ANCHORAGE IN CONCRETE · METHOD PAPER · REVISION 1 · AUGUST 2026

The Shared-Volume Anchorage Method

A volume-based treatment of anchor groups at concrete corners and in three-sided channel connections, where two anchorages compete for the same failure body and EN 1992-4 offers no clause.

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Implemented in AAS (Adit Anchor Software)

ABSTRACT

EN 1992-4:2018 verifies a fastening on one concrete face. It has no provision for the case in which two anchor plates sit on perpendicular faces of the same corner, nor for a channel section that wraps a member on three sides. Both are ordinary in façade and precast practice. Designers are left with two poor options: superpose the two anchorages, which counts the same concrete twice, or verify each in isolation and discard the interaction, which is uneconomic and still not a proof.

This paper sets out the method used in AAS for these two configurations. Its central idea is that competition between anchorages is a question of volume, not of area: each potential failure body is integrated numerically over the concrete, and the fraction of a body that is neither shared with a stronger neighbour nor outside the member becomes a scalar reduction factor r. The stronger anchorage — the leading face — is then verified at its full, unmodified EN 1992-4 resistance; the weaker one contributes a secondary term reduced by r and by a non-simultaneity factor. The construction is deliberately degenerate: as the corner interaction vanishes, $r \to 1$ and the result reduces identically to a plain EN 1992-4 verification.

The method is an engineering design aid, not a code-verified resistance, and this paper states its open assumptions as plainly as its results.

1. The gap this addresses

The concrete capacity design (CCD) method underlying EN 1992-4 is built on a single idealised failure body: a cone for a pull-off, a half-pyramid wedge for a shear toward a free edge. Group effects and edge effects enter through the ratio of a projected area to a reference area, and through the ψ factors. This works because all anchors under consideration break out into the same concrete region, in the same direction, from the same face.

A corner bracket breaks that premise. Plate A is anchored to one face, plate B to the perpendicular face, and a single applied load pulls one plate off its face while shearing the other toward the shared corner edge. The two failure bodies are not coplanar and their projected areas do not live in a common plane, so the area-ratio machinery of §7.2.1.4 has nothing to operate on. Yet the two bodies plainly occupy overlapping concrete, and near the corner edge that overlap can be most of the smaller body.

The same holds, in a different geometry, for a channel (U) connection that wraps a member on three sides: a base plate plus two integral walls, where some load components never reach the anchors at all because the section bears directly on the concrete.

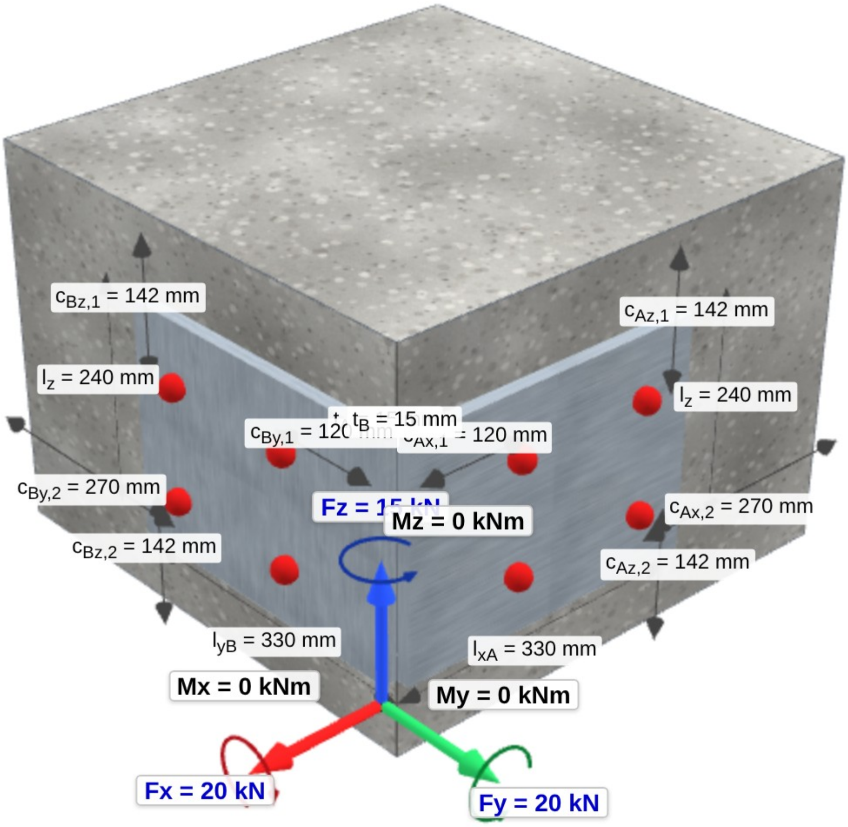

Figure 1 — The connection as the software models it. AAS 3-D view of the worked example of §8: plate A and plate B on perpendicular faces, four anchors each, the edge distances the calculation uses, and the applied triad Fx = Fy = 20 kN, Fz = 15 kN. Every in-plane load makes one plate a tension cone and the other a shear-edge wedge.

2. Scope, and what this method is not

> **STANDING OF THE METHOD**
>
> The leading/secondary decomposition, the volume factor r and the non-simultaneity factor 0.85 are ADIT's engineering method. They are not clauses of EN 1992-4 and the result is not a code-verified resistance. Every underlying single-anchor and group resistance is taken unmodified from EN 1992-4:2018 and from the product's ETA; the method governs only how two competing anchorages are combined.

No experimental programme is claimed here. The evidence offered is internal: exact degeneracy to EN 1992-4 in the limit, dimensional and symmetry consistency, and agreement with independent EN-based software on every quantity the two have in common (§9). A qualified engineer retains full responsibility for the design.

3. Failure bodies as solids

The method's first move is to stop treating the failure surface as a projected area and treat it as a solid. Two bodies are needed.

The tension body is the CCD cone rendered as a right pyramid: apex at the embedded end of the anchor, at depth h_ef, opening to the 3h_ef × 3h_ef square that CCD projects on the concrete face. Its half-width at depth x below the surface is

$$w(x) = 1.5 \cdot h_{ef} \cdot (1 - x / h_{ef}), \quad V_{cone} = \tfrac{1}{3} \cdot (3h_{ef})^2 \cdot h_{ef} = 3\, h_{ef}^3 \qquad (1)$$

The shear body is the same construction rotated onto the free edge: a wedge that opens toward the edge at distance c, with the 1.5c lateral spread of §7.2.2.5, and a depth that runs from the anchor's embedment to the edge breakout depth:

$$w(x) = 1.5c \cdot (1 - x/c), \quad d(x) = 1.5c + (h_{ef} - 1.5c) \cdot (x/c) \qquad (2)$$

Both are the standard CCD geometries; nothing here is new. What is new is that they are now solids that can be intersected with each other and with the physical member.

Figure 2 — The two solids. Standard CCD geometry re-expressed as volumes so one body can be intersected with another. The pyramid apex sits at the anchor's embedded end, not at the surface; the wedge opens toward the edge it breaks out to.

4. The shared-volume factor r

Consider the weaker of the two anchorages — call it the secondary. Part of its failure body is concrete it can genuinely mobilise. The rest is either outside the member, or it is concrete already claimed by the leading anchorage, which by construction fails first and takes that material with it. The factor r is the fraction that remains:

$$r = (\Sigma V_i - V_{outside} - V_{\cap lead}) / \Sigma V_i \qquad (3)$$

Three properties of equation (3) are deliberate and worth stating explicitly.

The denominator is ΣV_i, the sum of the individual bodies, not the volume of their union. Concrete shared between two anchors of the same group therefore also reduces r, which is the volumetric analogue of the group area-ratio in §7.2.1.4 and prevents a dense group from being credited twice.

The numerator removes each region once. A voxel that lies both outside the member and inside the leading body is subtracted once, not twice — otherwise r could go negative on a shallow corner.

For a single anchor, far from any edge, with no neighbour and no leading body, $V_{outside} = V_{\cap lead} = 0$ and r = 1 exactly. The method then contributes nothing and the verification is EN 1992-4 unchanged. This degeneracy is the method's most important property and is the reason the construction was chosen in this form.

The integral is evaluated by uniform quadrature over the bounding box of the bodies. Each sample point is tested for membership in the secondary body, in the leading body, and in the member; the three volumes accumulate. AAS uses a 22^3 lattice for the in-plane factor and 24^3 for the axial factor of §6 — roughly 10^4 point-in-solid tests per factor, which is immaterial at interactive speed. The lattice is uniform and the bodies are convex, so the quadrature error is bounded by the boundary-cell volume; no convergence study is published here, and a reader reproducing the method should treat the lattice size as a parameter to verify rather than as a settled choice.

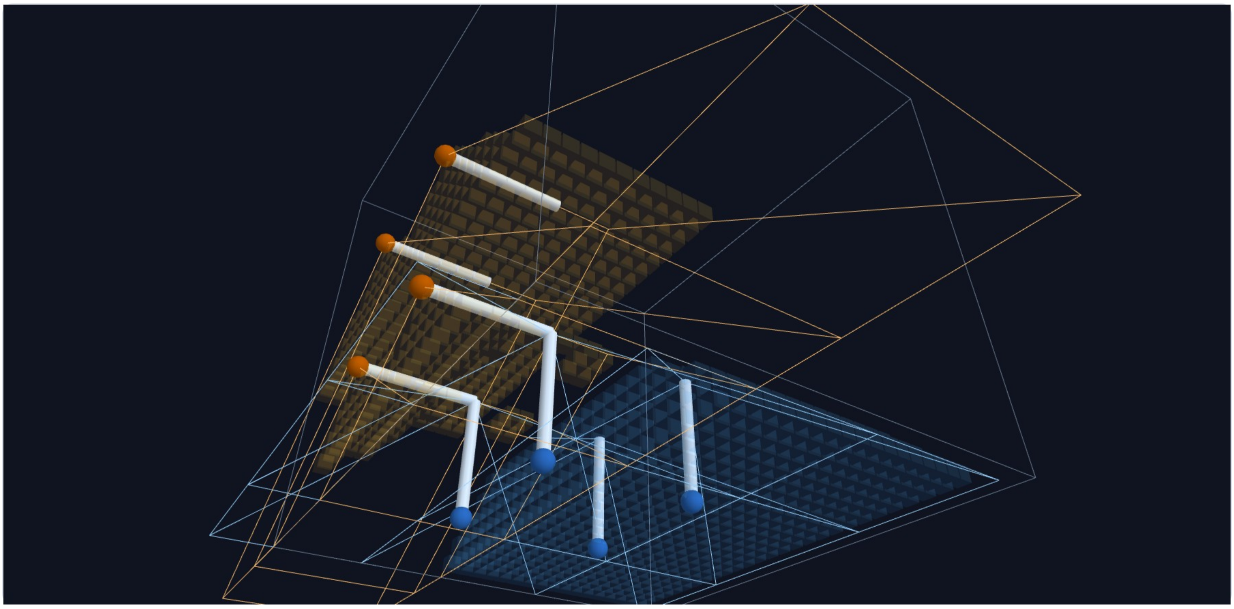

Figure 3 — The failure bodies, integrated. AAS renders both families as voxelised solids: blue tension cones on plate A, orange edge wedges on plate B, each anchor drawn at its embedment. This is the geometry the factor r is measured on, not a schematic of it.

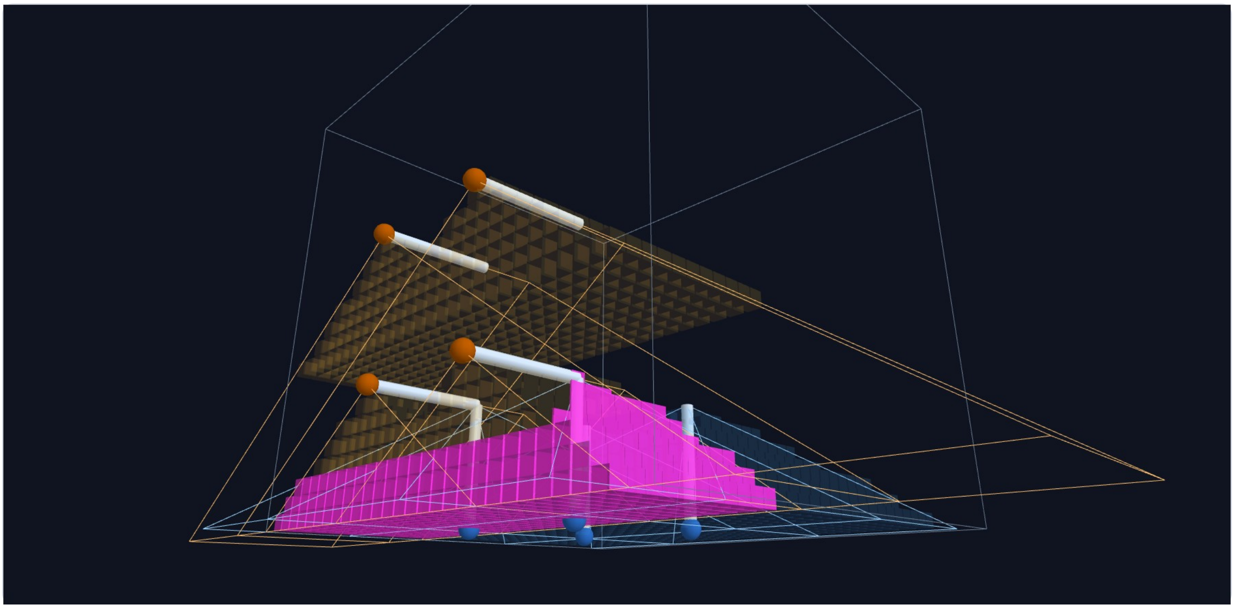

Figure 4 — The shared concrete, seen down the corner edge. The magenta solid is the concrete claimed by both anchorages at once. For the worked example it is 5,438 cm³ of a 14,071 cm³ secondary body, leaving 6,344 cm³ independent and r = 0.45. This volume is the whole subject of the method.

5. Leading and secondary composition

For each axis, the two candidate resistances are computed independently and to EN 1992-4: a tension-cone group resistance on one plate, an edge-breakout group resistance on the other. The larger is designated leading and is taken at its full, unreduced value — it is exactly a plain EN 1992-4 anchorage, verified as if the other plate did not exist. The smaller is the secondary contribution:

```
F_Rd = R_lead(full EN) + 0.85 · min( R_c · r , R_s , R_p )_secondary    (4)
```

Two reductions act on the secondary term, and they are independent, so they multiply. The factor r is geometric: the concrete is simply not there to be mobilised twice. The factor 0.85 is kinematic: the two faces do not reach their peak resistance at the same displacement, so their capacities cannot be added at face value. The secondary term also passes through min(·) against its own steel and pull-out resistances, because a reduced concrete body does not license a steel failure.

The 0.85 is a judgement, not a derivation, and it is the method's least defensible constant. It is applied to the smaller of the two contributions, so its influence on the result is bounded: in the worked example of §8 it moves the total resistance by under 2%.

Reporting the result in EN terms

A resistance produced by volume integration is hard to check by hand. The method therefore inverts it. Given the reduced secondary resistance, AAS solves the EN 1992-4 closed form backwards by bisection for the edge distance that would have produced it:

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find c′ such that V_Rd,c(c′) = R_secondary,reduced (44 bisection steps)(5)
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with the analogous inversion h′_ef for a tension body. The report then states, for example, that a secondary face at c = 90 mm behaves as a clean EN anchorage at c′ = 50 mm. The reviewer can check that number against the code without reproducing the integration.

6. The axial component: two faces, one free edge

An axial load F_z along the corner shears both plates toward the same top free edge. This is the configuration in which the two bodies compete most directly, and it is treated separately.

The leading side again takes its full EN edge resistance. The secondary side is split by position. The single anchor sitting at the corner absorbs the whole overlap and is penalised at double rate:

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F_Rd,z = V_lead(full) + V⁰_Rk,c · max(0, 2r_z − 1) / γ_Mc + (V_front-line / X) · (n − 1)   (6)
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The corner anchor's factor max(0, 2r_z − 1) falls to zero once r_z ≤ 0.5 — a corner anchor sharing more than half its wedge with the leading body is not counted at all. The remaining n − 1 anchors are credited at the front-line group rate, the AAS departure being that every anchor line resists edge failure rather than the first line alone.

No 0.85 appears in equation (6). Both faces are shearing, in the same direction, toward the same edge; the non-simultaneity argument that justifies the factor elsewhere does not apply here.

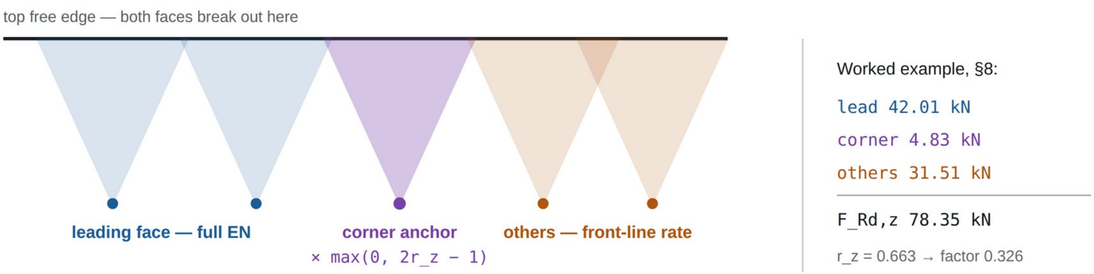

Figure 5 — The axial rule. The corner anchor is the one that genuinely shares its wedge with the leading face, so it alone carries the doubled penalty; it drops out entirely below r_z = 0.5. Figures are the worked example of §8, where the three terms sum exactly to F_Rd,z.

7. Steel, governing mode and interaction

Steel has no failure volume — it is a count. Each plate contributes $n \cdot N_{Rk,s}/\gamma_{Ms}$ or $n \cdot V_{Rk,s}/\gamma_{Ms,V}$ from the ETA, and the same leading-plus-0.85-secondary composition is applied, without r.

For each direction the design resistance is the smaller of the two independent tracks, $R = \min(R_{concrete}, R_{steel})$, as EN 1992-4 §7.2.3.1 requires the modes to be verified separately. Utilisations are $\beta = F_{Ed} / R$, and interaction is then applied per plate in the code's own form:

$$\text{tension–shear: } \beta_N^{1.5} + \beta_V^{1.5} \le 1 \text{ [EN 1992-4 (7.55)] ; shear–shear: } \beta_{V1}^2 + \beta_{V2}^2 \le 1 \text{ [vector resultant]} \quad (7)$$

A pair is evaluated only when both of its loads act, and the worse plate governs.

8. Worked example

A symmetric corner, chosen so that the symmetry itself is a check on the implementation: C30/37 cracked, M16 at h_{ef} = 120 mm, four anchors per face at s = 150 mm, all edge distances 120 mm, $\gamma_{Mc} = \gamma_{Ms} = \gamma_{Mp} = 1.5$, $\gamma_{Ms,V} = 1.25$. Applied $F_x = F_y$ = 20 kN, F_z = 15 kN.

Three internal checks are worth naming. The X and Y resistances are identical, as the geometry demands. The three terms of equation (6) — 42.01, 4.83 and 31.51 kN — sum to $F_{Rd,z}$ exactly. And the interaction value reproduces $2 \times 0.227^{1.5} = 0.216$, confirming that the β values fed to equation (7) are the ones reported.

QUANTITY	VALUE	SOURCE
$F_{Rd,x}$	88.22 kN	eq. (4), leading = tension cone on A
$F_{Rd,y}$	88.22 kN	eq. (4), mirror of X
$F_{Rd,z}$	78.35 kN	eq. (6)
r_z	0.663	24^3 volume integration
corner-anchor factor $2 \cdot r_z - 1$	0.326	eq. (6)
$\beta_x = F_x / F_{Rd,x}$	0.227	—
β_y	0.227	—
β_z	0.191	—
interaction $\beta_x^{1.5} + \beta_y^{1.5}$	0.216	eq. (7)
steel utilisation, peak anchor	0.020	§7
pull-out utilisation, peak anchor	0.127	ETA
governing utilisation	**0.227**	**max of the above**

Table 1 — Output of the AAS corner engine for the symmetric example. The equality of the X and Y rows is a necessary consequence of the symmetry and is not imposed anywhere in the code.

9. Verification against independent software

The method's degenerate limit permits a strong test: on a plain single-face anchorage the AAS engine must agree with any correct EN 1992-4 implementation to the last digit. In a façade bracket cross-check against a supplier's EN-based program — two M16 anchors at h_{ef} = 100 mm in cracked C30/37, edge distance 164 mm, shear 25.5 kN — the two agreed as follows.

The one quantity on which the two programs genuinely differ is the split of tension between the anchors and the concrete bearing zone of a rigid base plate — a statically indeterminate problem whose answer depends on assumed plate, anchor and contact stiffness, and on which neither result is uniquely correct. That difference is a property of base-plate modelling, not of the corner method.

QUANTITY	REFERENCE SOFTWARE	AAS	Δ
N^0_Rk,c	42.17 kN	42.17 kN	0.0%
A^0_c,N	90 000 mm²	90 000 mm²	0.0%
A^0_c,V	121 032 mm²	121 032 mm²	0.0%
Shear on the governing anchor	13.09 kN	13.09 kN	0.0%
V_Rd,cp (pry-out)	83.24 kN	83.24 kN	0.0%
N_Rd,s · V_Rd,s	84.0 · 50.4 kN	84.0 · 50.4 kN	0.0%
N_Rd,c (group)	41.95 kN	41.63 kN	0.8%
V_Rd,c (edge, governing)	28.21 kN	27.98 kN	0.8%

Table 2 — AAS against an independent EN 1992-4 implementation on a flat-plate case. The residual differences in the group terms arise from the ψ_ec treatment.

10. The channel (U) connection

A U section wraps the member on three sides: an anchored base plate and two integral side walls. The governing insight is that most load components never reach the anchors.

A component pressing a wall against the concrete is reacted by bearing. It is a rigid-body reaction requiring no anchor demand and no connection check, and it is removed from the anchor verification entirely. Only two actions remain: pull-off of the base plate, and the axial F_z.

The axial component is an in-plane shear toward the top free edge, resisted by the base group and by the two walls in parallel. The stronger side leads at its full EN value; the other is secondary, reduced by the same volume factor — here r_z, measuring the concrete the base and wall bodies share at the common top edge. As in §6, no 0.85 is applied, because both are shearing the same way.

Load distribution differs between the two actions and this matters. Tension is spread over the base anchors only: the peak anchor governs steel and pull-out, while the tension resultant governs the concrete cone through ψ_ec,N, and the compression side is carried by bearing. Shear is a rigid-channel action shared by all anchors — base plus both walls — so F_z divides over every anchor and any torsion is carried mainly by the walls on their long ±W_b/2 lever rather than being dumped on the few base anchors.

One installation condition is not optional and is stated as a requirement rather than an assumption: the annular gap must be filled for every shear anchor. Two walls act in parallel only if every shear anchor engages the concrete simultaneously; with hole clearance they load unevenly and the parallel assumption fails.

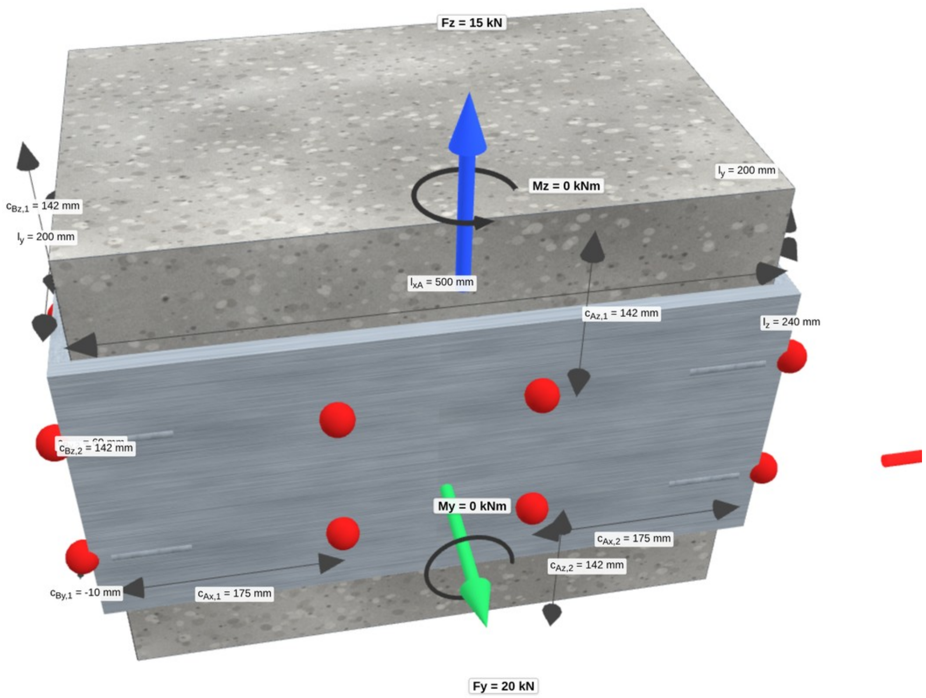

Figure 6 — The channel connection in AAS. The section wraps the member on three sides: an anchored base plate and two integral walls. Any component pressing a wall is reacted by bearing and never reaches the anchors; only base pull-off and the axial Fz do.

11. Open assumptions

These are the points on which the method is least settled. They are listed because a design aid that hides them is worse than useless.

- The tension pyramid is firm; the shape and placement of the shear wedge is the geometry most in need of confirmation. Both the 3-D visualisation and the factor r derive from the same solid, so they move together — an error there is consistent rather than compensating.
- The 0.85 non-simultaneity factor is engineering judgement. Its effect is bounded because it multiplies the smaller term, but it is not derived.
- The doubled corner reduction $2r_z - 1$ is a modelling choice about how the overlap concentrates on one anchor, not a measured distribution.
- A single shared top-edge distance c_z is assumed for both faces.
- The cone-as-secondary path exists but is rarely exercised, since the cone almost always leads; it has therefore had less scrutiny than the paths that run on every calculation.
- No physical test programme has been run against this method. Correlation with tests, and in particular with corner specimens at small c/h_{ef}, is the obvious next step and we would welcome collaboration on it.

12. Availability

The method is implemented in AAS (Adit Anchor Software), a single-file browser application requiring no installation. Every figure in this paper corresponds to a view the software renders live, including an interactive 3-D display of the failure solids and their shared region, and the full derivation is printed in the calculation report for any case the user enters.

Correspondence: office@adit.org.il. We are glad to supply the input files behind the worked examples to anyone wishing to reproduce them.

AAS — Hebrew: https://www.adit.org.il/software
AAS — English: https://www.adit.org.il/software-en
AAS — Español: https://www.adit.org.il/software-es
AAS — Русский: https://www.adit.org.il/software-ru
Website: https://www.adit.org.il
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Annex A — Worked calculation, step by step

Every number below is produced by AAS for the example of §8 and is reproduced here in the order the software derives it, so the chain can be checked by hand against EN 1992-4. Input: C30/37 cracked, M16, h_{ef} = 120 mm, 2×2 anchors per face at s = 150 mm, all edge distances 120 mm, $\gamma_{Mc} = \gamma_{Ms} = \gamma_{Mp} = 1.5$, $\gamma_{Ms,V} = 1.25$. Applied $F_x = F_y = 20$ kN, $F_z = 15$ kN.

A.1 · Single-anchor resistances [EN 1992-4 §7.2.1.4, §7.2.2.5]

$$N^0_{Rk,c} = k_1 \cdot \sqrt{f_{ck}} \cdot h_{ef}^{1.5} = 7.7 \cdot \sqrt{30} \cdot 120^{1.5} = 55.44\ \text{kN}\ (k_1 = 7.7,\ \text{cracked})\ ;\ V^0_{Rk,c} = k_9 \cdot d^{\alpha} \cdot l_f^{\beta} \cdot \sqrt{f_{ck}} \cdot c^{1.5} = 22.24\ \text{kN}\ (k_9 = 1.7\ \text{cracked},\ d = 16,\ l_f = \min(h_{ef}, 12d) = 120\ \text{mm}) \quad \text{(A.1)}$$

A.2 · Per-face capacity, each mode taken to its own limit

BODY	CONCRETE	STEEL	PULL-OUT / PRY-OUT	GOVERNS
A · tension cone	147.8	336.0	213.3	cone
B · shear edge (c_1)	59.3	201.6	160.0	edge
A · shear edge (c_N)	59.3	201.6	160.0	edge
B · tension cone	147.8	336.0	213.3	cone

Table A.1 — Design capacity of each face in each mode (kN). The governing column is what enters the leading/secondary composition of eq. (4).

A.3 · Group cone by projected area [EN 1992-4 §7.2.1.4]

The group is not four independent cones. With s = 150 mm well below $s_{cr,N} = 3h_{ef}$ = 360 mm the cones overlap, and the group follows the area ratio:

$$A_{c,N} = 450 \times 510 = 229{,}500\ \text{mm}^2 \cdot A^\circ_{c,N} = (3h_{ef})^2 = 129{,}600\ \text{mm}^2 \cdot A_{c,N} / A^\circ_{c,N} = 1.77 \quad \text{(A.2)}$$

A.4 · Volume integration — the factor r

TERM	VOLUME	MEANING
ΣV_i — secondary wedge bodies	14,071 cm³	sum of the individual bodies
shared with the leading body	5,438 cm³	concrete claimed twice
independent	6,344 cm³	what the secondary face keeps
r = independent / ΣV_i	**0.45**	**6,344 / 14,071**
r_z — axial, 3-D wedge overlap	0.663	used in eq. (6)

Table A.2 — Volume decomposition for the secondary face, from the integration shown in Figures 3 and 4.

This is the step that has no counterpart in EN 1992-4. The secondary body is integrated on a 22^3 lattice against the leading body and the member:

A.5 · Steel track — leading full + 0.85 · secondary

DIRECTION	SIDE 1	SIDE 2	COMBINATION	F_ST
F_st,x (A tension, B shear)	336.0	201.6	336 + 0.85·201.6	507.4
F_st,y (A shear, B tension)	201.6	336.0	336 + 0.85·201.6	507.4
F_st,z (both shear)	201.6	201.6	201.6 + 201.6 — same mode	403.2

Table A.3 — Steel resistance per direction (kN). No volume factor applies; steel is a count.

A.6 · Axial decomposition [eq. (6)]

`F_Rd,z = 42.01 (leading, full) + 4.83 (corner anchor × (2r_z − 1) = 0.326) + 31.51 (others, front-line rate) = 78.35 kN` (A.3)

A.7 · Governing check and interaction

COMPONENT	APPLIED	R CONCRETE	R STEEL	GOVERNS	B
X	20 kN	88.2	507.4	concrete	23%
Y	20 kN	88.2	507.4	concrete	23%
Z	15 kN	78.4	403.2	concrete	19%
X–Y interaction, plate A	tension–shear	—	—	—	22%
X–Z interaction, plate A	tension–shear	—	—	—	19%
Y–Z interaction, plate B	tension–shear	—	—	—	19%

Table A.4 — R = min(concrete, steel) per direction, then the per-plate interaction of eq. (7). The connection is adequate at a governing utilisation of 23%.

RESULT

Governing utilisation 23% — the connection is adequate. Had the two faces been superposed at full value the resistance would have read 167.0 kN against the 88.2 kN this method allows, an overstatement of 89% on the in-plane axes; had the secondary face been discarded entirely the resistance would have been 80.1 kN, 9% conservative. The method sits between the two and reports which concrete it counted.

References

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