Where Are the Cracks in the Definition of "Cracked Concrete"?

A Critical Review of the Normative Basis for the Cracked-Concrete Default in Post-Installed Anchor Design, and the Case for a Probabilistic Classification

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Abstract

EN 1992-4 permits a fastening to be designed for uncracked concrete only where the absence of cracking can be demonstrated over the whole anchorage depth; in the absence of that demonstration the concrete is taken as cracked. In practice the demonstration is rarely attempted, and the cracked assumption has hardened into a near-universal default. The design consequence is substantial: the characteristic concrete cone resistance in cracked concrete is approximately 70 % of the uncracked value, and for bonded fasteners the declared bond resistance in cracked concrete is commonly one half to two thirds of the uncracked value. This paper examines whether the default is proportionate to the evidence supporting it. Five observations are developed. First, both EN 1992-1-1 and EN 1992-4 define the reference crack by its width (0.3 mm) and are silent on its depth, so a shallow surface crack and a crack traversing the full section are treated identically, although their effect on an embedded fastener is not. Second, the guidance issued by the British Board of Agrément (Guidance No. 39) already frames the question probabilistically — as a joint probability involving the location of the crack, the variability of imposed load in time and space, and the independence of the fastening load from that imposed load — a framing that the Eurocode's binary classification discards. Third, a real flexural crack is wedge-shaped: it is widest at the tensile face and closes to zero at its tip, so a crack of 0.3 mm at the surface is necessarily narrower at every depth below it, whereas the qualification specimen is cracked to approximately uniform width through the member. The two geometries are mutually exclusive. Fourth, the action required to open a crack of 0.3 mm has never been related to the depths at which fasteners are installed; worked examples given here show that the reference crack corresponds to a steel stress of 300 to 350 N/mm², some 70 to 80 % of design yield, so that a slab in ordinary service carries surface cracks of 0.14 to 0.23 mm and engages, over a typical anchorage, a mean width under half the value at which the fastener was assessed. For a fastening loaded purely in shear the fastener contributes nothing to opening the crack at all, and none of the three checks that can then govern draws on any parameter obtained from testing in cracked concrete. Fifth, recent experimental work on the contribution of supplementary and surface reinforcement indicates that the cone model underlying the classification omits a resistance mechanism that is systematically present in real members. A worked example from a current European Technical Assessment shows the same pattern in the pry-out check, where the declared product-specific factor places the pry-out resistance permanently above the fastener's own steel resistance, so that the failure mode the factor quantifies cannot be produced by the product it describes. The paper also notes, as a limitation of the evidence base rather than as an allegation, that the great majority of anchor testing is funded by manufacturers whose commercial interest is served by the more onerous classification. In place of the binary default a graded framework of factors is proposed, ordered so that the condition of the member decides whether a crack of the reference kind can be present at all, the geometry of the anchorage decides how much of it the fastener would engage, and the properties of the connection

modify probability and consequence without ever deciding the classification on their own. Its boundaries are stated explicitly: seismic design, and any case of genuine doubt, remain cracked.

Keywords: post-installed anchors; cracked concrete; EN 1992-4; concrete cone failure; crack depth; supplementary reinforcement; probabilistic design; crack geometry; shear loading; pry-out failure; BBA Guidance No. 39; fastening technology

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1. Introduction

The classification of the base material as cracked or uncracked is one of the earliest decisions taken in the design of a post-installed fastening, and one of the most consequential. It is taken before the anchor is selected, it constrains the selection that follows, and it propagates directly into embedment depth, edge and spacing requirements, the number of fixing points and, ultimately, cost. In the author's commercial experience the difference between the two classifications routinely multiplies the cost of a fastening by a factor of two to four, because the reduced resistance must be recovered through larger diameters, deeper embedment, denser anchor patterns, or a move from a mechanical to a bonded system.

There is no dispute about the underlying physical phenomenon. That a crack passing through the anchorage zone reduces the load-bearing capacity of a fastener has been demonstrated repeatedly, is well understood mechanically, and is embedded in the European design and qualification framework. The question posed here is a different one. It is not *what the resistance of an anchor installed in a crack is*, but *what the probability is that an anchor in an ordinary application will in fact be installed in a crack of the kind the standards describe, and to the depth they implicitly assume.* The first question has been answered extensively. The second has scarcely been asked.

The distinction matters because the European framework converts a continuous, probabilistic reality into a binary switch, and then sets the default position of that switch to the conservative side. Conservatism in isolation is unobjectionable and often correct. Conservatism applied universally, at significant cost, on the basis of a condition whose actual frequency of occurrence has not been quantified, is a different proposition and deserves examination.

This paper proceeds as follows. Section 2 sets out what the normative documents actually say, and identifies what they conspicuously omit. Section 3 recovers an older, explicitly probabilistic reading of the same problem from the guidance of the British Board of Agrément. Section 4 addresses the provenance of the underlying evidence. Sections 5 and 6 examine, respectively, where cracks form in real members and when a crack actually governs the failure mode. Section 7 examines the pry-out check as a worked instance of the same pattern. Section 8 advances a hypothesis, clearly identified as such, concerning the role of the anchor type itself in crack formation. Section 9 proposes a graded framework of factors for classification in place of the binary default, and Section 10 states the limitations of the argument.

2. The normative framework

2.1 The crack width: EN 1992-1-1

EN 1992-1-1, 7.3.1, establishes crack control for reinforced concrete by reference to a limiting calculated crack width *w*max, for which the recommended value in the common exposure classes is 0.3 mm under the quasi-permanent load combination. This is a serviceability criterion concerned with durability and appearance. It is a statement about what is tolerated at the surface of a member, not a statement about the internal geometry of the crack, and still less a statement about the state of the concrete at an arbitrary depth below that surface.

2.2 The concrete condition: EN 1992-4

EN 1992-4:2018, 4.7, governs the determination of the concrete condition for fastenings. Two provisions are decisive. The first is the default: it is stated to be conservative to assume that the concrete is cracked over the service life of the fastening, and this is the position taken unless the alternative is demonstrated. The second is the demonstration itself, which requires that in the region of the anchorage, under the characteristic actions at the serviceability limit state,

$$\sigma_L + \sigma_R \leq \sigma_{adm}$$

where σ_L is the tensile stress from external loading including the action of the fastener, σ_R is the stress from restrained deformation (taken as 3 N/mm² where it is not calculated in detail), and σ_{adm} is the admissible tensile stress, for which the recommended value is zero. The recommended value of zero is what makes the demonstration difficult in practice: it requires that the concrete in the anchorage region be shown to be in compression, or at least free of net tension, over the entire embedment depth. Any restraint of any kind, unless separately quantified, consumes the entire allowance by itself.

The structure of the clause is therefore not "cracked unless proven otherwise" in a loose sense, but a genuine verification requirement with a default that engages whenever the verification is not performed. Since the verification requires information about restraint that is frequently unavailable to the fastening designer — who is typically neither the designer of the member nor in possession of its as-built stress state — the default engages almost always. The universality of the cracked classification is thus, in large part, an artefact of who performs the calculation and what information reaches them, rather than a finding about the concrete.

2.3 Qualification: the reference crack

The corresponding qualification framework is consistent with this. Under the European Assessment Documents governing mechanical and bonded fasteners, products intended for use in cracked concrete are assessed in test members in which cracks of width 0.3 mm are induced through the anchorage, with crack-cycling regimes typically opening and closing the crack between approximately 0.1 mm and 0.3 mm. The characteristic resistances declared in the European Technical Assessment for the cracked condition are the resistances measured under that regime. The relevant assessment documents and technical reports are collected, in their current versions, in the Adit standards and booklets library.

It should be noted precisely what this test configuration represents. A crack is induced in a comparatively thin test member and is opened, by design, *through the full depth of the anchorage*. The reference condition is therefore not a crack of unspecified depth; it is, in effect, a crack that traverses the embedment. That is a legitimate and deliberately severe qualification condition. It becomes a source of error only when the classification rule that invokes it — a 0.3 mm surface crack — is satisfied by a physical condition that is far less severe.

2.4 The magnitude of the penalty

The design consequence of the classification is not marginal. For concrete cone failure under tension, EN 1992-4 expresses the characteristic resistance of a single fastener in the general form

$$N^{0}_{Rk,c} = k_1 \cdot f_{ck}^{0.5} \cdot h_{ef}^{1.5}$$

with the factor k1 taking a cracked and an uncracked value. The ratio between them is approximately 0.70:

Fastener type	Cracked concrete	Uncracked concrete	Ratio
Cast-in headed fasteners	8.9	12.7	0.70
Post-installed fasteners (values declared in the ETA; typical)	7.7	11.0	0.70

Table 1. Values of the factor k1 for concrete cone resistance in cracked and uncracked concrete. For post-installed fasteners the governing values are those declared in the product's European Technical Assessment; the figures shown are the customary ones.

For bonded fasteners the penalty is generally larger and more variable, the characteristic bond resistance declared for cracked concrete commonly falling to between one half and two thirds of the uncracked value, with the precise ratio product-specific and stated in the European Technical Assessment. A designer using an EN 1992-4 calculation engine — for example the freely available [AAS anchor design application]() — can observe the effect directly by toggling the concrete condition on an otherwise identical model.

2.5 What the standards do not say: crack depth

Neither EN 1992-1-1 nor EN 1992-4 attaches any depth to the crack that defines the cracked condition. The width is specified; the depth is not mentioned. This is the central omission of the present framework, and it has a specific and asymmetric consequence.

Crack width at the surface and crack depth are not independent quantities in reinforced concrete, but neither are they equivalent. A flexural crack in a reinforced member propagates to the neutral axis and is arrested there; a restraint or shrinkage crack in the cover zone may be almost entirely superficial; a plastic-settlement or thermal surface crack may be a few tens of millimetres deep while presenting a fully compliant 0.3 mm width at the surface. All three satisfy the classification rule identically. Their effect on a fastener embedded 80, 120 or 200 mm below that surface is not remotely identical.

The framework therefore contains a genuine internal inconsistency. The classification criterion is a surface measurement of width; the qualification condition to which that criterion leads is a crack that traverses the anchorage. Between the two lies the entire population of cracks that are wide enough to trigger the classification and too shallow to justify the penalty it imposes. No provision in either standard distinguishes them.

2.6 The geometry of a real crack: width is not constant with depth

A second omission follows from the first, and is if anything more damaging, because it concerns not what the standards leave unsaid but what they implicitly assert. A flexural crack in a reinforced member is not a slot of constant width. It is a wedge: widest at the tensile face, narrowing continuously with depth, and closing to zero at its tip. The width is a function of the strain at the level considered, and the strain in a member with a bending gradient decreases from the tensile face towards the neutral axis. If the width at the surface is w_0, then the width at any depth z below that surface is smaller than w_0, and beyond the crack tip it is zero.

The classification is triggered by the surface value. EN 1992-1-1 limits the calculated crack width to 0.3 mm at the face of the member, and EN 1992-4 adopts the same figure as the reference condition. It follows directly that a fastener embedded below that surface is, in a flexurally cracked member, never exposed to a crack of 0.3 mm. It is exposed to whatever remains of the crack at its own depth, which is less — often very much less — and to nothing at all beyond the crack tip.

The qualification specimen behaves in the opposite way. Cracks in anchor test members are induced by applying tension across the specimen, so that the crack forms through the thickness and is opened and held at the nominal width by monitoring at the anchor position. The resulting geometry is a crack of approximately uniform width along the whole anchorage. That is not an approximation of a flexural crack of the same surface width; it is a different object.

The two conditions are, in a flexural member, mutually exclusive, and this can be stated without any experimental support at all. Either the crack measures 0.3 mm at the surface, in which case it is narrower than 0.3 mm at every point along the embedment and the qualification condition overstates it; or the crack measures 0.3 mm at the depth of the embedment, in which case it is wider than 0.3 mm at the surface and the member has already breached the crack-control limit that defines the classification. The framework cannot have both. It nevertheless invokes the first to trigger the classification and reproduces the second to determine the resistance.

The consequence is a second layer of conservatism sitting on top of the first, and an unquantified one. The cracked classification reduces the resistance by roughly 30 % for cone failure; the reduction was measured under a crack geometry more severe than the one the classification describes. How much more severe depends on the ratio of embedment to crack depth and on the strain gradient in the member, both of which are calculable for a given section and neither of which appears anywhere in the classification rule.

This argument is confined to cracking driven by a strain gradient, which includes flexural cracking and most cracking in slabs and beams. Where a crack is caused by axial restraint or by imposed deformation in a member with little bending gradient — a wall restrained along its base, a member in direct tension, an early-age restraint crack through a thin section — the width may indeed be close to uniform through the thickness, and there the qualification geometry is representative. The question is therefore again one of proportion: what share of anchorages sits in each class. That share has not been measured, which returns the argument to the gap identified in Section 4.

2.7 What action does the reference crack require? Two worked examples

The classification asks whether a crack of 0.3 mm may occur. It does not ask what action is required to produce one. That calculation is elementary — it follows from the crack-width provisions of EN 1992-1-1, 7.3.4 — and it is performed here in two configurations, because the answer bears directly on how often the reference condition is actually reached. The examples are illustrative of the magnitudes involved and are not offered as general results.

Example 1: flexural cracking in a suspended slab. Take a 200 mm slab in C30/37 with Ø12 at 150 mm in the tension face and 25 mm cover. The provisions give a maximum crack spacing of 234 mm, and the steel stress required to open a crack of 0.3 mm is 348 N/mm² — about 80 % of the design yield strength. The quasi-permanent moment corresponding to that stress is roughly 41 kNm/m, some 80 % of the section's bending capacity at the ultimate limit state. A 300 mm slab with Ø16 at 150 mm gives the same picture: 303 N/mm², about 70 % of design yield, at roughly 70 % of ultimate capacity.

The first finding follows immediately. The 0.3 mm reference crack corresponds, under the quasi-permanent combination in which crack width is checked, to a steel stress of roughly 300 to 350 N/mm². That is not a service condition; it is close to the ultimate one. A slab in ordinary service, at a quasi-permanent steel stress of 200 to 250 N/mm², carries surface cracks of 0.14 to 0.23 mm. The reference crack is therefore not the crack a normally loaded member exhibits — it is the crack a member exhibits at the top of its permitted range, and the classification applies it to every member regardless of where in that range the member sits.

The second finding is a correction to the argument of Section 2.5 and should be stated plainly. In both examples the crack depth is 81 to 83 % of the section — 165 mm in the 200 mm slab, 242 mm in the 300 mm slab. A flexural crack does reach the neutral axis, and for a fastening installed from the tensile face it therefore passes the entire anchorage. Crack depth is not, in that configuration, the protection. The protection is the width, and this is where the wedge geometry of Section 2.6 becomes the operative argument rather than a refinement of it.

Taking the 200 mm slab, assuming the width tapers linearly to zero at the neutral axis, and evaluating both at the reference condition and at a normal quasi-permanent steel stress of 250 N/mm²:

hef (mm)	Mean width over the anchorage at the reference condition (mm)	Mean width over the anchorage at σs = 250 N/mm² (mm)
60	0.245	0.151
80	0.227	0.140
120	0.191	0.118

Table 2. Crack width actually engaged by the anchorage, 200 mm slab in C30/37 with Ø12 at 150 mm, fastening installed from the tensile face. The reference condition is a surface width of 0.3 mm; the service column corresponds to a quasi-permanent steel stress of 250 N/mm², which produces a surface width of 0.185 mm.

For the commonest case of all — a hanger under a 200 mm slab at an effective embedment of 80 mm — the mean crack width engaged by the anchorage under quasi-permanent loading is about 0.14 mm, under half the width at which the fastener was assessed. The fastener is assessed at 0.3 mm through the anchorage; it experiences roughly 0.14 mm averaged over it. That factor is not recognised anywhere in the classification.

Example 2: restrained cracking of approximately uniform width. This is the case identified in Section 2.6 as the one in which the qualification geometry is representative, and it is worth asking what it requires. Take a 250 mm wall in C30/37 with Ø12 at 150 mm in each face. The maximum crack spacing is 674 mm, and a crack of 0.3 mm requires a steel stress of 148 N/mm², corresponding to an axial tension of 224 kN/m. But the force that first cracks the section is the section area times the mean tensile strength, 725 kN/m; were that force applied and fully transferred to the reinforcement, the steel stress would be 481 N/mm², beyond yield, and the resulting crack would be of the order of a millimetre rather than 0.3 mm. The reinforcement provided is half the 3 020 mm²/m that EN 1992-1-1, 7.3.2, would require for controlled 0.3 mm cracking in direct tension.

The resolution is that a uniform through-thickness crack of 0.3 mm is a deformation-driven state, not a force-driven one. The width is set by the restrained strain rather than by an applied load: with a crack spacing of 674 mm, a restrained strain of 4.5×10^{-4} produces it, which early-age thermal contraction together with restrained drying shrinkage can supply where the restraint is high. This is a real and thoroughly documented condition — it is the subject of the CIRIA guidance on restrained deformation cracking [11] and of EN 1992-3 for liquid-retaining and containment structures [12].

The conclusion is therefore not that uniform through-thickness cracking is theoretical. It is not. The conclusion is that it belongs to a definable class of member — walls and slabs cast into restraint, ground-bearing slabs, liquid-retaining and containment structures — and not to the suspended floors, beams and soffits in which the great majority of post-installed fastenings are made. In the flexural members that dominate the anchor population, the wedge geometry holds and the reference crack is reached only near the top of the member's permitted service range. The classification rule asks neither which class of member is involved nor where in its service range it sits.

3. A probabilistic reading: BBA Guidance No. 39

The binary treatment is not the only one that has been offered by a recognised body. Guidance No. 39 of the British Board of Agrément, *Anchor Bolts for Use in Concrete* (Issue 4, 2015), addresses the same question in explicitly probabilistic terms. A copy is available here. Three of its statements bear directly on the argument.

On existing buildings, the guidance states:

> *"In an existing building in use, ie where decanting does not take place, anchors can be installed in any location provided it is unlikely that a significant increase in loading will occur after the installation of anchors."* — BBA Guidance No. 39

The permission is unqualified as to location, and by its plain reading extends to anchors assessed for uncracked concrete only. The condition attached is not a condition about the concrete but about the *future* — the absence of an expected significant increase in load after installation. This is a substantively different criterion from the Eurocode's, and a more physically reasoned one: cracking that matters to an installed anchor is cracking that occurs, or widens, after the anchor is in place.

On the nature of the loading:

> *"Imposed loads applied to floors vary with time and space and thus any realistic consideration of loading will be in terms of probability."* — BBA Guidance No. 39

And on the relationship between the two load systems:

> *"The load carried by anchors is generally independent of the imposed loading applied to the structure and thus there is joint probability involved."* — BBA Guidance No. 39

The last of these is the most consequential and the most neglected. For a crack to reduce the resistance of a fastening in a manner that threatens the design, several conditions must hold simultaneously: a crack must form in the anchorage region; it must extend to a depth comparable with the embedment; it must be open, at the relevant width, at the moment the fastening is at or near its design load; and the fastening must at that moment be loaded in the direction and by the mechanism for which the crack is detrimental. These are not perfectly correlated events. The Eurocode treats them as though they were certain and simultaneous.

Two further probabilistic observations follow from the same reasoning. Cracks in a reinforced member form at broadly regular spacing governed by the reinforcement and the cover, so whether a particular anchor position coincides with a crack is itself a spatial-probability question; and the greater the number of fixing points sharing a load, the lower the probability that the connection as a whole is compromised, since the load shed by one unfavourably located anchor is redistributed among the remainder. A single short anchor in a tension zone and a group of twelve are not the same problem, yet the classification rule does not distinguish them.

4. The provenance of the evidence base

A limitation of the literature on this subject should be stated plainly, and stated as a limitation rather than as an allegation of misconduct. The overwhelming majority of experimental work on the behaviour of post-installed fasteners in cracked concrete has been commissioned, funded or performed by, or in collaboration with, the manufacturers of those fasteners. This is not surprising and is not in itself improper: the testing is expensive, the equipment is specialised, and the industry laboratories are among the most competent in the field. The qualification system itself requires manufacturers to fund the assessment of their own products.

The relevant point is narrower. The commercial consequence of the cracked classification is a substantially larger, deeper or more expensive fastening. The parties who fund the research are the parties whose revenue increases under the more onerous classification. That configuration does not invalidate any individual result, and the mechanical findings on anchor behaviour in an open crack are, in the author's assessment, sound and reproducible. What it does affect is the *research agenda* — which questions are asked, and which are not.

Specifically, the question that has been researched exhaustively is: what is the resistance of an anchor in a crack of width w? The questions that have attracted comparatively little investment are: what is the observed frequency, in real structures, of cracks of that width at the depths at which anchors are installed; what proportion of anchors in service are in fact intersected by such a crack; and what is the reliability index actually achieved by a population of fastenings designed as uncracked in members classified as cracked? An evidence base can be entirely honest in every measurement it reports and still be systematically incomplete in what it chooses to measure. That, rather than any impropriety, is the criticism advanced here.

The present paper is subject to the mirror image of the same caution, and the declaration of interests states the author's own interest explicitly.

5. Stress state and anchor location: the limits of the beam idealisation

The mental model that underlies most practical classification decisions is the simply supported beam: the upper fibre in compression, the lower fibre in tension. From it follows the familiar rule of thumb that a fastening into a soffit is into tensile concrete and must be treated as cracked, while a fastening into the top surface of a slab is into compressed concrete and may be treated as uncracked. The rule is a reasonable first approximation and is wrong in a substantial number of ordinary cases.

- It does not hold in prestressed members, in which the intended stress state is compression throughout or over most of the depth. Hollow-core and other prestressed floor units are among the most common substrates for post-installed fastening and are precisely the case in which the rule of thumb misdirects.
- It does not hold near supports. Flexural tension and compression both diminish towards a support, and over a continuous support the sign reverses, so that it is the concrete at the top of the member that is in tension. Where the supports are not at the ends of the member — cantilevered ends, propped conditions — the distribution changes again.

- It ignores the through-depth gradient. Flexural stress is greatest at the extreme fibres and passes through zero at the neutral axis. A fastening is not a point at the surface; it engages a length of concrete.
- It ignores the relationship between embedment depth and the depth of the zone in question. Consider a 400 mm member in which, on the simplified model, the upper 200 mm is in tension and the lower 200 mm in compression. A fastener with an effective embedment of 300 mm installed from the soffit passes through the compression zone and terminates within the tension zone; the same fastener installed from above does the reverse. In both cases the anchorage spans both zones, and the binary classification of the member has little to say about the concrete that actually resists the fastener.

The conclusion is not that the stress state is irrelevant — it is the single most important indicator available — but that the classification should be made for the *region of concrete engaged by the anchorage*, over its actual depth, and not for the member as a whole on the basis of which face the installer approaches from.

6. When does a crack actually govern?

6.1 Cone failure and crack geometry

For concrete cone failure the mechanism by which a crack reduces resistance is clear and is not in dispute. The cone is a tensile failure surface propagating from the embedded end of the fastener to the concrete surface. A crack lying in the plane of that surface, or intersecting it, splits the cone: part of the failure surface is pre-formed, the tensile resistance across it is already exhausted, and the measured resistance falls accordingly. The reduction embodied in the k1 factors of Table 1 is a reasonable representation of that effect for a crack that traverses the cone.

The severity of the effect is, however, a function of how much of the cone the crack actually intersects. A crack whose depth is a small fraction of the effective embedment intersects only the outermost, and geometrically largest but mechanically least critical, portion of the failure surface. The standards make no provision for this gradation, because they record no crack depth at all.

6.2 The omitted contribution of reinforcement

A second, independent source of conservatism in the cracked-concrete model is that the concrete cone equations of EN 1992-4 take no account of the reinforcement crossing the failure surface, unless that reinforcement is explicitly designed and detailed as supplementary reinforcement to a specific set of rules. In an ordinary reinforced member the cone is crossed by flexural and distribution reinforcement whose function is precisely to carry the tension the model assumes must be carried by concrete alone.

Two bodies of recent experimental work bear on this. Sharma, Eligehausen and Asmus [4], reporting a large programme of tests on anchorages with supplementary reinforcement, demonstrate that reinforcement crossing the breakout body materially increases the resistance and alters the failure mode, and that the code treatment is markedly conservative where such reinforcement is present. Nilforoush, Nilsson and Elfgren [5] examined the influence of member thickness, anchor-head size and orthogonal surface reinforcement on the tensile capacity of headed anchors, and found that surface reinforcement raises the breakout capacity, with its relative contribution increasing as the member becomes thinner.

Combining the two findings with the crack-depth argument of Section 2.5 produces a useful result, because the two effects act in the same direction across the whole range of member thickness. In a thick member, the reinforcement contribution is proportionally smaller, but the member is normally more heavily and more closely reinforced, and the embedment is a smaller fraction of the depth; in a thin member the reinforcement contribution is proportionally larger, and a crack is correspondingly less likely to develop to a depth comparable with the embedment. Neither limb of the argument depends on the other, and neither is captured by the classification.

Related work by the same groups examines the adjacent cases: the combined effect of surface reinforcement, member thickness and cracked concrete on anchor bolts [6], and concrete edge failure of multiple-row anchorages with supplementary reinforcement [7].

It should be stated that neither cited study set out to test the cracked-concrete classification, and neither should be read as endorsing the position taken here. They are cited for the narrower proposition that the cone model omits a resistance mechanism that is systematically present in real members, which is relevant to any assessment of how much additional conservatism the cracked default supplies.

6.3 The action required to open the crack, and the case of pure shear

The classification asks whether a crack of 0.3 mm may occur in the anchorage region. It does not ask what action is required to produce one, nor how far into the section that action carries it. Those are ordinary questions of reinforced concrete mechanics and are answerable for any given section: the depth of a flexural crack is fixed by the position of the neutral axis under the governing combination, and the width at the tensile face by the strain and the reinforcement detailing. From these it is possible to compute, for a stated section, the bending moment required to open a crack of 0.3 mm and the depth to which that crack then extends.

No such computation appears in the literature the author has been able to locate, and no study relates the action required to reach a given crack depth to the distribution of embedment depths actually used in practice. This is a striking absence, because the calculation is elementary and would immediately bound the problem. It would show, for each common section and reinforcement arrangement, whether the load level at which a crack reaches the depth of a typical anchorage is one the member will plausibly see in service — and in most sections a substantial part of the depth is in compression under any realistic combination, so that a crack extending to 80 or 120 mm requires an action considerably greater than the one that first cracks the surface.

The fastening’s own load is a second and independent contributor to the same question, and here the direction of loading is decisive. A fastener loaded in tension applies tension to the concrete surrounding the anchorage and can, in principle, extend or open a crack in it. A fastener loaded purely in shear does not. Its load is transferred to the concrete in bearing over a short length near the surface and, resolved on the plane of a crack running normal to that surface, contributes nothing to opening it. Whatever crack exists in the anchorage region of a purely shear-loaded fastening exists because of the member, not because of the fastening.

This has a consequence for the qualification requirement that is worth stating precisely, because it is easily overstated. The crack-related part of a fastener’s assessment for cracked concrete is a crack-cycling regime in which the crack is repeatedly opened and closed while the fastener carries tension, and what it tests is whether the fastener maintains its expansion force and follows up as the crack opens. That mechanism is a tension mechanism. In a fastening that carries no tension, it does not arise: there is no preload to lose and no follow-up expansion to demand.

The concrete-side reductions are a different matter and remain fully applicable, because they are properties of the concrete rather than of the fastener. EN 1992-4 reduces the concrete edge failure factor from 2.4 to 1.7 when the concrete is cracked, and pry-out is computed as a multiple of the concrete cone resistance, which carries its own cracked and uncracked values. Nothing in the present argument suggests that a designer may ignore these.

What remains is a narrower and, in the author's view, unanswered question. For a fastening in which tension is demonstrably absent, the failure modes available are steel rupture in shear, pry-out, and concrete edge breakout. The first is a property of the steel; the second and third are, in the code's own formulation, geometric. In that configuration the fastener behaves computationally as a steel dowel embedded to a stated depth, and it is not clear what mechanism the requirement for a cracked-concrete assessment of the product is protecting against, given that none of the three governing checks depends on the behaviour that assessment tests.

Two qualifications are necessary. First, a fastening described as purely shear-loaded seldom is: prying from a stand-off, restraint of the fixture, the rope effect at large displacements and the fastener's own installation preload all introduce tension, and the proposition should be confined to cases where tension is demonstrably absent or negligible. Second, the question raised is about the qualification requirement attaching to the product, not about the numerical reductions attaching to the concrete, and it should not be read as licence to disregard the latter.

6.4 The three shear checks, parameter by parameter

The claim just made — that none of the governing checks depends on the behaviour the cracked-concrete assessment tests — should not be left as an assertion, because every parameter involved is already on the record and the claim can simply be checked. For a fastening whose loading is demonstrably confined to shear, three checks can govern, and none of them requires a value obtained from testing in cracked concrete.

- Steel failure in shear is a property of the fastener's steel. The characteristic value declared in an assessment does not vary with the condition of the concrete, and no cracked-concrete test contributes to it.
- Concrete edge failure is computed from the edge distance, the outside diameter of the fastener and its load-transfer length, together with the concrete strength. The cracked and uncracked cases differ by the factor k9 — 1.7 against 2.4 — which is a value of the standard, not a declared product property. The two product parameters that enter, dnom and lf, are dimensions, and they are the same dimensions in cracked concrete as in uncracked.
- Pry-out is computed as k8 times the concrete cone resistance. The factor k8 characterises the fastener's stiffness and displacement behaviour in shear; there is no reason for it to differ between cracked and uncracked concrete, and no assessment the author has examined declares separate values for the two conditions. The cracked reduction enters through the cone term, and for post-installed fasteners it enters as kcr,N, a value the standard itself supplies. In any event, as Section 7 shows, the pry-out check does not govern once it is compared with the steel resistance.

The proposition follows. Where the loading is genuinely confined to shear, there is no computational impediment to using a fastener assessed for uncracked concrete only in a member classified as cracked. Everything the calculation requires is either a property of the steel, a dimension, or a factor of the standard. The mechanism that the cracked-concrete assessment exists to demonstrate — that the fastener maintains its expansion force as a crack opens and closes under tension — is never exercised, and its absence changes none of the three numbers.

Two limits on that proposition must be stated, and the first must be stated accurately, because it is easy to get wrong. The bar is formal, not computational. Every quantity the three checks require is in fact available for a fastener assessed in uncracked concrete only. The steel resistance in shear is declared and does not change with the condition of the concrete. The two product parameters in the edge-failure equation, dnom and lf, are dimensions and are declared; the cracked value of k9 belongs to the standard. In pry-out, k8 is declared and there is no reason for it to differ between the two conditions, and the cracked cone factor kcr,N is the generic value the standard gives for post-installed fasteners rather than a measured product property — ETA-11/0374 records it as not assessed, but the value it would take is not in dispute, and the same assessment adopts the generic uncracked value of 11.0 for the corresponding uncracked case. The calculation could therefore be carried out today, in full, with nothing invented and nothing borrowed from a product that was not tested.

What prevents it is the scope of the assessment, not a gap inside it. EN 1992-4 requires a fastener suitable for cracked concrete wherever the concrete is cracked, and an assessment covering uncracked concrete only does not cover that use, whatever the arithmetic would show. The prohibition is formal. That is precisely why the point is addressed to the bodies that set the scope rather than to the engineer: the obstacle they maintain is one of authorisation, and the usual justification for such an obstacle — that the information needed to design safely is not available — does not hold for a fastening loaded in pure shear. Nothing here entitles a designer to disregard the requirement; the requirement is simply not doing the work it is assumed to do.

One substantive reservation does survive, and it concerns the installed state rather than the calculation. An expansion fastener that loses preload as a crack opens and closes is no longer in the condition in which it was assessed, even though its resistance in shear is largely unaffected by that loss. Whether that matters over a service life is a question about long-term serviceability and about displacement under repeated loading, and it is a legitimate reason to require crack-cycling qualification of a fastener that will sit in a moving crack. It is not, however, a reason expressed in any of the three resistance checks, and it should be argued on its own terms rather than through a classification rule that does not mention it.

The second limit is the one set out in Section 6.3: the proposition is confined to fastenings in which tension is demonstrably absent. That is a stricter condition than it sounds, and it excludes stand-off connections, large-displacement configurations, and any arrangement in which the fixture is restrained.

7. Pry-out: a product-specific factor for a geometric mechanism

The pattern identified above — a coefficient introduced to represent a physical condition, calibrated in tests the designer cannot inspect, and applied in a form whose basis is not verifiable from the document that declares it — is not confined to the cracked-concrete classification. The pry-out check offers a compact worked example, and one in which the difficulty can be demonstrated arithmetically from a current European Technical Assessment rather than argued.

EN 1992-4 expresses the characteristic pry-out resistance of a fastening in shear as a multiple of its concrete cone resistance in tension,

$$V_{\mathrm{Rk,cp}} = k_8 \cdot N_{\mathrm{Rk,c}}$$

with default values of k_8 = 1 for h_{ef} < 60 mm and 2 for h_{ef} ≥ 60 mm. The assessment documents permit a product-specific value to be declared in place of the default where it is supported by testing, and manufacturers do declare higher values.

Consider the values declared for a widely used torque-controlled expansion anchor, the Hilti HSA, in ETA-11/0374 of 27 October 2023 [10]. For size M16 the assessment declares k_8 = 2.9 at all three setting depths, characteristic concrete cone resistances in uncracked concrete of 25.8, 35.2 and 50.0 kN at effective embedments of 65, 80 and 120 mm, and a characteristic steel shear resistance of 51.0 kN. Taking a single fastener in C20/25 remote from edges, the pry-out resistance follows directly.

hef (mm)	**N0Rk,c (kN)**	**VRk,cp (kN)**	**V0Rk,s (kN)**	**VRk,cp / V0Rk,s**
65	25.8	74.8	51.0	1.47
80	35.2	102.1	51.0	2.00
120	50.0	145.0	51.0	2.84

Table 3. Pry-out resistance against steel shear resistance for the Hilti HSA M16 (HSA / HSA-BW), computed from the values declared in ETA-11/0374, Annexes C1 and C2, for a single fastener in uncracked C20/25 remote from edges. Applying the partial factors of the assessment (1.25 on steel, 1.5 on concrete), the corresponding design-level ratios are 1.22, 1.67 and 2.37.

Two observations follow, one methodological and one mechanical.

The methodological observation is that the pry-out resistance exceeds the fastener's own steel shear resistance at every declared embedment, by a factor of 1.5 to 2.8 at characteristic level and 1.2 to 2.4 at design level. The pry-out mode therefore cannot govern this fastener in this configuration. More importantly, it cannot be produced in a test on this fastener as supplied: loaded in shear, the shank ruptures long before the concrete levers out. A factor obtained from testing must have been obtained under conditions in which the observed failure actually was pry-out, which for this product would require substitute shear elements of higher steel grade, concrete weaker than the reference grade, or an embedment shorter than any the assessment declares. Which of these applies is not stated in the assessment, and the designer using the value has no way to establish it. The factor is declared as a characteristic of the product, yet the failure mode it quantifies is one the product cannot reach.

It is worth noting how narrow the margin is under the code default. At the shallowest declared embedment, k_8 = 2 would give a pry-out resistance of 51.6 kN against a steel resistance of 51.0 kN — the two are, for practical purposes, equal. The product-specific value of 2.9 does not adjust a governing check; it moves the check permanently out of contention.

The mechanical observation is that pry-out is a concrete failure. The body of concrete that levers out behind the fastener is defined by the embedment depth and by the geometry of the breakout surface, in the same way that the body which breaks out towards a free edge is defined by the edge distance and the geometry of the edge cone. The code's own formulation makes this explicit: pry-out is not given an independent resistance function at all, but is written as a multiple of the tension cone resistance, which is itself purely geometric in h_{ef}. On the face of it there is no mechanism by which the expansion principle of the fastener changes the volume of concrete that levers out.

The standard's rationale should be stated fairly, because it is not empty. The factor k_8 is understood to reflect the fastener's stiffness and load-displacement behaviour under shear rather than the strength of the concrete: a fastener that deforms and redistributes at the surface does not develop the kinematics that lever out a cone, while a stiff fastener does. On that reading a product-specific value is legitimate, because what is being characterised is not the concrete but the manner in which the fastener delivers load to it.

The difficulty is that this reading, taken seriously, changes what the coefficient means. It makes k_8 a measure of how far the pry-out mode is from being reached for a given product — and a declared value that places the pry-out resistance permanently above the steel resistance is, on that reading, a statement that the mode is inapplicable. Expressing such a statement as a resistance factor multiplying a concrete cone resistance presents as a strength what is in substance a claim of inapplicability. It also leaves unanswered what, within the assessment, distinguishes a declared value of 2.9 from one of 2.4 or 3.5 when in each case the resulting resistance lies beyond the reach of the fastener's own steel.

The point of the example is not that the declared values are unsafe. They are not: the check they belong to is superseded by the steel check, and a designer who applies EN 1992-4 as written will arrive at a governing steel resistance and a correct answer. The point is that a coefficient presented as a measured product property, in a document a designer is required to rely on and not permitted to interrogate, may quantify a condition the product cannot be brought to exhibit. That is the same structural weakness identified in Section 4 for the cracked-concrete classification, appearing in a place where it can be demonstrated in three lines of arithmetic.

8. Anchor type as a variable in crack initiation: a hypothesis

The preceding sections concern the concrete. This section concerns the fastener, and is offered explicitly as a hypothesis for which the author has not located direct experimental confirmation.

Different fastening principles impose very different stress states on the surrounding concrete at installation. A torque-controlled expansion anchor — the ordinary wedge or through-bolt, and the heavy-duty expansion anchor — develops its hold by expanding a sleeve or clip against the wall of the hole. The installation torque generates a substantial and permanently maintained tensile field in the surrounding concrete, present in the absence of any external load and decaying over time to roughly 60 % of its initial value through relaxation. The practical evidence for the magnitude of this field is familiar to every installer: an expansion anchor set too close to a free edge can split the concrete during setting, before any service load is applied.

A concrete screw cutting its own thread, and a bonded (chemical) anchor, transfer load along the thread or the bond line respectively, and impose no comparable pre-tension: the concrete is stressed only when the fastener is loaded. Their zone of influence within the concrete is correspondingly narrower. Where such fasteners are loaded in service, the induced tension typically peaks at a small fraction — of the order of one third — of the fastener's resistance, whereas the installation-induced tension around an expansion anchor may approach the same order as its resistance.

The hypothesis is therefore as follows: the permanent installation-induced tensile field of torque-controlled expansion anchors, combined with their wider zone of influence, makes them more likely than screw or bonded fasteners to initiate or to widen a crack at their own location. If correct, this has an uncomfortable circularity for the classification debate, since the fastener type most often specified on the assumption of cracked concrete would be, in part, the agent of the condition it is designed to tolerate.

The hypothesis is testable. The comparison required is a matched set of expansion, screw and bonded fasteners installed in nominally uncracked members, with crack mapping of the anchorage region before installation, immediately after installation, and after a sustained interval, at a range of edge distances and embedment depths. The author is not aware that such a comparison has been published, and it is offered here as a proposal rather than as a finding.

9. A graded framework of factors for classification

What follows is a proposal for structuring the classification decision on the factors identified above, in place of a binary default. It is not a substitute for the verification required by EN 1992-4, 4.7, and where that verification can be performed it should be. It is offered for the ordinary case in which the verification cannot be performed for want of information, and the designer must otherwise fall back on the default.

Two boundaries are absolute and are stated first. In seismic design the concrete is taken as cracked in every case, without exception, and the fastener must hold the corresponding seismic assessment (C1 or C2). And wherever genuine doubt remains after the criteria below have been applied, the cracked classification is the correct engineering answer; the argument of this paper is that the doubt is often assumed rather than established, not that it can be assumed away.

For an anchorage in a concrete region under compression over its full embedment, the concrete is uncracked. For an anchorage in, or spanning, a region under tension, the following criteria are proposed.

Group	Factor	How it bears on the classification
The member	Stress state in the anchorage region: compression, low tension, or high tension	Decisive. Compression over the full embedment means uncracked. High tension — steel stress under the quasi-permanent combination approaching the range identified in Section 2.7 — means cracked.
The member	Prestress	Supports uncracked where the anchorage remains in compression under the relevant combination.
The member	Restraint, and cracking already present from imposed deformation	Supports cracked, and is the case in which the uniform through-thickness crack of the qualification regime is representative.
The member	Expected change of loading after installation	A significant expected increase supports cracked; its absence supports uncracked.
The member	Seismic design	Overrides everything else: cracked in all cases.
The anchorage	Embedment depth relative to the depth of the tension zone and to plausible crack depth	Determines how much of the anchorage a crack could engage; a deep anchorage reaching beyond the tension zone supports uncracked.
The anchorage	Position relative to supports and to the neutral axis	Determines whether the region is in tension at all, and at what magnitude.
The anchorage	Member thickness and reinforcement density crossing the breakout body	Does not change the classification, but reduces the consequence of an unfavourable one.
The connection	Number of fixing points sharing the load	Reduces the probability that the connection as a whole is compromised. Never sufficient on its own.
The connection	Fastener type: torque-controlled expansion against concrete screw or	Affects the probability that the fastener itself initiates or widens a crack, not whether the concrete

Group	Factor	How it bears on the classification
	bonded	is cracked. Never sufficient on its own.
The connection	Edge distance and the utilisation of the fastener	Affect the severity of any installation-induced tension. Never sufficient on its own.

Table 4. Factors bearing on the classification of the concrete condition, in place of a universal default. The groups are not equivalent in weight: the member factors decide whether a crack of the reference kind can be present at all; the anchorage factors decide how much of the anchorage it could engage; the connection factors modify probability and consequence only.

One qualification is essential to the stress-state factor, because without it the framework collapses back into the default it replaces. Reinforced concrete is, as a matter of routine, designed in the cracked state: the section analysis assumes the concrete carries no tension, and EN 1992-1-1 then controls the resulting crack width to 0.3 mm at the surface. That is true of very nearly every reinforced member ever built. It is therefore not a criterion at all — a test that every member passes discriminates nothing — and the reasoning “the concrete standard designs it cracked, therefore the concrete is cracked” is precisely the conflation this paper is concerned with. The design assumption concerns how the section is analysed; the fastening classification concerns whether a crack of a stated width is physically present along the anchorage. What the factor asks is therefore not whether the section was analysed as cracked, but whether the anchorage region carries tension of a magnitude that would actually open a crack of the reference width — a question the designer can answer from the steel stress under the quasi-permanent combination.

The ordering of the groups is the substance of the proposal, and it corrects a confusion that is easy to fall into — including in earlier formulations of this framework. A fastener type cannot make concrete uncracked. Whether a crack of the reference kind is present in the anchorage region is a property of the member and its history: the stress state, the prestress, the restraint, the loading it will see. The choice of a concrete screw or a bonded fastener in place of a torque-controlled expansion fastener changes the probability that the fastening itself initiates or widens a crack, and it changes the width of the zone the fastener disturbs, but it does not alter the condition of the concrete it is installed into. A factor in the third group therefore strengthens or weakens a classification that the first group has already established; it never establishes one by itself.

The decision that follows is accordingly ordered rather than cumulative. Establish first, from the member factors, whether a crack of the reference kind can be present in the anchorage region at all. If it cannot — the region is in compression over the embedment, or the member is prestressed and remains so, or there is no mechanism by which tension of the required magnitude could arise — the concrete is uncracked, and the remaining groups are not needed. If it can, ask from the anchorage factors how much of the anchorage such a crack would actually engage, using the width-against-depth relationship of Section 2.6 rather than the surface value. Only then do the connection factors enter, to judge how much the answer matters. And in seismic design, or wherever genuine doubt survives the sequence, the classification is cracked.

Where the classification remains finely balanced, the most productive response is usually not to argue it but to design it away — by increasing the number of fixing points, by increasing the embedment so that the anchorage extends beyond any plausible crack depth, or by selecting a fastening system that carries a cracked-concrete assessment at an acceptable resistance. The two classifications can be compared quantitatively for a given connection in a few minutes using an EN 1992-4 design tool such as AAS; the wider set of free design applications maintained by the author's firm is listed on the software index.

10. Limitations

Several limitations of the argument should be acknowledged. It rests on the interpretation of normative documents and on the mechanical implications of published experimental work, not on new experimental data; no tests were performed for this paper. The crack-depth argument, although mechanically straightforward, is not supported here by a quantitative distribution of crack depths in service structures, and the absence of such a distribution is precisely the gap in the evidence base identified in Section 4 — the argument therefore identifies a missing dataset rather than supplying it. The crack-geometry argument of Section 2.6 is analytical: it follows from the shape of a flexural crack and from the two provisions read together, and requires no measurement, but neither has it been accompanied here by measurements of width against depth in real members, which would establish how large the discrepancy is rather than merely that it exists. The argument of Section 6.3 concerning purely shear-loaded fastenings identifies a calculation that has not been performed rather than performing it, and is confined to the qualification requirement attaching to the product; it does not touch the concrete-side reductions. The pry-out example of Section 7 rests on a single European Technical Assessment for a single product family; whether the same relationship between declared factor and steel resistance holds across other products and other manufacturers has not been examined here, and the observation about how the factor could have been obtained is a question addressed to the assessment, not a finding about it. The hypothesis of Section 8 is unverified. The criteria of Section 9 are qualitative and have not been calibrated against a target reliability index; converting them into partial factors or into a formal reliability framework would require exactly the frequency data that is presently unavailable. Finally, national provisions differ, and nothing in this paper displaces a national annex, a specific European Technical Assessment, or the judgement of the engineer responsible for the structure.

11. Conclusions

The European standards defining cracked concrete are internally consistent between the concrete standard and the fastening standard: both define the condition by the possible occurrence of a crack of width 0.3 mm. Neither attaches a depth to that crack. The consequence is that a crack of trivial depth is sufficient to trigger the classification, while the qualification regime to which the classification leads reproduces a crack that traverses the anchorage. The standards do not distinguish surface cracking from through-depth cracking. In a flexural member the crack does reach the neutral axis, so for a fastening installed from the tensile face the depth is not the protection; what the fastening rules overstate there is the width, which over a typical anchorage under quasi-permanent load is well under half the reference value.

A further inconsistency lies in the geometry. A flexural crack is a wedge, widest at the tensile face and closing to zero at its tip, so a crack of 0.3 mm at the surface is narrower at every depth below it. The qualification specimen, by contrast, is cracked to approximately uniform width through the member. In a flexurally cracked section the two conditions cannot both hold: a crack of 0.3 mm at the depth of the embedment is wider than 0.3 mm at the surface and has already breached the limit that defines the classification. The framework triggers the classification on the first geometry and measures the resistance under the second.

Two further gaps concern loading rather than geometry. The action required to open a crack of 0.3 mm to a stated depth is calculable for any given section and has never been related to the distribution of embedment depths in use, although doing so would bound the problem directly. And for a fastening loaded purely in shear the fastener contributes nothing to opening the crack: the mechanism that the cracked-concrete assessment of the product tests — the maintenance of expansion force as a crack opens and closes under tension — does not arise, even though the concrete-side reductions properly continue to apply.

The pry-out check illustrates the same structural weakness in a form that can be checked arithmetically. A current assessment declares a product-specific factor which places the pry-out resistance of an M16 expansion anchor between 1.5 and 2.8 times its own steel shear resistance, so that the failure mode the factor quantifies cannot be produced by the product it describes. Nothing unsafe follows, since the steel check governs; but a coefficient presented as a measured product property, in a document the designer must rely on and cannot interrogate, may describe a condition the product cannot be brought to exhibit.

Three further conclusions follow. First, the classification is properly a probabilistic judgement about a joint event — crack present, crack deep, crack open, fastening loaded — and was recognised as such in BBA Guidance No. 39 before the binary Eurocode formulation displaced that reading. Second, the cone model that quantifies the penalty omits the contribution of ordinary reinforcement crossing the failure surface, and recent experimental work indicates that this omission is not small. Third, the research effort that supports the framework has been directed almost entirely at the severity of the condition and almost not at all at its frequency, and the funding structure of that research offers a straightforward explanation for the asymmetry.

Recommendation

The recommendation of this paper is not that the classification be relaxed. It is that two of its premises be re-examined, and re-examined empirically rather than by argument, because both are currently assumed rather than established.

The first is the plausibility of the reference condition itself: how often, and under what circumstances, a crack of 0.3 mm is genuinely present *along the whole length of an anchorage*. The qualification regime reproduces that condition universally, and the classification invokes it for every fastening in a member deemed cracked. Section 2.7 indicates that in flexural members it is reached only near the upper end of the permitted service range, and that where it is reached the width over the anchorage is well below the surface value; in restrained members it is real but confined to a definable class of structure. Whether a condition of that rarity should be the reference for every fastening is a question that has not, so far as the author can establish, ever been put.

The second is the depth at which cracks actually occur in structures in service, and the effect of that depth on an installed fastener — with two quantities treated as the inputs that govern the decision rather than ignored by it: the embedment depth of the fastener, and the tension actually applied to it. A crack of a given depth is not the same problem for a 60 mm anchorage as for a 160 mm one; and a fastening working at a third of its resistance is not in the same position as one at its design load. The classification presently takes account of neither, although both are known to the designer at the moment the classification is made.

A third item requires no new measurement at all, and is set out in Section 6.4: for a fastening whose loading is demonstrably confined to shear, every parameter the three governing checks require is either a property of the steel, a dimension, or a factor of the standard. None of them is obtained from testing in cracked concrete. There is therefore no computational impediment to using a fastener assessed for uncracked concrete only in a member classified as cracked, provided the absence of tension is genuine. That conclusion is addressed to the bodies that write the rules rather than to the engineer applying them, for the reasons given there, and it is the single change that would remove the largest amount of unnecessary cost from ordinary practice at no cost in reliability.

What would settle these questions is measurement rather than reasoning: crack-depth and crack-width surveys at anchor installation depths in structures in service, and a reliability analysis of the population of fastenings designed as uncracked in members that would be classified as cracked. Neither is beyond the resources of the industry that funds the rest of this field, and neither has been undertaken.

Until they are, the practical position can be stated as a rule — and the rule is the reverse of the one now in force. Where there is no realistic mechanism by which a crack of the reference kind could appear in the anchorage region, the concrete should be classified as uncracked. Only where genuine doubt remains should it be classified as cracked.

This is a proposal and should be recognised as one. EN 1992-4, 4.7 sets the default the other way, and nothing in this paper permits a designer to depart from it. But a default is a statement about where the burden of demonstration falls, and it belongs on the less common condition rather than the more common one. The evidence assembled here points to the cracked condition being the exception in ordinary construction rather than the rule: the reference crack corresponds to a steel stress near the ultimate range rather than the service range; in a flexural member the width engaged by the anchorage is well under half the value at the surface; the uniform through-thickness crack belongs to a definable and comparatively small class of member; and under pure shear none of the governing checks draws on cracked-concrete testing at all. A framework that requires the exception to be disproved in every case, using information the fastening designer does not hold, will return the cracked answer every time — which is precisely what it does.

The asymmetry of cost follows from the asymmetry of the default. Under the present arrangement the penalty is paid on every fastening. Under the proposed one it is paid only where doubt is real, and there the answer is unchanged: design for cracked concrete, because the penalty is a known cost and the alternative is an unknown risk. What changes is not the treatment of the doubtful case but the treatment of the clear one.

Declaration of interests

The author is a practising structural engineer and a principal of Adit Ltd, an Israeli company that supplies anchoring and fastening products and provides engineering support for their use. That commercial interest runs in the *opposite* direction to the argument advanced here — a cracked classification increases the value of the products the author's firm sells — but it is an interest in the subject matter and is declared for the same reason that the funding of the wider literature is discussed in Section 4. No external funding was received for this work.

Data and software availability

No new experimental data were generated. The normative and assessment documents relied upon, in their publicly distributable form, are collected in the Adit standards and booklets library. The EN 1992-4 design applications referred to in the text are freely available and require no registration: AAS (anchor design to EN 1992-4) and the full index of design applications. Copyright-protected standards published by CEN and other bodies are cited by reference only and must be obtained from the publisher. Related engineering commentary by the author is published at eng.adit.org.il/articles. Correspondence: eng.adit.org.il/contact-us.

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