mechanical alternatives that already exist in the research literature and in fib Bulletin 58 could be adopted without making design more laborious.

8 Proposed research programme

- **Interaction:** single anchors near an edge, with the anchor type chosen so that pull-out governs in tension, loaded at 0°, 30°, 45°, 60° and 90°; complementary nonlinear FE mapping of cone–edge, pull-out–edge and cone–pry-out pairs.
- **Splitting:** members of controlled width and thickness, with and without reinforcement to Eq. (2), comparing uncracked resistances with and without the reinforcement; development of a splitting model based on radial force and member cross-section.
- **Parallel shear:** re-evaluation of existing parallel-shear tests against the constant and the resistance-dependent expressions, stratified by c_1/d_{nom} ; no new tests are needed for a first answer.
- **Shell spalling:** cone tests at 40 to 100 mm embedment in slabs with controlled cover and bar spacing.
- **Cracked concrete, pry-out, edge failure:** the programmes proposed in [7–9], in particular crack-depth measurements at anchor locations in service, pry-out tests of mechanical anchors with known pull-out resistance, and tests of multi-row groups with filled hole clearance.

The second-generation Eurocodes are due for national implementation between 2027 and 2028 [19]; the revised EN 1992-4 was not available to the author, and this review refers to the 2018 text. Each of the questions above can be checked against the revised text as soon as it is published.

9 Conclusions

1. Seven provisions of EN 1992-4:2018 were identified whose formulae depart from observed or mechanically expected behaviour. Three — the cracked-concrete default, the pry-out factor and the front-row rule for edge failure — have been examined in detail elsewhere [7–9].
2. The tension–shear interaction of Table 7.3 combines the most utilised tension and shear modes with one exponent regardless of the mechanisms involved; for pull-out combined with edge failure an anchor at 70 % of both resistances fails the check (1.17), although the two mechanisms share little concrete.
3. The splitting provisions allow an uncracked member to avoid the splitting check only by designing it as cracked. For a 2×2 M12 wedge-anchor group the verified resistance falls from 63.1 kN to 32.2 kN with the check, or to 40.0 kN plus 138 mm² of reinforcement without it.
4. The constant factor $\psi_{90^\circ, V} = 2.0$ for shear parallel to an edge is conservative at small edge distances but, compared with a resistance-dependent expression of the fib type, unconservative by 16 % to 87 % for $c_1 = 100$ to 200 mm with an M12 anchor. This is the provision whose correction matters most for safety.
5. The shell-spalling factor reduces the cone, bond and pry-out resistances of anchors shallower than 100 mm by up to 30 % because reinforcement is present, has no counterpart in ACI 318, and is exempted by denser reinforcement of small diameter; its basis should be re-established by tests.

6. For each provision a specific, limited research programme is proposed. Most of the questions can be answered with existing test databases or with small test series; none requires changing the basic resistance models of the standard.

Conflicts of Interest

The author is Head of the Engineering Department of Adit Ltd, which supplies post-installed anchoring systems, and develops the AAS anchor design software. A change to the provisions discussed could affect the design of fastenings with such products. The author declares no other conflicts of interest.

References

- [1] CEN. EN 1992-4:2018 Eurocode 2 — Design of concrete structures — Part 4: Design of fastenings for use in concrete. Brussels: CEN; 2018.
- [2] fib. Design of anchorages in concrete. fib Bulletin 58. Lausanne: International Federation for Structural Concrete; 2011.
- [3] ACI Committee 318. Building Code Requirements for Structural Concrete (ACI 318-19) and Commentary. Farmington Hills, MI: American Concrete Institute; 2019.
- [4] CEN. EN 1992-1-1:2004 Eurocode 2 — Design of concrete structures — Part 1-1: General rules and rules for buildings. Brussels: CEN; 2004.
- [5] Eligehausen R, Mallée R, Silva JF. Anchorage in Concrete Construction. Berlin: Ernst & Sohn; 2006.
- [6] Grosser PR. Load-bearing behavior and design of anchorages subjected to shear and torsion loading in uncracked concrete. Doctoral thesis, University of Stuttgart; 2012.
- [7] De Lathouwer Y. Where Are the Cracks in the Definition of 'Cracked Concrete'? Zenodo; 2026. [doi:10.5281/zenodo.22172139](https://doi.org/10.5281/zenodo.22172139)
- [8] De Lathouwer Y. The Pry-Out Factor: A Critical Re-examination of the Link Between Tension and Pry-Out Resistance in EN 1992-4. Zenodo; 2026. [doi:10.5281/zenodo.22772444](https://doi.org/10.5281/zenodo.22772444)
- [9] De Lathouwer Y. Does the Front Row Carry It All? Concrete Edge Failure of Multi-Row Anchor Groups in EN 1992-4. Zenodo; 2026. [doi:10.5281/zenodo.22936315](https://doi.org/10.5281/zenodo.22936315)
- [10] Bokor B, Sharma A, Hofmann J. Experimental investigations on the concrete edge failure of shear loaded anchor groups of rectangular and non-rectangular configurations. Engineering Structures 2020;222:111153. [doi:10.1016/j.engstruct.2020.111153](https://doi.org/10.1016/j.engstruct.2020.111153)
- [11] Bokor B, Sharma A, Hofmann J. Concrete edge failure of anchor groups placed parallel to an edge. ACI Structural Journal 2021;118(2):237–248. [doi:10.14359/51728193](https://doi.org/10.14359/51728193)
- [12] Bokor B, Sharma A, Hofmann J. Nonlinear spring modelling approach for concrete edge breakout failure of shear loaded anchorages of arbitrary configurations. Engineering Structures 2023;279:115608. [doi:10.1016/j.engstruct.2023.115608](https://doi.org/10.1016/j.engstruct.2023.115608)
- [13] ETA-12/0397. European Technical Assessment for the MTP-G / MTP-X torque-controlled expansion anchors (values as held in the AAS product database).
- [14] Morgan RT. Shear concrete breakout calculations for anchorages with multiple rows. STRUCTURE magazine, January 2024.

- [15] Sharma A, Eligehausen R, Asmus J. Experimental investigation of concrete edge failure of multiple-row anchorages with supplementary reinforcement. Structural Concrete 2017. [doi:10.1002/suco.201600015](https://doi.org/10.1002/suco.201600015)
- [16] fib. fib Model Code for Concrete Structures 2010. Berlin: Ernst & Sohn; 2013.
- [17] DAfStb. Commentary to EN 1992-4 — Design of fastenings for use in concrete. DAfStb Heft 615. Berlin: Beuth; 2019.
- [18] Adit Ltd. AAS — anchor design software (EN 1992-4 and AAS methods). eng.adit.org.il (English); www.adit.org.il (Hebrew)
- [19] European Commission, Joint Research Centre. Second generation of the Eurocodes — timeline. eurocodes.jrc.ec.europa.eu

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