Shallow Embedded Anchors

Load-carrying capacity of mechanical anchors under tension

by Werner Fuchs and Jan Hofmann

ACI 318-14, Chapter 17,[1] provides design requirements for anchors in concrete used to transmit structural loads between:

- Connected structural elements; or
- Safety-related attachments and structural elements.

Provided that they are used correctly, these provisions result in safe and economical solutions for fastenings and connections. However, Chapter 17 provisions are restricted to the design of structural anchors. In fact, the Commentary to the Code explicitly states that specialty inserts—devices that include those used for anchoring nonstructural elements—are "not within the scope of this Code."

Modern buildings require the installation of cable trays, fire sprinklers, air conditioning equipment, and pipes. The installations frequently are made using shallow fastenings consisting of an individual anchor or groups of two or four anchors embedded in the concrete cover (Fig. 1). This means that significant loads are carried by anchors that are embedded in the zone between the reinforcement and the outer surface of reinforced or post-tensioned concrete slabs, precast hollow core concrete slabs, or concrete slabs on metal decks.

ICC-ES AC446[2] covers the prequalification of cast-in specialty inserts and refers to ACI 318 as the design method resource for these nonstructural applications. The critical parameter is embedment depth h_{ef} (Fig. 1 and 2). Post-installed anchors with $h_{ef} \geq 1.5$ in. (40 mm) are prequalified according to ICC-ES AC193,[3] which is based on ACI 355.2[4] and also refers to ACI 318 for design provisions. ICC-ES AC193 also allows anchors to have $h_{ef} < 1.5$ in., but the lower limit for h_{ef} is 1.0 in. (25 mm) and the anchors must be used in redundant anchorages in interior applications only. ICC-ES AC193 also provides a special design method for these redundant anchorages. In the event that one anchor fails or exhibits excessive deflection, the method relies on having a fixture that is capable of redistributing the load of the insufficiently behaving anchor to the neighboring anchors.

European design provisions for anchors are provided in EN 1992-4.[5] In this standard, the unfavorable effect of the concrete properties in the concrete cover is taken into account by the capacity reduction factor ψ_{re}, even for anchors with $h_{ef} \geq 1.5$ in. Smaller embedment depths are allowed only in statically indeterminate (redundant) nonstructural systems subjected to static loads only. They are designed using an approach similar to the one in ICC-ES AC193. The minimum h_{ef} is 1 in. for anchors subject to internal exposure conditions, and the minimum h_{ef} is 1.25 in. (30 mm) for anchors in all other applications.

These applications raise the question: Can ACI 318 be used to calculate the concrete break-out capacity of cast-in specialty inserts or post-installed anchors with $h_{ef} < 1.5$ in.?

This paper presents background information on the ACI 318 design procedure, parameters influencing the concrete tension capacity in the cover concrete, test results used to develop the European design approach, and a proposal for modifying the ACI 318 design concept to yield a conservative result for mechanical anchors with shallow embedment.

Shallow Anchorage

Cast-in specialty inserts (Fig. 2) and mechanical post-installed anchors (Fig. 3) with shallow embedment have become very popular for anchoring suspended mechanical, electrical, and air conditioning equipment, and piping and conduit applications in buildings. In most cases, cast-in

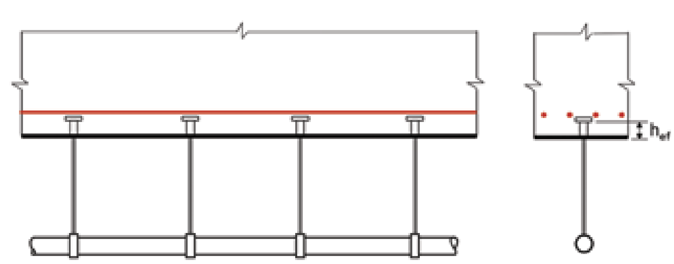

Fig. 1: Anchorage of nonstructural loads with shallow embedded anchors. This example shows a redundant system with four individual anchors

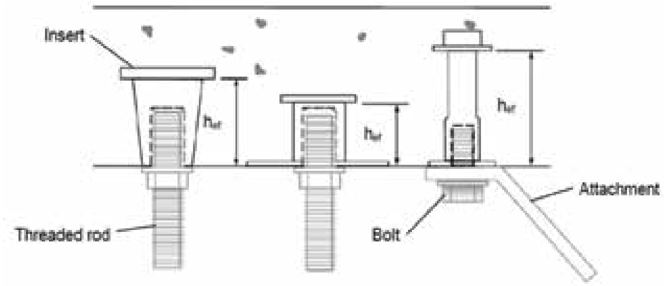

Fig. 2: Examples of cast-in specialty inserts covered by ICC-ES AC 446[2]

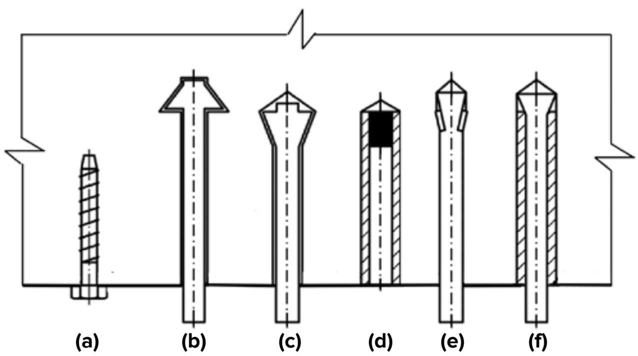

Fig. 3: Examples of mechanical post-installed anchors (after EN 1992-4[5]): (a) concrete screw; (b) undercut anchor, type 1; (c) undercut anchor, type 2; (d) drop-in anchor; (e) wedge type expansion anchor; and (f) sleeve type expansion anchor

specialty inserts and mechanical post-installed anchors with internal threads are used since adhesive anchors present challenges in making overhead installations, may have a smaller fire resistance, and may have insufficient bond when used with shallow embedment depths. The latter issue is the result of installation effects such as pre-damage of the concrete surface caused by hammer drilling.

However, it has to be noted that the behavior of anchors embedded in the concrete cover differs significantly from anchors with larger embedment depth. This is mainly due to the properties of the cover concrete and presence of reinforcement:

- **Properties of cover concrete**

The concrete in the cover depth is unfavorably influenced by vibration conditions and incomplete curing of the fresh concrete, shrinkage cracking, environmental effects, and carbonation. That is, the concrete properties are less favorable in the cover zone as compared with the interior core region of the concrete component serving as base material for structural anchors.

While curing and shrinkage are major factors affecting the properties of unformed concrete surfaces, the "wall effect"[6-10] is of major importance for formed surfaces. The wall effect is characterized by a local reduction in the concrete strength caused by a high paste content (which decreases with increasing distance from the formed surface).

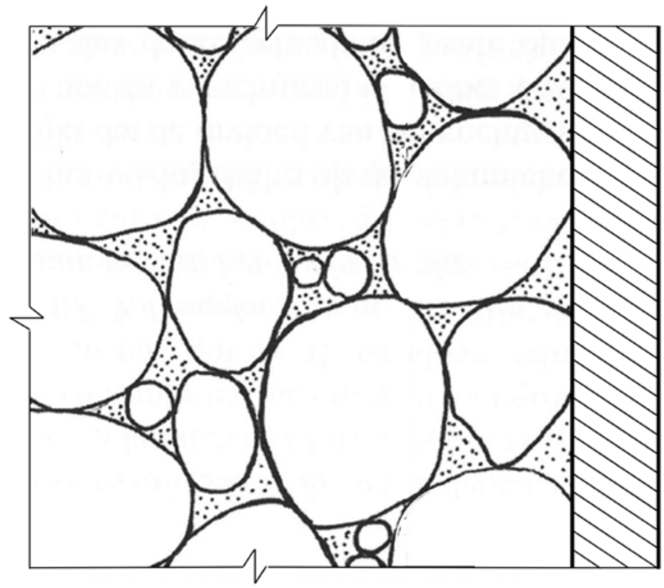

Fig. 4: Wall effect, based on Sourwerbren[8]

The high paste content arises because dense packing and uniform distribution of the aggregates are prohibited by geometrical constraints close to the formed concrete surface (Fig. 4). While the volume of aggregates in the core concrete usually can be found to comprise 70 to 75% of the total, the volume of aggregates in the cover concrete can be as low as 40%. The high paste content leads to a reduced fracture energy, a lower strength, and a more brittle failure mode for the cover concrete. Therefore, the concrete break-out capacity of shallow anchors can be lower than the value determined using the ACI 318 design approach.

- **Presence of reinforcement**

In nonstructural applications, the anchors might be anchored at the level of dense reinforcement or adjacent to lap splices. In these locations, the tensile stresses originating from the anchors and the bond of the reinforcing bars are locally superimposed. This can result in an earlier crack development compared to cases where no reinforcement is present or where the load is introduced by anchors with a sufficient distance to the reinforcing bars.[11] Furthermore, the presence of dense reinforcement will disturb the proportioning of the aggregates. These unfavorable effects will be less pronounced with increasing anchor embedment depth.

Nevertheless, shallow embedded anchors are frequently used in many types of construction and therefore play an important role in engineering. Their particular importance might be underlined by regarding the variety of safety-related applications and the serious economic consequences in case of failure. Therefore, only products prequalified according to ICC-ES AC446 and ICC-ES AC193 (which is based on ACI 355.2) should be used for the anchorage in the concrete cover. Both prequalification procedures imply that the concrete break-out capacity of these prequalified products is to be determined according ACI 318. However, ACI 355.2 prescribes the testing programs for structural post-installed mechanical anchors for use with the design method of ACI 318, which is intended for only structural design. Therefore, anchorage in the concrete cover presents an extrapolation of the ACI provisions to a new field of application and must be reviewed in detail.

In the following sections, the mechanical properties of the concrete cover are presented, and their effects on the load carrying capacity (limited by concrete failure) of mechanical anchors under tension are provided to allow for the efficient and safe design of shallow embedded anchors.

Background

Prequalification procedures

The basis of design of anchors is a reliable product prequalified by an acknowledged procedure. For post-installed anchors, ACI 355.2 is the prequalification standard, and it is implemented through compliance with ICC-ES AC193. For the prequalification of cast-in specialty inserts, ICC-ES AC446 is used.

The relationships among ICC-ES AC446, ACI 355.2, ICC-ES AC193, and ACI 318 are shown schematically in Fig. 5. It should be noted that ACI 318 covers structural fasteners and explicitly does not address specialty inserts for nonstructural applications.

Prequalification procedures included in each document are as follows:

- **ICC-ES AC446**

ICC-ES AC446 covers the prequalification of headed cast-in-place specialty inserts in concrete components and in the soffit of concrete on metal deck floor and roof assemblies. It provides requirements on the geometry and head bearing area of inserts necessary to achieve equivalency with the bearing behavior of headed studs or headed bolts that comply with the ACI 318 provisions. Therefore, the prerequisite for the design of headed cast-in specialty inserts according to ACI 318 is fulfilled.

ICC-ES AC446 states that the structural design of compliant headed cast-in specialty inserts must be performed in accordance with ACI 318, considering: 1) strength reduction factors; 2) determination of tension strength as governed by concrete breakout or side-face blowout; and 3) requirements on headed cast-in specialty insert edge distance, spacing, member thickness, and concrete strength.

However, ICC-ES AC446 gives no limitations on embedment depth and diameter of the insert. Hence anchorages with $h_{ef} < 1.5$ in. could also be used. Due to lack of a better approach, applications considered as "nonstructural" would be designed as a structural element with the ACI 318 design methods originally intended for "structural" loads. This is a key reason why the behavior of anchors under tension located in the cover concrete should be further considered.

For installations in the soffit of concrete on metal deck, the tension strength of the specialty insert must be determined according to ACI 318 provided the dimensions of the concrete break-out body are idealized as shown in Fig. 6. Although the metal deck serves as "smeared reinforcement" to the concrete breakout strength, its contribution must be neglected. This restriction is essentially set by serviceability concerns since the metal deck will positively influence the anchor strength only after the tension load introduced by the anchor has initiated cracking and displacement of the anchor.

ICC-ES also allows the establishment of the concrete break-out strength of inserts by means of tests performed in concrete on metal deck floor and roof assemblies. These tests must reflect the intended use in accordance with ICC-ES AC193 and Section D.4.2 of Appendix D in ACI 318-11.[12] For anchors meeting these standards, the calculation of the

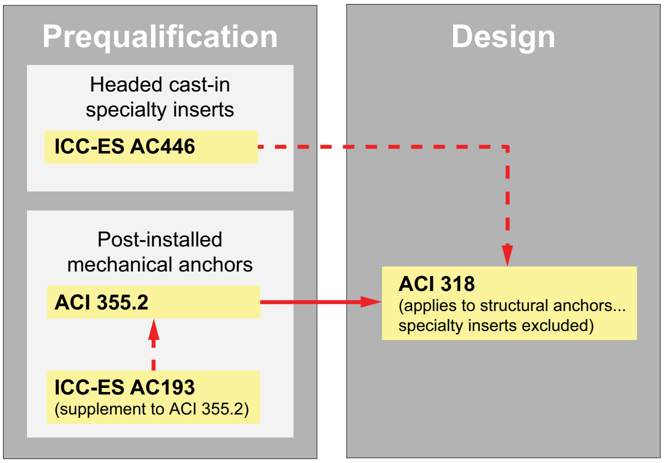

Fig. 5: Relationships among ICC-ES AC446, ACI 355.2, and ICC-ES AC193 for product prequalification and ACI 318 for design

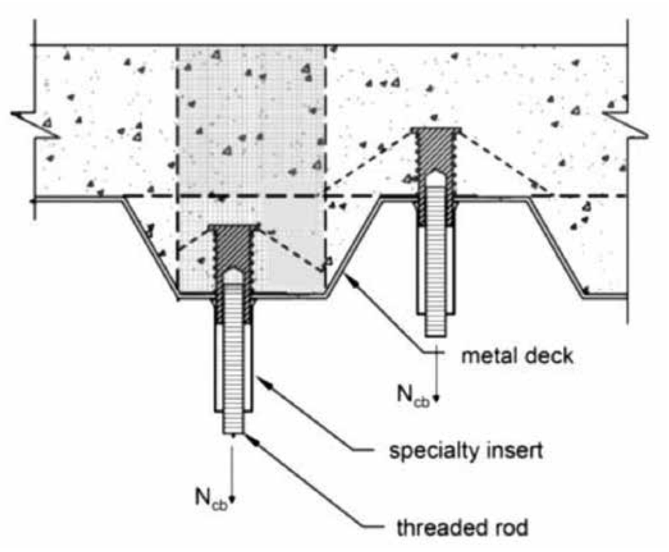

Fig. 6: Inserts in the soffit of concrete on deck assemblies with idealized concrete break-out body—examples from ICC-ES AC446[2]

concrete breakout strength is not required and the characteristic tension strength for a single insert based on tests is reported in the corresponding Evaluation Service Report (ESR).

- **ACI 355.2**

ACI 355.2 applies to post-installed expansion and undercut anchors intended for use in concrete designed under the provisions of ACI 318. Anchor diameters must be at least 1/4 in. (6 mm). This is based on practical considerations regarding the limitation to structural anchor applications.

- **ICC-ES AC193**

ICC-ES AC193 is based on ACI 355.2 and represents the current state of knowledge in mechanical post-installed anchor prequalification. It extends the range of ACI 355.2 to post-installed screw anchors with a threaded length embedded in the concrete of at least 1.5 in., which also represents the minimum value of the effective embedment depth for post-installed expansion and undercut anchors. Then the structural design of the anchors is to be performed in accordance with ACI 318.

Appendix A4 of ICC-ES AC193 gives prequalification and design provisions for anchors with h_{ef} < 1.5 in. and are outside the scope of ACI 355.2 and ACI 318. These types of anchors are prequalified exclusively for redundant applications and must have h_{ef} of at least 1 in. The anchor installation is limited to normalweight and sand-lightweight cracked and uncracked concrete structural components with compressive strengths between 2500 and 8500 psi (17 and 59 MPa). In design, however, only a concrete compressive strength of 2500 psi is used because ICC-ES AC193 permits no increase in anchor capacity for greater concrete strengths. The maximum factored load per anchorage point is 2 kN (450 lb) in case of three anchorage points and 3 kN (675 lb) per anchorage point in case of at least four anchorage points supporting a linear element.

Design provisions (background)

In the following, background information regarding the design provisions of ACI 318 and EN 1992-4 is presented:

- **ACI 318**

The design method in ACI 318 for determining the concrete break-out capacity of anchorages under tension loading is based on an analysis of a database of cast-in and post-installed anchors with diameters of up to 2 in. (50 mm) and h_{ef} values ranging from 1.5 to 25 in. (40 to 635 mm),[13] as shown in Fig. 7. Anchors with h_{ef} < 1.5 in. were not used for the development of the equations because shallow embedded anchors were not considered structural and there was lack of sufficient test data.

- **EN 1992-4 (Europe)**

The design provisions of EN 1992-4 apply only to anchors with a prequalification according to a European Technical Product Specification. They distinguish between the following two cases:

  - **Anchors with $h_{ef} \geq$ 40 mm (1.5 in.)**

For anchors with $h_{ef} \geq$ 40 mm, it is conservatively assumed that the unfavorable influence of dense reinforcement in the vicinity of anchors is limited to anchorages with $h_{ef} \leq$ 100 mm (4 in.). Then the tension concrete break-out strength of cast-in-place and post-installed anchors is multiplied with the shell spalling factor $\psi_{re,N}$:

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{200} \leq 1 \qquad \text{(SI units)} \qquad (1a)$$

$$\psi_{re,N} = 0.5 + \frac{h_{ef}}{8\,\text{in.}} \leq 1 \qquad \text{(in.-lb units)} \qquad (1b)$$

For a shallow embedded anchorage with an embedment depth of 40 mm, the multiplication with the factor $\psi_{re,N}$ results in a concrete break-out capacity reduction of 30%.

The factor $\psi_{re,N}$ can be set at 1.0, if reinforcement (any diameter) is present at a spacing of 150 mm (6 in.) or more; or reinforcing bars with a diameter of 10 mm (No. 3 bars) or smaller are present at a spacing of 100 mm or more.

These conditions must be fulfilled for both layers of an orthogonal grid of reinforcing bars.

  - **Anchors with h_{ef} < 40 mm**

In case of embedments smaller than 40 mm, EN 1992-4 refers to CEN/TR 17079, "Design of fastenings for use in concrete—redundant nonstructural systems."[14] It provides guidance for post-installed fasteners for fixing statically indeterminate nonstructural lightweight systems with at least three anchorage points (refer to Fig. 1 for an example). While the standard applies for the case where one anchor or an anchor group is installed in cracked or uncracked normalweight concrete or precast prestressed hollow core slabs, it does not cover applications in seismic areas.

In design, it is assumed that the anchors are prequalified and that, in case of failure or excessive slip of an anchor, the load can be transferred to adjacent anchors without violating the requirements on the attached element with respect to the serviceability and ultimate limit state. Under exterior

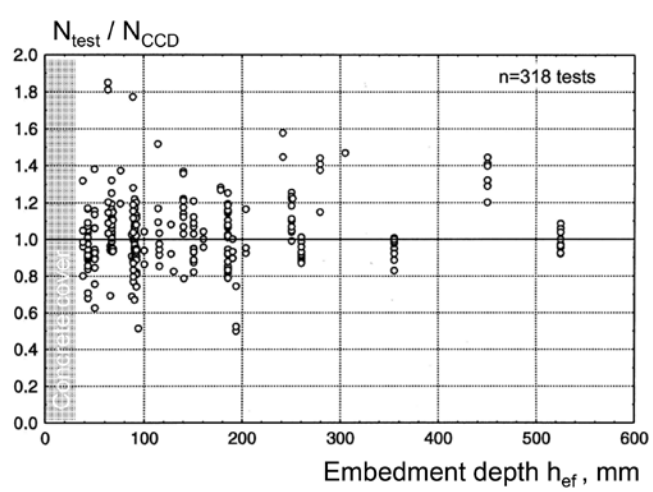

Fig. 7: Results of tests that served as the basis for the development of the equation for determination of the concrete break-out strength of single headed anchors subjected to tension according to the CCD-method (Reference 13)

conditions, the minimum embedment depth is 30 mm (1.2 in.); in internal exposure conditions, a minimum embedment depth of 25 mm (1 in.) is permitted. The actual anchor capacity is based on prequalification tests and must be taken from the relevant European Technical Product Specification which is the European equivalent to an ESR. However, the maximum applicable design load is 2 kN per anchorage point in case of three anchorage points and 3 kN per anchorage point in case of minimum four anchorage points. In principle, this approach corresponds to the rules given in ICC-ES AC193 for redundant applications.

Anchors with h_{ef} values less than 25 mm are not covered by European prequalification and design provisions.

Investigations

Results from the investigations described herein indicate how the ACI 318 design approach can be modified for design of anchorages in the concrete cover.

Anchors in concrete cover of highly reinforced beams

The concrete break-out strength for anchors embedded in the concrete cover of heavily reinforced concrete beams under service load conditions was investigated by Fuchs.[15] The tests were performed on single anchors and four-anchor groups (Fig. 8) placed in cracks in formed surfaces and in manually-troweled concrete surfaces of beams. Undercut and sleeve-type torque-controlled expansion anchors were tested, with h_{ef} ranging from 40 to 60 mm (1.5 to 2.4 in.).

The concrete compressive strength was about 35 MPa (4300 psi). The flexural reinforcement consisted of 28 mm diameter deformed bars (No. 9 reinforcing bars) placed with a clear spacing of about 30 mm. The concrete cover was 45 mm (1.8 in.), so some anchors were embedded in the concrete cover and others extended to near the centroid of the reinforcing bars. To avoid an edge effect, the distance of the anchors to the edges of the beam varied between $1.8h_{ef}$ and $2.25h_{ef}$. The spacing was between $2.4h_{ef}$ and $3h_{ef}$ so that an overlapping of the concrete break-out bodies was just possible. Examples of the tested configurations are shown in Fig. 8.

The anchors were installed according to the corresponding manufacturer's installation instructions. All single anchors were placed in hairline cracks. For four-anchor fastenings, two of the four anchors were located in the same crack. After anchors were installed, test beams were loaded until V-shaped flexural cracks grew to an average width of about 0.3 mm (0.012 in.), measured on the surface. This corresponds approximately to the service load of the beam. In the final step, the anchorages were subjected to increasing tension load until failure occurred. The failure was characterized by shell spalling of the concrete cover at the level of the flexural reinforcement (Fig. 9). This failure mode can be explained as follows:

- The load on the anchorage had to be resisted by the concrete cover, and the concrete strength in the cover is expected to be lower than in the core;
- The bond stresses associated with the reinforcing bars were superimposed on the tensile stresses generated by the anchors; and
- The closely spaced reinforcement represented a discontinuity that limited the possible shape of the concrete break-out body.

Figure 10 summarizes the effect of anchor installation in the concrete cover on the capacity of four-anchor fastenings. In all cases, the test peak load, N_{test}, is less than the capacity predicted using the Concrete Capacity Design (CCD) method, N_{CCD}.[13] The data include installations of expansion anchors (EA) and undercut anchors (UA) in cracked concrete. Installations were made in formed and troweled surfaces. As

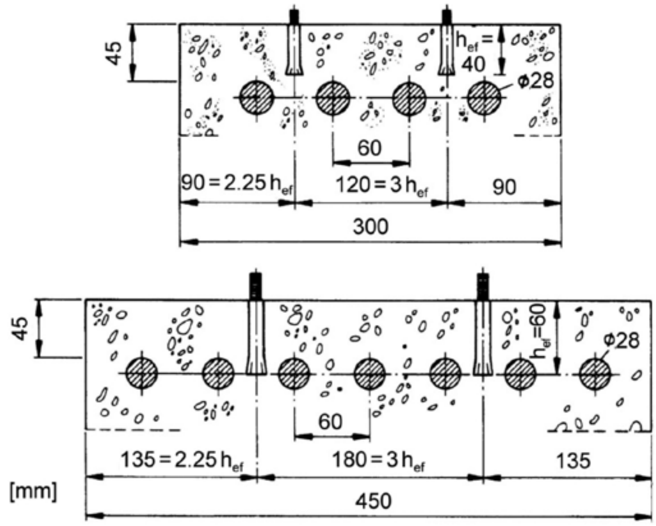

Fig. 8: Examples of anchorages in concrete cover of beams with heavy reinforcement tested by Fuchs[15] (Note: 1 mm = 0.04 in.)

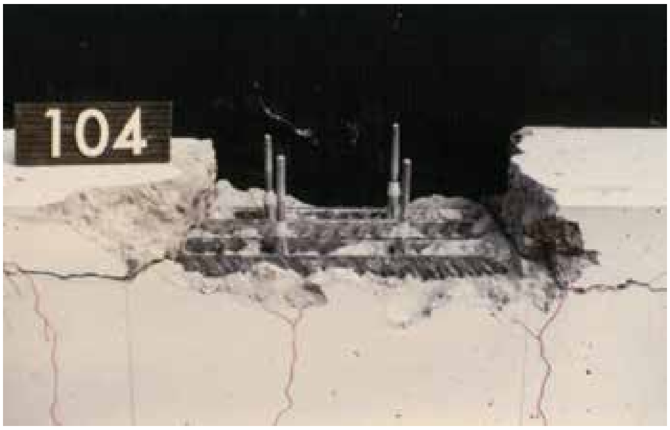

Fig. 9: An example of spalling of the concrete cover of a beam with heavy reinforcement and a quadruple fastening comprising expansion anchors subjected to tension load.[15] Note that the anchors were placed in their initial locations for the photograph

expected, for fastenings in which three out of the four anchors in a group were coincidentally located in cracks, the behavior was the most unfavorable. This effect (the ratio of N_{test} and N_{CCD} fell to nearly 0.5) is described by Eligehausen et al.[11] As this is an exceptional case in practice, these results should not be overstated and therefore were not further considered in European design rules. The scatter observed in these tests is somewhat higher than in prequalification tests in cracked concrete slabs. This is attributed to the unfavorable concrete properties in the cover region. While a significant difference between anchorages in the formed or troweled surface could not be detected, it must be noted that the specimens were produced under laboratory conditions. Because the test results scatter around the same amount, it is apparent that the superimposition of stresses introduced by the anchors and the reinforcement has a minor influence on anchorage behavior.

Similar results were found in the tests with single anchors. Regardless of the type of anchor, the embedment depth, or the surface (troweled or formed), the failure loads averaged about 30% lower than could have been expected in cracked concrete with widely spaced reinforcement. A comparable behavior is anticipated for headed cast-in-place inserts.

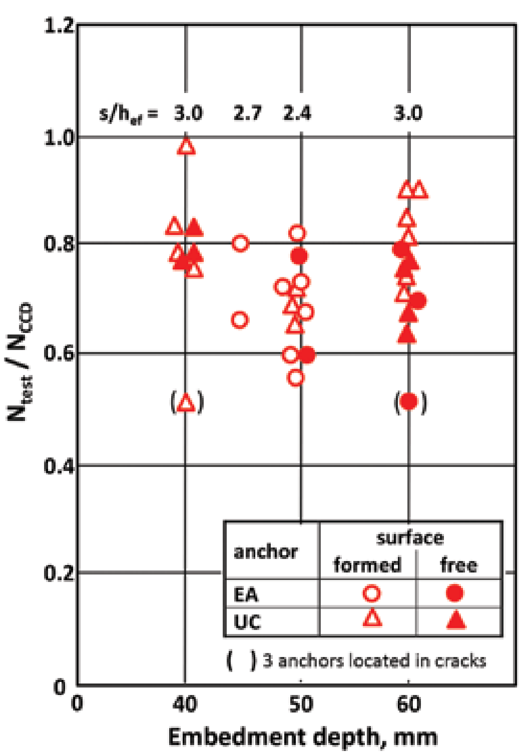

Fig. 10: Results of tensile tests on four-anchor fastening groups, showing the ratios of anchor group test capacities and capacities predicted using the CCD-method as functions of embedment depth. In this series, EA and UC were embedded in formed and troweled surfaces. For all but two cases, two out of four anchors were located in cracks, from Fuchs[15] (Note: 1 mm = 0 04 in.)

Shallow embedded post-installed anchors

Hofmann and Kaupp[16] performed tension tests with single bolt-type anchors post-installed in low strength concrete. The anchors had an outer diameter of 6 mm (1/4 in.), and h_{ef} ranged from 10 to 30 mm (0.4 to 1.2 in.) in 5 mm (0.2 in.) increments. All tests were performed on the formed surface of concrete slabs. For tests conducted in uncracked concrete, unreinforced slabs served as base material. For tests conducted in cracked concrete, the reinforcement of the slabs was designed so as to avoid influencing the behavior of the anchors. The cracked concrete tests were carried out in line cracks with a crack width of 0.35 mm (0.014 in.).

The anchors were installed according to the manufacturer's installation instructions; however, installations did not comply with embedment depth requirements in all cases. The tests were carried out in accordance with the prequalification provisions of ACI 355.2. All anchors considered in the evaluation failed by concrete break-out.

The ultimate loads observed in uncracked concrete tests were normalized to a concrete compressive strength of 25 MPa (3600 psi) and are plotted in Fig. 11 as function of the embedment depth together with the calculated value (red line) according to the CCD-method,[13] which served as the basis for the ACI 318 anchor design provisions. While the test results follow the trend line representing the CCD-method, on average, the measured values are about 30% lower than the calculated values. Furthermore, the coefficient of variation increases from 6% for h_{ef} = 30 mm to 24% for h_{ef} = 10 mm.[16] Similar results were found by Olsen et al.[17] for concrete screws and Appl,[18] who performed one test series with an adhesive anchor (h_{ef} = 30 mm). It should be noted that for

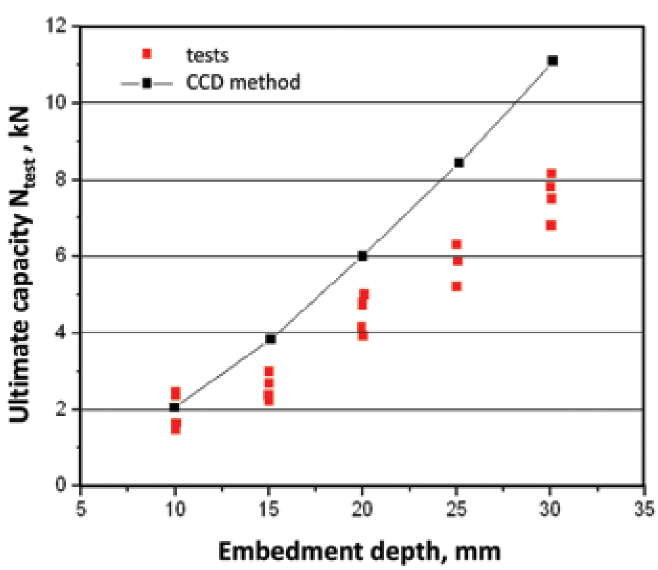

Fig. 11: Ultimate loads from tests in uncracked concrete (25 MPa [3600 psi]) as a function of the embedment depth in comparison to the values predicted according to the CCD-method, after Hofmann et al.[16] (Note: 1 kN = 224 lb; 1 mm = 0.04 in.)

anchors embedded in the core of an uncracked concrete slab tested in the laboratory, coefficients of variation between 5 and 8% normally can be expected.

The ultimate loads observed in the tests in cracked concrete are shown in Fig. 12. Some tests with h_{ef} = 10 mm failed by pull-out, with minimal resistance. These tests were not taken into account in the further evaluations because this failure mode represents a product dependent behavior. For larger embedments, the test results follow the trend line given by the CCD-prediction[13] for post-installed anchors in cracked concrete. However, as with the tests conducted in uncracked concrete specimens, the test results are about 30% lower than the values predicted using the CCD-method.[13] The scatter of the test results is between 10 and 20%, which is also higher than would be expected for anchors embedded in the core of the test slab.

Proposal for design of shallow embedded anchors based on ACI 318

The load-bearing behavior of mechanical anchors post-installed in the cover zone of low-strength concrete beams and slabs was investigated in detail. Parameters included:

- Concrete properties;
- Tensile stresses in both anchors and reinforcing bars;
- Reinforcing bar congestion and resulting discontinuity in the concrete;
- Type, quantity (single or group of four), and embedment depth of anchors;
- Concrete surface type (formed or troweled); and
- Substrate condition (cracked or uncracked).

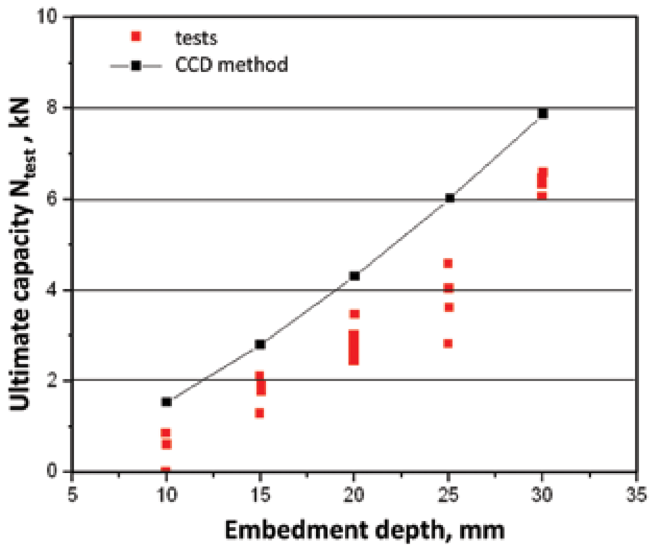

Fig. 12: Ultimate loads from tests in cracked concrete (25 MPa [3600 psi]) with a crack width of 0.35 mm (0.014 in.) as a function of the embedment depth in comparison to the values predicted according to the CCD-method,[13] based on Hofmann et al.[16] (Note: 1 kN = 224 lb; 1 mm = 0.04 in.)

In cracked or uncracked concrete, the concrete break-out capacity of anchorages under tension located in the concrete cover tended to be about 30% lower than the break-out capacity expected for anchors embedded in the core of concrete components. Given that there are only a limited number of test results available and that no environmental effects were included in the testing program, the reduction should be assumed to be around 30% only for formed, interior surfaces. For troweled surfaces with exterior exposure, a greater reduction might be justified. Another open question is if the carbonation of the concrete cover might have an effect on the load bearing capacity of the shallow embedded anchors.

To open the ACI 318 approach to “nonstructural” fasteners and to account for the unfavorable concrete properties in the cover zone, we recommend multiplying the strength reduction factor ϕ given in ACI 318-14, Section 17.3.3(c), by an additional factor of 0.6 to 0.7. This recommendation is valid only for the considered post-installed mechanical anchors prequalified analogously to ACI 355.2 and for headed cast-in specialty inserts meeting ICC-ES AC446. With this modification, the design of mechanical anchors could be performed according to ACI 318-14, Chapter 17. Tables 1 and 2 summarize the procedure for anchors with $h_{ef} \geq 1.5$ in. and with $h_{ef} < 1.5$ in., respectively.

Summary

Many applications in building practice—including anchorage of hangers for heavy ductwork, air conditioning ducts, and piping—require that anchors are installed in the cover zone. To ensure occupant safety, such anchors must function reliably in cracked and uncracked concrete under seismic loading conditions. They therefore need to be prequalified. This is why ACI 355.2, ICC-ES AC193, and ICC-ES AC446 should be updated to properly recognize shallow embedments.

Due to lack of other design provisions, ACI 318 provisions developed for "structural" applications are currently often used as the design method for shallow anchors. In case of post-installed anchors, however, a prequalification in accordance with ACI 355.2 is required.

This article presents the current state of knowledge on prequalification and design provisions for anchorages in the concrete cover. Until now, in the case of post-installed anchors, only redundant applications of post-installed mechanical anchors are allowed in the concrete cover. For headed cast-in specialty inserts, ICC-ES AC446 refers to ACI 318 for the design method and does not take into account the special situation in the concrete cover originating from the stresses in the reinforcement and the unfavorable concrete properties.

Considering the existing research on anchors under tension embedded in the concrete cover, the ACI 318-14, Chapter 17, design provisions can be applied provided that:

- Post-installed anchors are prequalified analogously to ACI 355.2-07;
- Cast-in specialty inserts are prequalified in accordance with ICC-ES AC446;
- The field of application for both anchor types is limited to nonstructural loads; and

Table 1:
Anchor strength governed by concrete breakout, pry-out, and side-face blowout if $h_{ef} \geq 1.5$ in.

Supplementary reinforcement	Type of mechanical anchor	Sensitivity/reliability category from ACI 355.2	Strength reduction factor ϕ	
			Tension	Shear
Present	Cast-in	Not applicable	0.75	0.75
	Post-installed	1	0.75	
		2	0.65	
		3	0.55	
Not present	Cast-in	Not applicable	0.70	0.70
	Post-installed	1	0.65	
		2	0.55	
		3	0.45	

Table 2:
Anchor strength governed by concrete breakout, pry-out, and side-face blowout if $h_{ef} < 1.5$ in.

Supplementary reinforcement	Type of mechanical anchor	Sensitivity/reliability category from ACI 355.2	Strength reduction factor ϕ	
			Tension	Shear
Present	Cast-in	Not applicable	Not applicable	Not applicable
	Post-installed	1		
		2		
		3		
Not present	Cast-in	Not applicable	0.45	0.45
	Post-installed	1	0.40	
		2	0.35	
		3	0.25	

- The capacity calculated using ACI 318 is further reduced by about 30% for anchors installed in formed surfaces subjected to interior exposures. The reduction could be performed by multiplying the strength reduction factors according to ACI 318-14, Section 17.3.3 (c), with an additional factor of 0.7 (or less).

For anchors installed in troweled surfaces subject to exterior exposure, a larger reduction than 30% could be warranted. To cover this situation, further research is necessary.

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