Anchors in Concrete: Certification, Construction Inspection, and Compliance Testing—Part 4 of a four-part series

by Dr. Donald F. Meinheit

This article is part 4 in a four-part series addressing concrete anchorage in the reorganized Section 5 of the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*,[1] published in 2017. At that time, AASHTO added Article 5.13, Anchorage to Concrete, to the design specifications. Part 1 of this series of articles (see the Summer 2020 issue of *ASPIRE*®) outlined a PCI program sponsored by the Transportation Research Board to educate bridge engineers on the implementation of the new anchorage provisions adopted from the American Concrete Institute's (ACI's) *Building Code Requirements for Structural Concrete* (ACI 318-14) *and Commentary* (ACI 318R-14).[2] Part 2 (see the Fall 2020 issue of *ASPIRE*) focused on the qualification procedures for post-installed concrete anchors. Any anchor that is designed with the provisions of Article 5.13 of the AASHTO LRFD specifications must be qualified, and its behavior must be shown to be consistent with the design provisions in the AASHTO LRFD specifications. Part 3 (see the Winter 2021 issue of *ASPIRE*) reviewed the mechanisms that are available to procure concrete anchors indicated in specification sections and on contract drawings once they have been designed. This current article concludes the series by reviewing adhesive-anchor installer certification, explaining an anchor inspector certification program, and discussing guidance on field testing anchors for compliance to design requirements in ACI standards ACI 318-19[3] and ACI 355.4-19 *Qualification of Post-Installed Adhesive Anchors in Concrete* (ACI 355.4-19) *and Commentary*.[4]

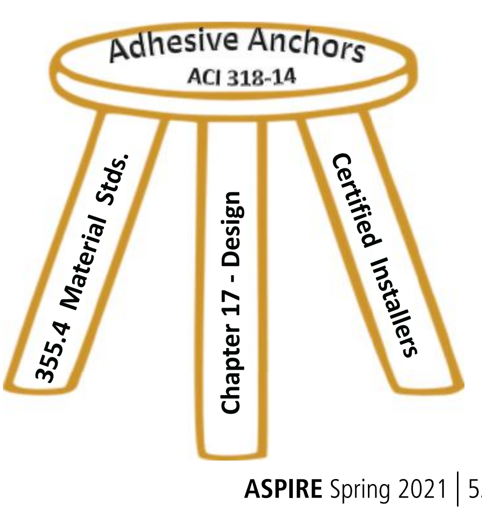
Installer Certification

The origin of many of the current requirements for installation and inspection of anchors can be traced to ACI 318-11,[5] when the adhesive anchor design procedures were first introduced into the ACI building code. During the discussions in the ACI 318 committee before publication of ACI 318-11, the committee was aware of the 2006 ceiling collapse in the Interstate 90 tunnel in Boston, Mass., and that the National Transportation Safety Board report identified that the creep properties of the adhesive used in the project were deficient.[6] However, others, including members of the ACI 355 committee, believed that although the adhesive did not have adequate creep resistance for the application, the overhead installation was also the most difficult orientation for adhesive installation and inexperienced installers should not be in control of many of the factors that affect the performance of overhead post-installed adhesive anchors under sustained load. A closer examination of the failed anchors revealed that the embedment hole was frequently not filled with adhesive or that the adhesive did not flow well into the threads of the anchor and thus compromised the bond strength.

My two copresenters of the PCI webinar series on concrete anchor design, Dr. Ronald A. Cook and Neal S. Anderson, were members of the ACI 318 committee at the time ACI 318-11 was being written. To get approval of the adhesive anchor provisions in the code, there were some heated committee discussions. Two critical issues were debated: sustained load and overhead installation. The ACI 355.4 standard was about to be published, and the testing protocols it specified to ensure that an adhesive has adequate performance when subjected to sustained load were available. The other critical issue was installation. Installation is not a task for a novice. Adhesive anchor installation is on par with structural welding—welders must be certified to do structural welding. The ACI 318 committee recognized that installation had a part in the failure in Boston and proceeded to incorporate provisions in ACI 318-11 that required any post-installed adhesive anchor carrying a sustained load and installed in an "upwardly inclined" orientation be installed by a certified adhesive anchor installer. ACI has developed an adhesive anchor installer certification program, which was available when ACI 318-11 was published.

Think of designing an adhesive anchor like a milking stool (**Fig. 1**): you need three legs for it to be stable.

Figure 1. There are three legs to the adhesive anchor quality stool: the design procedure in ACI 318-14 Chapter 17[2] (or Article 5.13 of the AASHTO LRFD specifications[1]), the qualification protocol in the ACI 355.4 material standard,[4] and an operational installer certification program. Figure: Neal S. Anderson.



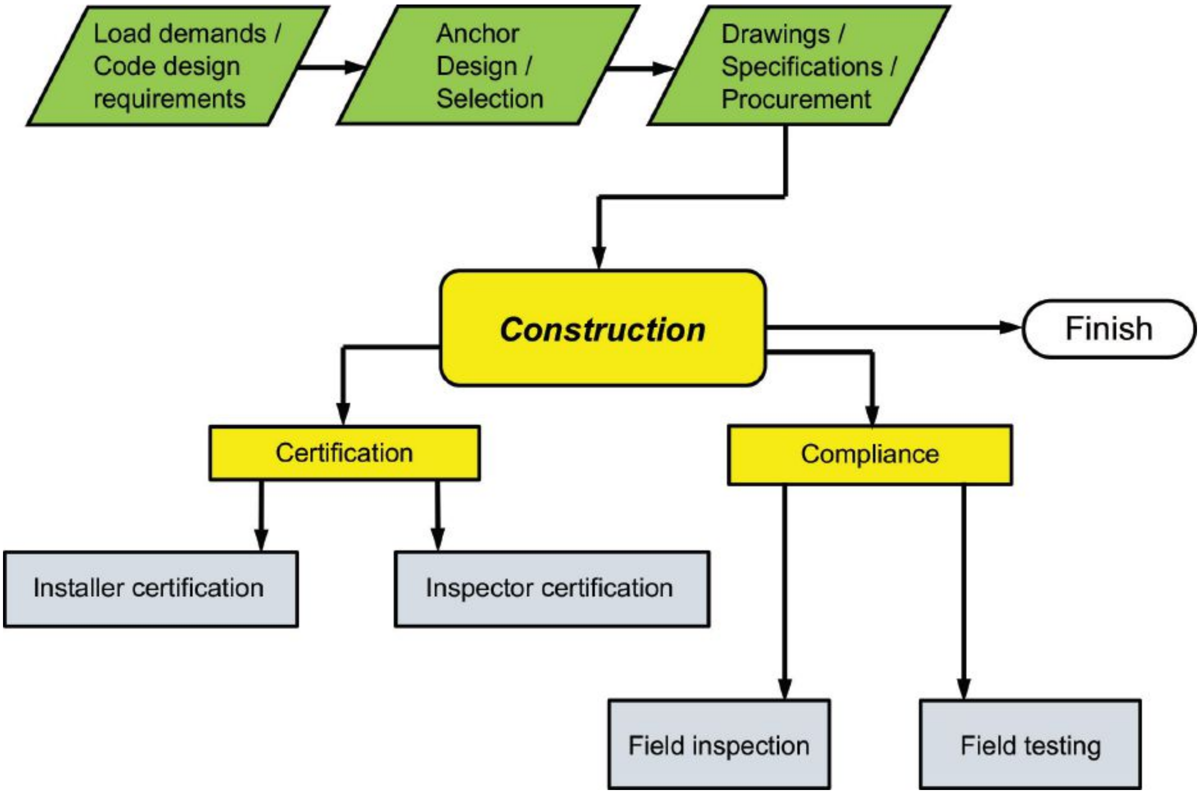


Figure 2. Flowchart depicting anchorage activities during construction. Figure: Dr. Donald F. Meinheit.

The first leg is the material standard, ACI 355.4, which qualifies the anchor as satisfying the requirements that are in the design code. The second leg is the design requirements found in Chapter 17 of ACI 318 and Article 5.13 of the AASHTO LRFD specifications, which define how the anchor carries load. The third leg for the successful use of adhesive anchors is an installer who can install them correctly in accordance with the manufacturer's printed installation instructions. That third leg is supplied by a certification program that ensures that the installer understands the installation procedures in the manufacturer's printed installation instructions and can perform the installation as intended. It is critical to install anchors according to the manufacturer's printed installation instructions because if the instructions are not followed, the anchor manufacturer is not obligated to ensure the published load values.

Inspection Requirements and Inspector Certification

The flowchart in **Fig. 2** shows anchorage installation activities. Anchor installation requires a certified installer who knows how to install an anchor in any orientation, inspection of the anchor installation as required by ACI and AASHTO specifications, and construction documents that specify proof-load requirements specifically for adhesive anchors—also required by ACI and AASHTO specifications. Acceptance testing is discussed in the final section of this article.

Construction inspection is required by the *International Building Code*[7] for all post-installed anchors used in building construction. The AASHTO LRFD specifications and ACI code also require inspection of adhesive anchor installation. This requirement has been in the ACI code since 2011. The new requirements in ACI 318-19, which are pending adoption by the AASHTO Committee on Bridges and Structures, are for all post-installed anchors (torque-controlled and displacement-controlled anchors), concrete screw anchors, undercut anchors, and adhesive anchors to be inspected by a certified inspector or a qualified inspector specifically approved for that purpose by the licensed design professional. ACI offers a program to certify such inspectors as ACI post-installed concrete anchor installation inspectors. The certification program requires that the inspector has demonstrated the knowledge required to properly inspect the installation of post-installed adhesive and mechanical anchors, and understands the responsibilities of and the qualification requirements for the installer. A post-installed concrete anchor installation inspector does not have to be a qualified installer but is obligated to understand the procedural steps for the anchor installation. A certified inspector must understand inspection requirements cited in the documents governing the construction specifications as well as the inspection requirements in the product evaluation service report (ESR).

A licensed design professional can specify periodic or continuous inspection of installed anchors in their specifications. The type of inspection required by code also depends on what the anchor manufacturer states in its ESR. All ESRs for the installation of adhesive anchors in overhead orientations carrying sustained load require continuous inspection.

ACI 318-19 requires certification of installers and inspectors. AASHTO is considering revising its requirements and adopting both Chapter 17 and the inspection and certification requirements in Chapter 26 of ACI 318-19. Certifications obtained through the ACI programs are valid for a period of five years.

Construction Compliance

General

Construction compliance includes both construction inspection and construction testing, as shown in Fig. 2. The question the designer or the inspection agency must ask is, what frequency is required for inspection and field testing? And for the inspector's part, the inspector must know if periodic inspection or continuous inspection is required. Guidance for inspection is found in the project specification section on anchors or in the ESR for that anchor. Another excellent general reference on field inspection is in an article by Silva and Mattis.[8] Reading this article before writing specifications or planning field-testing programs is highly recommended.

Inspection

Inspection can be required for either cast-in-place anchors or post-installed anchors. For a cast-in-place anchor, inspection is usually done before the placement of concrete. Inspection of cast-in-place anchors is similar to inspecting formwork and reinforcing bar placement before placing concrete.

For post-installed anchors, requirements for inspection are found in the appropriate ESR for the anchor. The AASHTO LRFD specifications list the resistance factor ϕ used for design. The ϕ-factors vary depending on the anchor reliability. Lower ϕ-factors are specified for anchors that receive periodic rather than continuous inspection. Periodic special inspection requires a certified inspector and is performed *intermittently*—the inspector is not present every time anchor installation steps are executed. Code for overhead installation requires continuous inspection, and this inspection is performed by a certified inspector who is *continuously* present. It is critical to have overhead installations continuously inspected to provide assurance that the design assumptions are justified.

Field Testing

Field testing can take place in one of two formats. In the first format, expendable anchors are installed and tested to failure to either develop site-load criteria or for direct comparison with the average capacity that is embedded in the design equations. In this first format, many tests must be conducted—30 or more for a given size (diameter) and embedment depth. The second format is a proof test on the anchor to some load such that the anchor can still be used in the structure if it passes the proof-load test.

The first format of field testing anchors as a means of establishing in-place strength is often confused with proof loading. Establishing in-place strength is not the intent of a proof-loading program. Proof loading is to make sure that there are no gross errors in the installation.

A fitting definition for proof loading is the application of tension load to fully cured adhesive anchors or, in the case of torque-controlled expansion anchors, application of a torque to an installed anchor to verify proper set of that anchor. Proof loading of screw anchors may be performed for anchors that have been prequalified for resetting. However, proof loading screw anchors should be approached with caution because tension testing may damage the screw threads cut into the concrete. It may be more appropriate to torque test an installed screw anchor.

The proof-load level is selected to be sufficiently high to provide assurance of correct installation, but the objective is that the proof-loaded anchor can still be used in the structure. Therefore, the load on the anchor should not be so high as to result in damage such as yielding or, for an adhesive anchor, any permanent slip. Currently there is no AASHTO or ACI standard for conducting proof-load tests.

- **Proof-load magnitude.** The magnitude of the proof load is typically set as a percentage of the anchor's tested tension capacity. The proof load is not the load used on the load side of the design equation. Proof-load magnitude has historically been about twice the allowable tension for the anchor in concrete. Considering that anchors have a global factor of safety of about 4, resulting in the "allowable" load being about 25% of the average ultimate capacity, the proof load should be about 50% of the mean ultimate anchor tension strength using the traditional criteria. The proof load should not be influenced by edges and member thicknesses. So, a typical proof load can be set at about 50% of the mean ultimate tension strength of the anchor or 70% of the "characteristic" design value, but not more than 80% of the nominal yield stress of the steel components. The proof load only has to be maintained on the anchor for about 10 seconds.
- **Deformation acceptance criteria.** Acceptable displacements at the proof load depend on the anchor type, diameter, and embedment. For an adhesive anchor, the rule of thumb is that no displacement should be allowed at the proof load. For a post-installed mechanical anchor, the anchor should not slip (deform) unless the proof load exceeds the preload in the anchor at installation. For mechanical expansion anchors, it has been suggested that a slip of as much as 10% of the anchor diameter is acceptable. A remedial action plan should exist in the event of failure.
- **Frequency of proof-load testing.** The frequency of testing is up to the designer. The suggested minimum is 5% to 10% of the total number of anchors installed, and the anchors to be tested are to be randomly selected. If any anchors fail, there might be an issue with the installation and the number tested should be increased.

Summary

This is the last article of a four-part series discussing the content of a webinar series prepared by PCI as a comprehensive training program for highway bridge engineers to explain the implementation of the provisions in the AASHTO LRFD specifications for the design of post-installed anchors in concrete. This final article discusses certification for installers and inspectors, inspection requirements depending on anchor type and installation orientation, and compliance testing of installed anchors.

Access to the five-session webinar training series on concrete anchor design is available at PCI.org/AnchoringToConcreteImp. For each of the five webinars, the following are available to download: the PowerPoint slides used in the presentation, a video of the presentation, the text of the presentation, course resource documents to amplify the written discussion, and a transcript of all the questions asked at the end of each webinar and the answers provided. These materials are available at no charge to anyone desiring more in-depth learning on the provisions for design of concrete anchors now in Article 5.13 of the AASHTO LRFD specifications.

References

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