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ANCHORS AWEIGH

Changes in ACI provisions for the seismic design of anchors.

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THE 2011 EDITION of ACI 318, *Building Code Requirements for Structural Concrete (ACI 318-11) and Commentary*, contains significant revisions to the requirements for the design of anchors in concrete (Appendix D).

These provisions are applicable to the design of all safety-related connections to concrete, including anchors for column base plates, beam-to-wall connections and a host of other cases that typically arise in the design of steel structures. This article will address changes to the seismic design provisions of Appendix D (Anchoring to Concrete) as given in Section D.3.3 of ACI 318-11.

The seismic design provisions of Appendix D have traditionally been oriented around the requirement that the capacity of the anchor should be governed by ductile yielding of the bolt. This approach has antecedents in the anchor design requirements of the ACI 349 code for nuclear structures, which has historically required that "…embedment design…be controlled by the strength of the embedment steel." Implementation of the "ductile anchor" concept in earlier editions of the ACI 318 provisions used a simple comparison of the design strength of the steel element to the design strength associated with concrete failure (unlike other sections of the ACI code, which typically reference to the nominal yield strength of reinforcing, the anchor provisions of Appendix D reference the nominal ultimate strength of the steel for design since "…the large majority of anchor materials do not exhibit a well-defined yield point").

Furthermore, the equations for concrete strength are derived from a requirement that the calculated resistance represent the 5% fractile (a strength that will be exceeded by 95% of the population with a 90% confidence) and default to an assumption of cracked concrete. This value is further reduced for the seismic design condition to account for concrete damage and load redistribution effects associated with earthquake loading. In short, the provisions result in conservative estimates of anchor resistance that properly reflect the high degree of variability associated with this design condition.

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Nevertheless, feedback from the design community has indicated that the provisions had become increasingly difficult to implement from a practical design standpoint. Consequently, an effort was begun in 2009 to recast the seismic design provisions of Appendix D. Observations of anchor performance in the magnitude 8.8 Chilean earthquake of February 2010 provided additional background and incentive for this effort.

Changes to the seismic design provisions in the ACI 318-11 provisions may be summarized as follows:

1. Implementation of a threshold load value (20%) for triggering seismic design requirements in a given load component direction (tension or shear)
2. Inclusion of language to permit alternate forms of protection against premature anchor failure
3. Complete revision of the ductile anchor design requirements
4. Elimination of the ductile anchor design option for shear loading
5. Revision of the non-ductile anchor design provision and replacement of the non-ductile anchor strength reduction factor by a reference to overstrength (Ω_0)

The establishment of a threshold value for triggering the seismic design provisions avoids cases where small levels of load in either principal load direction result in excessive edge distance or embedment requirements while still maintaining a reasonable level of safety.

Where seismic design requirements are triggered for the anchor design, a variety of options are now provided to satisfy those requirements. These include design of the anchor as a ductile yielding element, design of the anchor for a force corresponding to the point of significant inelastic deformation of the connected element, design for the maximum force that can be transmitted by a non-yielding element or design for overstrength (Ω_0) in accordance with, for example, ASCE 7.

Changes to the ductile anchor requirements include recasting of the ductility proof in terms of nominal strengths, with an overstrength factor applied to the steel strength term. This parallels the approach taken in the ACI 349 anchor design provisions and resolves a longstanding difference in the two documents.

Stretched anchor bolts at the CAP Acero steel mill, resulting from the Maule (Chile) earthquake of 2010.

Additionally, a stretch length requirement has been added to the ductile anchor option. This provision resulted from reconnaissance work conducted in Concepcion, Chile, following the magnitude-8.8 Maule (Chile) earthquake in February of 2010. In surveys of anchor rods used for anchorage of tanks, vessels and steel braced frame elements in Chilean industrial facilities, it was found that rods provided with adequate free length to accommodate the displacement requirements generated by the earthquake underwent significant tensile yielding without rupture. Rods designed without stretch length typically ruptured at the first thread. Note that the stretch length requirement is accompanied by a corresponding requirement on the ratio of the nominal ultimate tensile strength to yield strength of partially threaded anchor rods unless upset threaded ends are used (ductile anchors are required for the anchorage of tanks and vessels per ASCE 7-10 Chapter 15, but they may not be suitable for all cases, particularly those in which significant anchor stretch could result in structural instability).

Likewise, elimination of the ductile anchor option for shear loading followed from the observation that while shear deformations corresponding to steel rupture may be significant in some instances, where base plates carry significant vertical load, shear displacements at rupture tend to be relatively small and do not afford significant ductile response. In all cases, it is permissible to employ dedicated reinforcing (referred to in ACI 318 as "anchor reinforcement") to avoid concrete breakout.

IBC Implementation

An abbreviated International Code Council (ICC) code cycle in the 2010-2012 timeframe resulted in disruptions to the normal code development processes for many standards development organizations. In the case of the ACI 318-11 code, adoption in the 2012 International Building Code (IBC) was accommodated through an "administrative update" of the code without the corresponding changes to the relevant portions of the IBC that make reference to ACI 318. In particular, IBC section 1905.1.9, as currently published in the 2012 version, erroneously points to sections from ACI 318-08. A code change proposal to resolve this issue, S340, is currently under consideration by ICC (for additional information contact S.K. Ghosh, Ph.D., with S.K. Ghosh Associates, Inc., www.skghoshassociates.com). MSC

Chilean braced frame anchorage details illustrating the provision of stretch length.

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Shear failure of a post-installed expansion anchor.