Bonded Anchors

A Convenient Solution or Potential Liability

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Introduction

Dateline - July 10, 2006 Boston - tunnel ceiling collapses, kills one, fingers point to an adhesively bonded anchor, criminal investigation, NTSB.

This kind of headline is the last thing a structural designer ever wants to hear. NTSB spreads the blame for the ceiling problem to many parties and advises caution relative to the use of adhesively-bonded anchors. Designers may ask "should I use adhesively-bonded anchors?" Contractors may ask "what are my liabilities when installing adhesively-bonded anchors?"

Is there a rational way to design adhesively bonded anchors? Am I safe enough to use working loads and a Factor of Safety of 4 or 5 on a manufacturer's catalog value?...rational questions that deserve realistic responses.

Definitions

To foster a common language regarding adhesively-bonded anchors, the following definitions are important to this discussion:

- Drill hole diameter – the diameter of the hole drilled into the concrete that is slightly larger than the anchor rod.
- Anchor rod – usually a continuously threaded bar of mild carbon, stainless, or high strength steel; could also be a deformed reinforcing bar.
- Bonding agent – the agent (chemical or cementitious) used to fill the gap between the anchor rod and the drill hole; chemical adhesives include polyesters, vinyl esters, epoxy acrylates, and methacrylates.
- Failure modes (*Figure 1*);
  - steel failure mode (same as cast-in and mechanical expansion anchors)
  - concrete breakout (same as cast-in and mechanical expansion anchors)
  - bond failure (a failure mode similar to bond of a reinforcing bar embedded in concrete)

Designing Bonded Anchors

The code writing bodies and the anchor system manufacturers have not been idle. Even before the Boston tunnel ceiling collapse, an ACI published paper, *Behavior and Design of Adhesively Bonded Anchors* (*ACI Structural Journal*, Vol. 103, No. 6, 2006), outlined a proposed procedure to design bonded anchors. The proposed design procedure fits nicely with the current ACI 318 *Appendix D* procedures, and adds the additional calculation of checking the bond stress under tension. Capacity is modified for anchor spacing and edges in almost the same way the cast-in and mechanical expansion anchors in ACI's *Appendix D* address these variables for tension loading. No additional shear design rules are required.

So… can I safely design an adhesively-bonded anchor now?

Note that various adhesives (epoxies, polyesters, etc.) have different characteristics, and the designer needs to know these characteristics for design. ACI's Committee 355, *Anchorage to Concrete*, has not yet completed its consensus review process on the standard procedures to qualify and categorize the performance of the chemical adhesives. Looking ahead, provisions addressing adhesively-bonded anchors will likely first appear in the ACI 318-11 code.

WHAT!!! Designers need to wait 4 more years before adhesively-bonded anchors are codified? Yes… BUT… there is currently an alternative that is rational and permits only qualified anchoring materials.

Anchor manufacturers and ICC-ES worked together on a product acceptance criteria for adhesively-bonded anchors, ICC-ES AC308 *Acceptance Criteria for Post-installed Adhesive Anchors in Concrete Elements*. AC308 not only provides the testing protocols and criteria for acceptance but at the beginning of AC308 the design procedure is included along with all the capacity reduction factors (Φ) for design, which are based on the anchor performance during the extensive qualification testing protocol. AC308 looks very similar to the document that hopefully ACI will eventually publish. In fact, AC308 started out as a draft of the ACI committee document.

So there is a self-contained design/qualification procedure available for the designer to use (ICC-ES AC308), meant to ensure performance of the installed anchor.

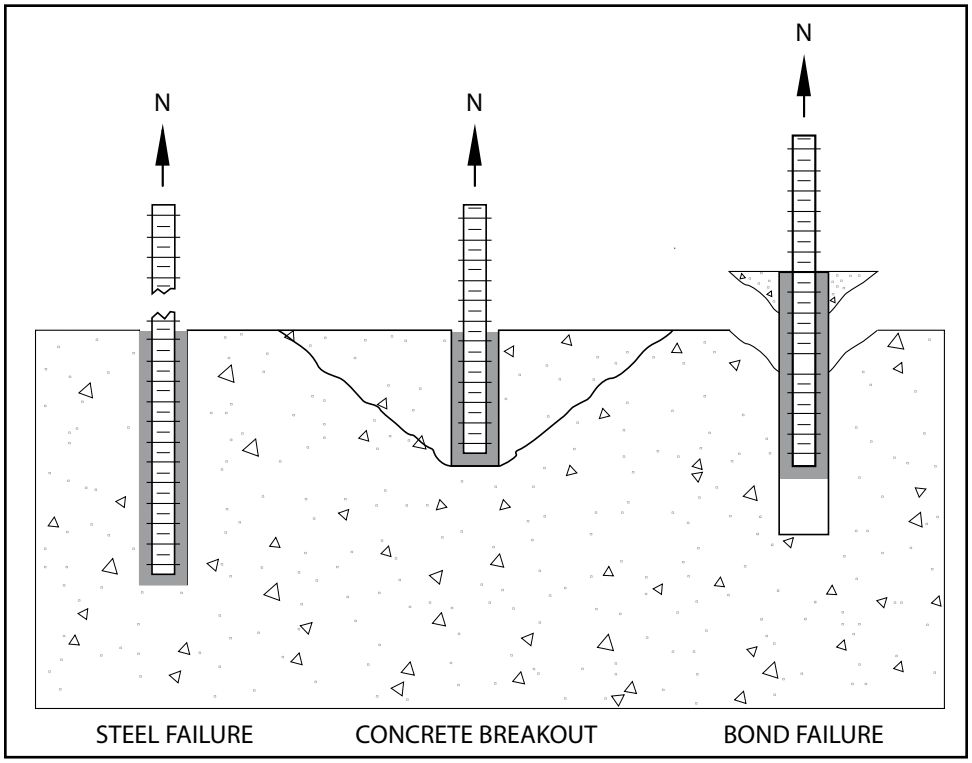

Figure 1: Failure modes for adhesive anchors.

The Qualification Testing Hoops

Those who are designing with ACI 318 *Appendix D* will recognize that there is a qualification procedure for mechanical expansion anchors. The document, ACI 355.2-07 *Qualification of Post-installed Mechanical Anchors in Concrete*, requires that mechanical expansion anchors must pass extensive test protocols to qualify for use with *Appendix D*. The adhesively-bonded anchor qualification procedure, in ICC-ES AC308, is just as comprehensive as ACI 355.2 and even more involved to ensure safety of the anchor in service. The qualification procedure for adhesively-bonded anchors will consist of the following basic tests.

- **Identification tests** - these tests describe the anchor system; that is, the anchor element and "fingerprint" of the adhesive characteristics.
- **Reference tests** - these tests are the baseline values for the reliability and service conditions tests; strict and ideal installation procedures are required.
- **Reliability tests** - these tests are used to establish the anchors' capability to function under adverse installations that are likely to occur in practice;
  - sensitivity to hole cleaning in dry concrete
  - sensitivity to hole cleaning with concrete saturated, water filling the hole, and concrete completely submerged
  - sensitivity to crack width
  - sensitivity to sustained load and crack width cycling
  - sensitivity to installation direction for the "dry" condition
  - sensitivity of sustained load at standard and elevated temperature (*increased scrutiny expected for this test*)
  - sensitivity to freezing and thawing environments
- **Service-condition tests** - these tests are to determine the performance of anchors under service conditions;
  - check for full anchor capacity in a corner given minimum edge distances
  - check for minimum spacing between two anchors and minimum edge distance to preclude splitting failure of the concrete
  - check performance of the adhesively installed anchor to aggressive chemical environments
  - check bond of anchor with decreased installation temperatures
  - check of cure time at standard temperature
  - check the tension bond in cracked and uncracked concrete
  - check for member thickness influences
- **Anchor category determination**
  - from results of the reliability and service-condition tests, a category is assigned to the anchor; this category number "assigns" a capacity reduction factor (Φ) to the anchor; this Φ is used on the resistance side of the design equation to determine capacity
  - the testing also produces the characteristic design value, that is, the 5% fractile bond stress to be used in the load capacity equation on the resistance side of the design equation

Summary

Getting back to the question: Can I design using adhesively-bonded anchors now? The answer is yes!

There are existing procedures, AC308, to qualify adhesively-bonded anchors, which push the installed anchor through a number of tests to determine its worthiness to conform to the assumptions made by the structural design procedure. The qualifying procedures that exist in AC308 are thorough enough to provide the designer, contractor, manufacturer, and public with assurance that the installed anchor will perform in accordance with the design procedure.▪

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