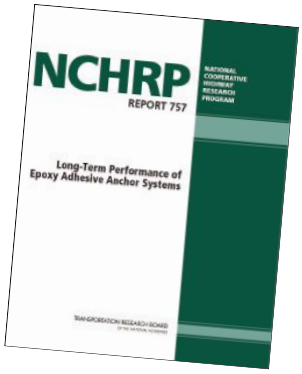


Anchors in Concrete: Guidance for Bridge Engineers—Part 1 of a four-part series

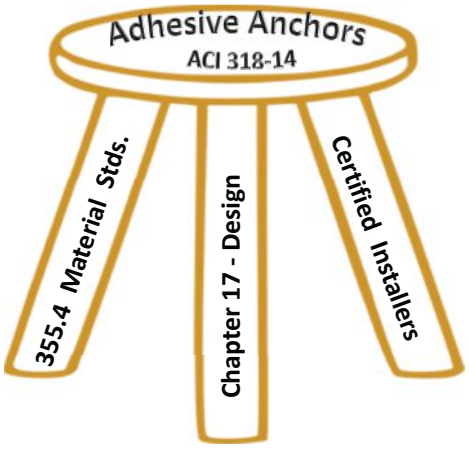
by Dr. Donald F. Meinheit

In 2006, adhesive-bonded anchors supporting a concrete-panel suspended ceiling in the Boston Interstate 90 Seaport Connector Tunnel ("Big Dig") project failed and 26 tons of concrete and hardware fell onto the roadway.[1] This tragic event resulted in one fatality and one injury and spurred an examination of the use of adhesive-bonded anchors carrying sustained tensile loads. Since that time, research has been performed,[2,3] and specifications have been introduced and improved for all anchor types. Furthermore, new resources to inform bridge engineers of design methodology and best practices are on their way.

NTSB Recommendations

A National Transportation Safety Board (NTSB) report[1] identified the creep of the epoxy adhesive as the cause of the Boston anchorage failure. The NTSB report contained safety recommendations for many parties, including the American Concrete Institute (ACI) and American Association of State Highway and Transportation Officials (AASHTO), to address the creep characteristics of the adhesive anchors.

There are three legs to the adhesive anchor quality stool: the design procedure in ACI 318-14 Chapter 17,[10] the qualification protocol in the ACI 355.4 material standard,[11] and an operational installer certification program. Figure and all Photos: Dr. Donald F. Meinheit.



Additionally, the NTSB report recommended that the Federal Highway Administration (FHWA) and all state departments of transportation (DOTs) prohibit the use of adhesive-bonded anchors in overhead tensile-loaded applications until testing standards and protocols were developed and implemented. That recommendation was based on what was known at that time. Prior to 2006, few studies on the sustained-load behavior of adhesive-bonded anchors had been done. The National Cooperative Highway Research Program managed by the Transportation Research Board (TRB) has subsequently published two studies on adhesive anchors in concrete under sustained loading.[2,3] That research, as well as improvements in regulations, specifications, and certification programs, contributed to a January 2018 FHWA Technical Advisory (T5140.34),[4] which canceled the previously issued T5140.30,[5] which strongly discouraged the installation of certain fast-set epoxy anchors. FHWA T5140.34 gives recommendations for the design of adhesive anchors in new Federal-Aid projects and guidance for inspection, retrofit, or replacement of anchors on existing projects.[6]

Improved Specifications

The first design provisions for cast-in-place and some types of post-installed anchors appeared in ACI's *Building Code Requirements for Structural Concrete* (ACI 318-02) *and Commentary* (ACI 318R-02),[7] and adhesive anchor design provisions were added in ACI 318-11.[8] Prior to ACI 318-11, design provisions for adhesive anchors were not included in any widely used U.S. design standard. When the eighth edition of the *AASHTO LRFD Bridge Design Specifications*[9] was published in 2017, concrete anchors were covered in a reorganized Section 5. Instead of writing its own design requirements for concrete anchors, AASHTO's Technical Committee T-10 Concrete Design adopted, with a few amendments, ACI 318-14[10] (see AASHTO LRFD articles in the Summer 2015 and Winter 2017 issues of *ASPIRE*®).

Recognizing the Human Factors

In its report on the Boston tunnel failure,[1] NTSB recommended that ACI use its "building codes, forums, educational materials, and publications to inform the design and construction agencies of the potential for gradual deformation (creep) in anchor adhesives…" Following that recommendation, ACI has been on a campaign to inform the engineering design community of the design provisions in ACI 318 regarding anchoring to concrete.

Additional factors that contributed to the Big Dig incident were the irregular installation of the adhesive anchors in an overhead condition and the inspectors' failure to understand the critical implications when they saw anchors displaced from their embedment holes.

Although addressing the human factors that can contribute to failures is recognized as an important step toward improving the performance of installed adhesive anchors, there remain substantial knowledge gaps to overcome. Undergraduate and graduate courses in concrete design typically do not cover concrete anchors. Also, bridge designers tend to be less familiar than designers of other types of facilities with anchoring to concrete because the AASHTO LRFD specifications did not include guidance until 2017, about

Concrete breakout failure of an anchor where the tension load strength has been influenced by the distance from the center of the anchor to the free edge of the member.

15 years after ACI 318-02 was published. It has therefore become evident to many stakeholders in the concrete bridge community that educational programs for structural designers are urgently needed to improve their understanding of anchors in concrete and the relevant parts of ACI 318 and the AASHTO LRFD specifications.

New Educational Opportunities

To respond to this need, the Prestressed/Precast Concrete Institute (PCI) submitted a proposal to TRB to prepare a comprehensive training program for highway bridge engineers on implementation of the new provisions on concrete anchors. PCI envisioned working with the TRB panel on a series of webinars so designers in every state would consistently receive the same important information on design, specification, approval, installation/construction, and inspection of all types of anchors to concrete.

An example of an external support anchored using post-installed concrete anchors. Anchors are loaded in combined tension and shear.

To lead this effort, PCI selected a team of subject matter experts to explain the unique characteristics of concrete anchors to designers and specifiers. The PCI team is composed of Dr. Ronald A. Cook, professor emeritus, University of Florida-Gainesville; Neal S. Anderson, staff consultant, Simpson, Gumpertz, and Heger, Chicago, Ill.; and Dr. Donald F. Meinheit, retired principal, Wiss, Janney, Elstner Associates Inc., Chicago, Ill. These subject matter experts have collaborated to develop and present two pilot, daylong seminars to highway bridge engineers. These modules and materials will be made available to the bridge community as 90-minute webinars with an additional 30 minutes for questions and answers.

To design, install, and inspect an anchor embedded in concrete, one needs more than an ability to follow rote guidelines. A thorough understanding of the failure modes of tension-loaded anchors and shear-loaded anchors is an important step in understanding the design provisions. Because concrete anchors are complex structural elements, the subject matter expert team, the FHWA, and industry committees have taken a holistic approach to educate the bridge community. The program developed by the team of experts assembled by PCI has major sections devoted to the following:

- Understanding the failure modes in tension and in shear
- Reviewing the basic code design equations for single anchors and anchor groups
- Reviewing the basic code design equations accounting for edge distance, anchor spacing, eccentricity, and cracking of the concrete
- Discussing which concrete anchor is best suited for a particular application
- Reviewing free design software options
- Discussing at length why anchors must be qualified against a standard and where to find the qualification data for a particular anchor from a particular manufacturer
- Reviewing how to procure the anchor specified on contract drawings and in specifications
- Discussing why there are two certification programs, one for adhesive anchor installers and one for anchor inspectors
- Reviewing field implementation and proof testing

All participants receive information for each course as a download, which includes course resource documents and copies of the slide presentation along with a transcript of the presenter's comments for each slide.

Pilot presentations of the seminar to two state highway bridge design groups were well received, and plenty of technical questions were asked. Once the TRB panel accepts the deliverable, which is anticipated by mid-2020, all information will be available on the TRB and PCI websites as a free download that can be used and customized by individual state highway agencies.

Future Articles in This Series

Future articles in this four-part series based on the PCI training program

on concrete anchors will focus on anchor qualification, specifications and procurement, and inspection and compliance testing.

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