Code Changes Affecting Post-Installed Concrete Anchor Design

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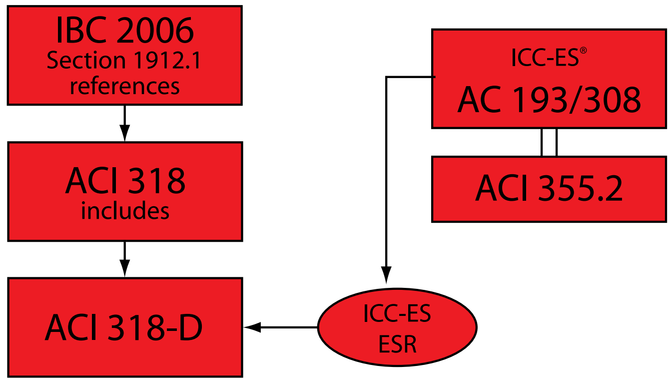
Resembling the LRFD method currently gaining popularity in structural steel design and the time proven ACI 318 strength design approach for concrete structures, harmonization efforts introducing strength design (SD) procedures for post-installed anchors is appearing in the codes. With the publishing and the adoption of the International Building Code (IBC) 2003 and 2006, Structural Engineers will begin to design post-installed anchorage into hardened concrete using SD. The evolution from allowable stress design (ASD) to a more statistically based SD approach originates from increased understanding of post-installed anchor behavior and performance. Numerous product qualifications and research programs conducted during the past quarter century, with different types of post-installed anchors, validates this approach.

Figure 1: Code Interaction / overview (new code landscape).



IBC - International Building Code®
ACI 318-D - American Concrete Institute®; Design Provisions
ACI 355.2 - American Concrete Institute®; Test Provisions
AC 193 ICC-ES Acceptance Criteria; acceptance criteria for mechanical anchors in concrete elements
AC 308 ICC-ES Acceptance Criteria; acceptance criteria for post-installed adhesive anchors in concrete elements
ICC-ES ESR - Evaluation Service Report => Final published document containing design data

Background

As the number of municipalities adopting the 2003 and 2006 IBC increases in the United States, a growing number of Structural Engineers will be designing anchorage to concrete according to the new SD provisions. *Figure 1* provides an overview of how the various code documents interact.

With the publication of the IBC 2003, anchors installed in hardened concrete shall be designed in accordance with appendix D of ACI 318 [IBC 2003 Section 1913.1 and IBC 2006 Section 1912.1]. ACI 318-D contains SD provisions for cast-in and post-installed mechanical anchors in both uncracked and cracked concrete; addressing seismic applications in conjunction with cracked concrete for seismic design categories (SDC) C-F. Earlier ASD provisions only addressed uncracked concrete applications (including seismic applications) and design data was generated by taking the average of the peak test loads, independent of failure mode, and dividing it by a global safety factor. This reduced value was then published as the allowable load capacity. The new SD method enables load capacities to be generated for both uncracked and cracked concrete. SD load capacities are based on the 5% fractile value of test results associated with the various failure modes; steel failure, concrete breakout, anchor pullout, anchor pull-through, bond failure and concrete splitting. The 5% fractile values are calculated using the formula:

$F_{5\%} = F_m*(1-K\nu)$ where:

- $F_{5\%}$ = 5% fractile value @ 90% confidence
- F_m = Average the peak load in test series
- K = Statistical Owen factor (varies from 13.09 for n=2, to 1.645 for n = ∞, where n = sample size)
- ν = Coefficient of variation (COV) of the anchor test series

The Design Example below illustrates that predictable post-installed anchor systems producing consistent test results (ultimate loads and failure modes), while yielding small COV, will outperform inferior systems and be favored by the design community. This is a direct consequence of the new design philosophy which rewards predictable behavior by increasing the efficiency of the system, and at the same time providing the Structural Engineer with additional transparency regarding the governing failure mode.

ICC-ES Acceptance Criteria

Historically, model building codes published in the United States have permitted manufactuers to demonstrate code compliance of products not specifically prescribed by the various codes. Verification of code compliance is typically accomplished through product testing according to Acceptance Criteria (AC). An AC outlines specific product sampling, testing, and quality requirements to be fulfilled in order to obtain an evaluation report. The ICBO-ES published post-installed anchor evaluation reports complying with the Uniform Building Code (UBC). These reports, currently referred to as Legacy Reports, offered Structural Engineers unbiased code compliant product information when designing post-installed anchors using an ASD approach. After the unification of the three model code groups (BOCAI, ICBO and SBCCI), the International Code Council Evalu-

Design Example

To illustrate the benefit of the SD approach, consider the following anchor design capacity:

Category 2 post installed anchor, test sample size of, n = 10, coefficient of variation (COV) = 15%,

$\phi N_n = \phi F_{5\%} = \phi F_m(1- k\nu) = \phi F_m(1- 2.568*0.15) \approx 0.61*\phi F_m$ (ACI 355.2, (A2-1)

$\phi N_u = 1.2*0.55+1.6*0.45 = 1.38$ (ACI 318, (9-2)

$\phi = 0.55$ (ACI 318-D D4.4)

$1.38 = 0.55*0.61*SF \Rightarrow SF \approx 4.1$ (ACI 318-D D4.4)

UBC 1997 / IBC 2000		
ASD		Base Material
AC01	Mechanical expansion	Un-cracked concrete & CMU
AC106	Mechanical screw	
AC58	Adhesive	

Table 1: ASD Acceptance Criteria

IBC 2003 & 2006		
SD		Base Material
AC193	Mechanical expansion & screw	Cracked and uncracked concrete*
AC308	Adhesive	

*AC01, 106 and 58 covers Masonry base material

Table 2: SD Acceptance Criteria

ation Service (ICC-ES) has published new ACs in order to address the SD requirements for post–installed anchors in accordance with the IBC 2003 and IBC 2006. *Table 1* and *Table 2* illustrate the evolution of the acceptance criteria for various base materials.

Acceptance criteria for both design methods are similar in the sense that either allowable or strength design capacities are derived from reference tests. These tests are conducted without concrete edge and anchor spacing influences in various concrete compressive strengths ($f'_{c\ low}$ and $f'_{c\ high}$). Anchors are then qualified through a series of reliability tests, which are compared to the reference tests. Examples of reliability test are testing conducted using only half of the prescribed installation torque (T_{inst}), drilling holes with either an oversized or undersized drill bit compared to the specified drill bit, evaluating the performance of an anchor which is installed in a crack whose opening width is cycled or anchors installed in holes cleaned using reduced cleaning efforts. According to the AC193 for mechanical anchors and AC308 for adhesive anchors, results from the reliability tests are used to establish anchor categories yielding various ϕ factors to be used with the SD provisions in ACI 318-D.

Ensuring Code Compliance of Post-Installed Anchors

Structural Engineers designing anchorage to concrete according to the IBC 2003 and IBC 2006 code(s), and Building Officials verifying code compliance, may follow a few simple guidelines to properly accomplish these tasks:

Current ICC-ES Evaluation Service Reports (i.e. ESR-1917) may be downloaded from ICC-ES's website **www.icc-es.org**:

Once on the ICC-ES homepage select the "Evaluation Reports" button which will prompt the following search tool:

Evaluation Reports

List Reports
Search Reports
CSI List

You may search ALL reports by entering a number alone; or narrow your search by selecting a prefix and then entering a report number.
Report Organization:
Report Number:
Manufacturer:

Select the "Search Reports" button and four search options emerge:

1) Report organization
2) Report Number
3) Manufacturer
4) Product

The simplest way to find a report is to either enter an anchor manufacturer's name or a specific ESR number (i.e. 1917).

After successfully downloading an ESR, particular attention should be given to the following sections:

1) ***Section 1.0 Evaluation Scope*** – lists the applicable model codes for the product evaluated.

Table 3: Code and AC Matrix

Anchor Classification	ICC-ES Acceptance Criteria	Concrete Condition	Code Reference											
			UBC 1997			IBC 2000			IBC 2003			IBC 2006		
			Non-Seismic	Seismic Zones 1-2A	Seismic Zones 2B-4	Non-Seismic	Seismic Design Category A-B2)	Seismic Design Category A-F	Non-Seismic	Seismic Design Category A-B2)	Seismic Design Category A-F	Non-Seismic	Seismic Design Category A-B2)	Seismic Design Category A-F
			UCC			UCC		CC	UCC		CC	UCC		CC
Adhesive	AC58	UCC	✓	✓1)	✗	✓	✓1)	✗	✓	✗	✗	✗	✗	✗
	AC308	UCC	✓	✓	✓	✓	✓	✗	✓	✓	✗	✓	✓	✗
		UCC & CC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Mechanical	AC01	UCC	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
Screw	AC106	UCC	✓	✓1)	✗	✓	✓1)	✗	✓	✗	✗	✗	✗	✗
Mechanical Incl. Screw	AC193	UCC	✓	✓	✓	✓	✓	✗	✓	✓	✗	✓	✓	✗
		UCC & CC	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

UCC = Uncracked Concrete
CC = Cracked Concrete
✓ = Permitted
✓ = Permitted due to AC extension until January 1, 2008
✗ = Not Permitted

1) Based on the assumption that the optional uncracked concrete seismic tests according AC58/106 have been conducted (see findings concerning "seismic recognition in concrete" in the currently published ESR/ER reports on the ICC-ES website).

2) Not applicable. ACI 318-D Section D.3.3.2 and IBC Section 1908.16 requires seismic test for SDC C-F as part of the total cracked concrete test program of Table 4.2. Table 4.2 notes state that seismic qualification is optional.

2) ***Section 2.0 Uses*** – lists the intended use of the product (i.e. cracked and uncracked concrete or uncracked concrete only).
3) ***Section 5.0 condition of use*** – lists particular conditions pertaining to the product for code compliance.
4) ***Section 6.0 Evidence Submitted*** – lists which AC was used for product qualification (i.e. AC193) and may be used to correctly interpret compliance using Table 3 below.

Due to a transitional period for the validity of the different ACs, *Table 3* establishes the relationships amongst various design parameters (i.e. SDC, cracked or uncracked concrete) the appropriate model code and the accompanying AC for post-installed anchorage in hardened concrete.

The importance of correct interpretation of these relationships is essential because products qualified according to AC01, AC58 and AC106 verified compliance for both concrete and masonry base materials in the past. These approvals have now been re-published with updated code references and reduced scopes since they now pertain to only CMU base materials, except for the extension referenced in *Table 3*.

Interpretation of AC193 and A308 ESRs

Q What does *NA* in a load table for published design values mean?

A This term indicates that the anchor reached the concrete cone capacity for this particular embedment depth and concrete strength during testing. In *Figure 2* below it can be determined that the three shallowest embedment depths (h_{ef} = 2, 3 and 4 inches) of the test results fall on the concrete cone curve defined by $N_u = k^*\sqrt{f'_c}*h_{ef}^{1.5}$ and pull-out/pull-through is not the decisive failure mode. For the three deeper embedments (h_{ef} = 5, 6 and 7 inches) pull-out/pull-through capacities are clearly less than that of the concrete cone curve, hence these design values must be provided in order for the Structural Engineer to evaluate these capacities.

Q If pull-out/pull-through was determined to be decisive and a load value is published in the load tables, why is an efficiency factor, k_{cr} or k_{uncr} for concrete necessary?

A The efficiency factor k_{cr} or k_{uncr} is necessary for the calculation of concrete capacities of single anchors affected by proximities to an edge or multiple edges or groups of anchors where spacing and/or edge distances will reduce the concrete capacity.

Q Why is $\Psi_{c,N}$ published when both k_{cr} or k_{uncr} are provided in the design tables?

A In lieu of the $\Psi_{c,N}$ published in ACI 318-D Section D.5.2.6, Manufacturers of post-installed anchors can provide $\Psi_{c,N}$ values based on ACI 355.2/AC193/AC308 testing. Since $\Psi_{c,N} = \frac{k_{uncr}}{k_{cr}}$, the Structural Engineer may evaluate the uncracked concrete capacity by either multiplying $k_{cr}*\sqrt{f'_c}*h_{ef}^{1.5}$ by $\Psi_{c,N}$ or simply use the k_{uncr} provided and calculate $k_{uncr}*\sqrt{f'_c}*h_{ef}^{1.5}$ directly.

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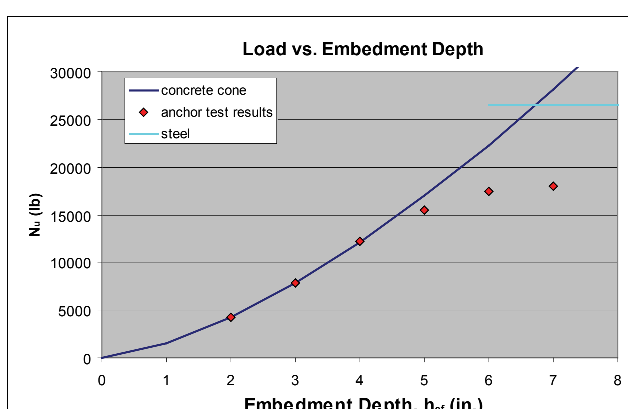

Figure 2: Example of Ultimate Load vs. Embedment Depth.

Q Some load tables provide a numerical value for $N_{p,uncr}$ and a *NA* for $N_{p,cr}$. When evaluating the characteristic capacity for high strength concrete ($f'_{c\ high}$) the cracked capacity seems to exceed the uncracked capacity, this makes little sense?

A Generally, load values provided in design table have been normalized to f'_c = 2500 psi. Where α has been determined by comparing tests results obtained in both $f'_{c\ low}$ and $f'_{c\ high}$ the Structural Engineer may scale the pull-out/pull-through value (be it $N_{p,uncr}$ or $N_{p,cr}$) to the desired concrete strength by multiplying the number by $\left(\frac{f'_{chigh}}{f'_{c2500}}\right)^{\alpha}$. The scaling factor, α, is provided in the ESR and may vary depending on anchor performance.

Q For some anchor sizes the seismic capacity is less than the static capacity, however for other sizes they are equal. How is this interpreted?

A When no reduction is required the anchor can sustain the full static load capacity for both static and seismic applications. However, ACI 355.2 Section 9.5.3 (tension) and Section 9.6.3 (shear) allows for reduced seismic capacity and states that "…*Anchors that fail during the tests shall be permitted to be tested at lower maximum cyclic loads to establish a reduced nominal capacity.*" Therefore, some reported seismic capacities are less than the reported static capacities.

Q Why is the additional factor $\Psi_{cp,N}$ referenced in ACI 318-D Section D.5.2.7 required when the uncracked concrete capacity has already been reduced by $\frac{A_{Nc}}{A_{NcO}}$ and $\Psi_{ed,N}$?

A Certain post-installed mechanical anchors require a critical edge distance, c_{ac}, that exceeds the $1.5*h_{ef}$ which forms the basis for calculating the concrete capacity. This factor is only to be used for calculating uncracked concrete capacity where supplementary reinforcement to control splitting is not present.

Enforcement

Special inspection is required, in accordance with Section 1701.5 of the 1997 UBC and Sections 1704.4 and 1704.13 of the 2000, 2003 and 2006 IBC. The special inspector shall be on the jobsite continuously during anchor installation to verify anchor type, anchor dimensions, concrete type, concrete compressive strength, hole dimensions, hole cleaning procedures, anchor spacing, edge distances, concrete thickness, anchor embedment, and tightening torque. Continuous inspection is required for mechanical anchors; however, for adhesive anchors systems, manufacturers may qualify their products for either continuous or periodic inspections depending on system performance or the desired technical data load levels.▪

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References

1. ICC-ES Acceptance Criteria for Expansion Anchors in Masonry Elements, AC 01, Approved December 2006, Effective January 1, 2007.
2. ICC-ES Acceptance Criteria for Adhesive Anchors in Concrete and Masonry Elements, AC58, Approved June 2005, Effective July 1, 2005.
3. ICC-ES Acceptance Criteria for Predrilled Fasteners (Screw Anchors) in Masonry, AC106, Approved June 2006, Effective July 1, 2006.
4. ICC-ES Acceptance Criteria for Mechanical Anchors in Concrete Elements, AC193, Approved October 2006, Effective January 1, 2007 (corrected April 2007).
5. ICC-ES Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete, AC308, Approved February 2006, Effective March 1, 2007.
6. ACI 318-05 building Code Requirements for Structural Concrete.
7. ACI 355.2-04 Evaluating the Performance of Post-installed Mechanical anchors in Concrete.
8. Hilti North America Product Technical Guide, 2006 edition.
9. ICC-ES ESR 1917.
10. 1997 Uniform Building Code™
11. 2000 International Building Code®
12. 2003 International Building Code®
13. 2006 International Building Code®
14. Fuchs, W.; Eligehausen, R; and Breen J., "Concrete Capacity Design (CCD) Approach for Fastening to Concrete" ACI *Structural Journal*, V 92, No 1, Jan-Feb., 1995, pp. 73-93.

Mechanical Anchors Inspection Checklist for Concrete & Masonry

Special Inspection shall be in compliance with Section 1701 of the UBC and Section 1704 of the IBC as described below. (See Structural Drawings for Inspection requirements)

Project Name:____

Project Location:____

Weather:___________________ Air Temperature:____________(°F/°C)

CODES
- ☐ UBC 1997
- ☐ IBC 2000
- ☐ IBC 2003
- ☐ IBC 2006

Seismic Zone/
Seismic Design Category

Product

Product Name/Manufacturer:____

Lot No.:____

ICC-ES Report No.:____

Head Configuration: ☐ Hex Nut/Threaded ☐ Hex Bolt Head ☐ Torque Cap ☐ Countersunk

Diameter/Dimension: ☐ 1/4″ ☐ 3/8″ ☐ 1/2″ ☐ 5/8″ ☐ 3/4″ ☐ 1″

☐ M8 ☐ M10 ☐ M12 ☐ M16 ☐ M20 ☐ M24

Overall Anchor Length:________(in/mm)

Steel Grade/Coating:________________

Base Material

Base Material Type: ☐ NW Concrete ☐ LW Concrete ☐ LWC over Steel Deck ☐ CMU Block

☐ Other____________

Base Material Strength: ☐ 2000psi ☐ 3000psi ☐ 4000psi ☐ Other____________

Base Material Thickness:_________(in/mm)

Drilling & Hole Cleaning

Drill Bit Diameter:___________(in/mm)

Hole Depth:______________(in/mm)

Drill Bit Type: ☐ Carbide-Tip Drill Bit (ANSI B212.15-1994) ☐ Diamond Core Bit (if appropriate and allowed) Other____________

Hole Cleaning: ☐ Compressed Air ☐ Hand Pump ☐ Wire Brush ☐ Nylon Brush ☐ Other____________

Hole Condition: ☐ Dry ☐ Water Saturated

Application

Anchor Application: (please check all that apply)

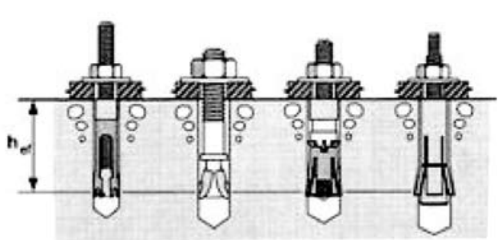
☐ Tension ☐ Shear ☐ Overhead ☐ Other____________

Anchor Spacing:_______________(in/mm)

Edge Distance:_________________(in/mm)

Embedment(h_{ef}*):_______________(in/mm)

Installation Torque:_____________(in/mm)



*h_{ef} = Effective embedment depth, measured from the concrete surface to the deepest point at which the anchor tension load is transferred to the concrete, measured prior to appling torque to the anchor.

Completed by:________________________________(Signature) Date:____/_____/____

________________________________(Print) Company:____________________________________

________________________________(Title)

Version 09_2007

Figure 3, Sample of inspection form