Anchorage to Concrete Design: The Transition from Tabular Load Capacity to Rational Design and Anchor Qualification Procedures to Manage Risk

Neal S. ANDERSON
V. Pres. of Engineering
Concrete Reinforcing Steel Institute
Schaumburg, Illinois, USA
nanderson@crsi.org

Neal S. Anderson, born 1962, received his BS and MS degrees in civil engineering from Purdue University, West Lafayette, Indiana. He has been involved with concrete anchorage research, focusing on cast-in, headed stud anchors, and rational design methods.

Donald F. MEINHEIT
Affiliated Consultant
Wiss, Janney, Elstner Associates, Inc.
Chicago, Illinois, USA
dmeinheit@wje.com

Donald F. Meinheit, born 1943, received his BS from Purdue University, MS from the University of Illinois, and PhD from the University of Texas at Austin, all in civil engineering. He is chairman of ACI Committee 355, *Anchorage to Concrete.*

Summary

Anchorage to concrete design has progressed considerable in the past 10 years. Provisions now exist in the ACI 318 Code for designing cast-in and post-installed expansion anchors. No other US code has provisions that are as detailed as those in ACI. Other code bodies, AASHTO and AISC are currently lacking in specific code language for designing anchors that are embedded in concrete.

This brief paper describes some of the history and important milestones in developing the current provisions in ACI 318. It is not the intent that this be a complete history of anchorage to concrete design but a review of the positive and negative aspects in the development of the current (2008) design provisions.

Keywords: concrete anchorage, post-installed, cast-in, adhesive, ACI Appendix D, concrete capacity design (CCD) method.

1. Introduction

Since the mid-1980s, the design of anchors embedded in concrete, whether cast-in or post-installed, was generally by allowable stresses, manufacturers' catalog values, and / or a design model based on shear-punching failure concepts. Research starting in the late 1970s and continuing to the present has been used to calibrate design models that can predict the tension and shear capacity of cast-in anchors, post-installed mechanical expansion anchors, adhesively bonded anchors, and concrete/masonry screw anchors. This discussion reviews the history of anchorage design development in the United States. In particular, the development of qualification procedures for certain anchor types is discussed.

2. Anchorage to Concrete - The Codified Times

In the 2002 Edition of the ACI Building Code (ACI 318-02), anchorage design provisions were finally codified into one document. The ACI 318 Appendix D provisions are based on the Concrete Capacity Design (CCD) method, which was an adaptation of the original European Kappa Method proposed in Germany in the late 1980's. The CCD method was moulded into ACI Code Provisions, based on successful use of the design provisions in Europe.

Placing anchorage requirements in the ACI Code was motivated by a need to rationally design post-installed anchorages, that is, anchorages installed in hardened concrete; cast-in anchors, including headed studs and bolts, were also incorporated into the design provisions. Appendix D provides the designer with a transparent means to perform anchorage design and incorporates a rational procedure for computing a minimum design capacity based on capacity at essentially first cracking.

https://doi.org/10.2749/222137908796293253

The ACI provisions present a simple physical concrete breakout model, which can readily accommodate the effects of anchor spacing in two directions and effects of edge conditions. Appendix D provides for these effects through the use of psi (ψ) modification factors on the basic breakout capacity.

The Appendix D provisions are necessarily a one size fits all design method; however, the behavior of post-installed and cast-in anchorages can be different, especially given the individual actions of shear, tension, or some combination thereof, coupled with the variability of field installation conditions verses plant production conditions. In tension, the in-place strength should be taken as the minimum value based on computing the concrete (breakout, side-face blowout, or pullout/pull-through) and steel capacity for the given anchorage configuration. Similarly, the strength of an anchorage in shear should be taken as the minimum value based on computing the concrete breakout, concrete pryout, or steel capacity for the characteristic anchorage configuration.

3. Post-installed Anchor Qualification Procedures

Design resistance in the ACI Code is based on how a specific post-installed anchor performs relative to qualification criteria. Post-installed anchors, in order to be used with the design procedures is the ACI Code, must be "prequalified." Cast-in anchors do not have to be qualified. The qualification of an anchor implies that the anchor satisfies minimum requirements. The qualification procedures are similar to ASTM requirements, which are written so that the designer has assurance of performance. These procedures are solely intended to reduce the risk to the end-user, the public. It should not be assumed that every post-installed anchor on the market will perform the same or even in a manner that satisfies the Code CCD behavior assumptions.

Qualification testing's objective is to evaluate, by test, how well the anchor performs, not just relative to load capacity. The qualification procedure includes a variety of different aspects from manufacturing to installation to load performance. An overview of the typical qualification procedure format follows.

Identification Tests - These tests evaluate the conformance of the anchor with the specifications for manufacturing the anchor. *Reference Tests* - This battery of tests establishes the baseline performance for other test comparisons. *Reliability Tests* - These crucial tests establish data for the safe and effective behavior under normal and adverse conditions. *Service-Condition Tests* - These mandatory tests establish data for the performance of the anchor under in-service conditions. *Qualification Report* - An independent laboratory conducts these tests and then writes a report that summarizes the tests and "grades" the anchor into a performance category.

This testing is rigorous and not inexpensive. All anchor manufactures are required to have these tests conducted if they hope to sell anchors for structural purposes.

4. The Anchor Designer

Today's structural engineer, who has to learn and apply the anchorage design procedures in ACI 318 Appendix D, is reluctant to fully welcome this new design procedure. The Appendix D document presents too many rules that have to be followed and too many calculations are required to get to an answer. The cry heard from the design community is *provide simplification* to the design for Appendix D applications.

5. Conclusions

Anchorage to concrete has progressed to a sophisticated state. Older models used to calculate the concrete breakout capacity have been replaced by models that are based on extensive test databases. However, designers do not want to give up the simplified approaches used in the past for more sophistication because the new models are complicated and have too many rules and exceptions to remember. Dr. Jack Breen, in his keynote address at the *2nd International Symposium on Connections between Steel and Concrete* in 2007, reminded the audience that we have come a long way in anchorage design but our design approach must be simplified for designers to embrace the Concrete Capacity Design approach of anchorage to concrete.