Demystifying ACI 318 Appendix D
A practical guide for anchoring to concrete using strength design

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How has anchor testing and evaluation been affected?

Post-installed mechanical anchors qualified for strength design are required to be tested by an independent laboratory, according to ACI 355.2. Qualification of Post-Installed Mechanical Anchors in Concrete. Performance is tested over a wide range of concrete compressive strengths (2,500 to 8,000 psi) and a wide range of installation conditions, which may include sensitivity to drill hole diameter, reduced and excessive torque, and for in-service applications such as cracked concrete and seismic loading. Additionally, the design values are now based on statistical analysis of independent test results that ensure more reliable anchor performance. And, after mechanical anchors have been tested and evaluated according to ACI 355.2, the manufacturer may obtain an ICC-ES Evaluation Service Report (ES Report), which provides evidence of code compliance to the building official.

How has anchor design been affected?

Section 1913 of the 2003 IBC and Section 1912 of the 2006 and 2009 editions of the IBC, respectively, state that anchors resisting seismic forces and post-installed anchors such as expansion anchors and undercut anchors installed in hardened concrete shall be designed in accordance with the strength design procedure that references Appendix D of ACI 318. Appendix D requires post-installed anchors to be tested and qualified according to ACI 355.2 (which is supplemented by ICC-ES Acceptance Criteria ACI 193). ACI 355.2 introduced several new tests including the performance of anchors in cracked concrete conditions.

What is cracked concrete? When should I account for it in my design?

The term "cracked concrete" relates to the likelihood of the concrete base material developing cracks in the region of anchorage at (or below) the expected service load level. Factors that may contribute to concrete cracking, and must be considered by the design professional, include the effects of restrained shrinkage, flexure in tension zones, seismic activity, temperature fluctuations, soil pressure, differential settlements, etc.

Only post-installed mechanical anchors that have met the requirements for use in cracked concrete in accordance with ACI 355.2 are permitted for use in applications where crack development is expected, and/or in a geographic region of moderate or high seismic risk. In geographic regions of moderate or high seismic risk (Seismic Design Categories C, D, E, or F), anchors resisting earthquake forces must also pass the Sumulated Seismic Test in accordance with ACI 355.2.

Note that in lieu of extensive analysis to prove that the concrete will remain uncracked throughout its
The 2003, 2006, and 2009 IBC is now adopted in nearly all United States jurisdictions, making strength design of anchors, including ‘cracked concrete’ requirements, applicable nationwide.

Post-Installed Mechanical Anchors in Shear

Based on ACI 318 (2008) Appendix D and ICC-ES AC193

D.6 - Design Requirements for Shear Loading

D.6.2 - Concrete Biaxial Strength of an Anchor in Shear

D.6.2.1 - Nominal Concrete Biaxial Strength of a Single Anchor in Shear

D.6.2.2 - Basic Concrete Biaxial Strength for a Single Anchor in Shear

D.6.2.3 - Modified Concrete Biaxial Strength for a Single Anchor in Shear

D.6.2.4 - Modified Concrete Biaxial Strength for an Anchor Group in Shear

D.6.3 - Steel Strength of an Anchor in Shear

D.6.3.1 - Nominal Concrete Biaxial Strength of an Anchor in Shear

D.6.3.2 - Basic Concrete Biaxial Strength for a Single Anchor in Shear

Figure 2. Use this flowchart for analyzing and designing post-installed mechanical anchors in shear.

service life, and to minimize the risk of the unqualified anchors being used in a cracked concrete application, many design professionals choose to always assume “cracked concrete” and only specify those anchors that have been tested and qualified accordingly.

What happened to the allowable stress design (ASD) tables? Can I still use them for anchor design?

The allowable stress design (ASD) method of designing concrete anchor- age is still in Section 1111 and Table 1111.2 of the 2006 and 2009 IBC. However, the ASD method of designing concrete anchors and applying spacing and edge reduction factors to determine an allowable load is no longer applicable under the International Building Code for post-installed anchors in hardened concrete and anchors resisting earthquake forces. Only strength design is recognized as code compliant for these anchors and only concrete anchors qualified to the new standards are permitted for these conditions.

So what is strength design?

Strength design is a design procedure used by engineers to ensure acceptable levels of safety and the proper functioning of a structure for its expected lifetime. Strength design is based on statistics, engineering principles, and a general knowledge of material behavior. Section 1602 of the IBC defines strength design as, “A method of proportioning structural members such that the computed forces produced in the members by factored loads do not exceed the member design strength.” When applied to anchorage to concrete, strength design requires the design resistance (anchor capacity) to be greater than the factored load (load demand). This is simply stated as the following:

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The flowcharts — general (figure 1), shear (figure 2), and tension (figure 3) — found on these pages serve as a practical guide for the design community. They are intended to give the reader a general understanding of the strength design method as it applies to post-installed mechanical anchors in concrete. Although the information provided should not be considered a substitute for ACI318 Appendix D, it will provide a resource for concrete anchor design using the strength design method.

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Many anchor manufacturers have recognized the complexity of the new code requirements and have developed software packages capable of conducting anchor design utilizing the strength design method according to ACI 318 Appendix D.

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References
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- American Concrete Institute (ACI) 318-08 (Appendix D) – Building Code Requirements for Structural Concrete and Commentary (Anchoring to Concrete)

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