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Adhesive Anchor Installation and Inspection

Understanding the requirements to ensure proper performance

BY RICHARD E. WOLLMERSHAUSER AND LEE MATTIS

Post-installed adhesive anchors, also known as epoxy anchors, chemical anchors, bonded anchors, and adhesive-bonded anchors, have been successfully used to make connections to concrete structures for many years. With the failure of adhesive anchors in the Boston I-90 Tunnel Project, commonly called the Big Dig, the use of these types of anchors has been called into question. This article reiterates the proper installation and associated inspections necessary for adhesive anchors to achieve the desired performance.

WHAT ARE ADHESIVE ANCHORS?

Adhesive anchors in concrete or masonry derive their resistance to applied tension load by adhesion or bond. The adhesive, available in both cartridge and capsule configurations, consists of two essential components: a resin and a hardener.

When cartridges are used, the two components are contained in separate parallel tubes connected to a manifold that proportions the materials in the proper ratio and mixes them together. The cartridge tool forces the materials out of the tubes, through the manifold and mixing nozzle, and into the drilled hole. The mixing nozzle ensures that the components are well mixed so the adhesive resin is activated by the hardener.

When an adhesive capsule is used, the resin and hardener are kept separate but are contained within a single glass or foil capsule. After inserting the entire capsule into the drilled hole, the anchor element, usually a threaded rod, is inserted into the predrilled hole with a rotational motion using a rotary drill. The rotary motion of the anchor breaks the capsule, causing the resin and hardener to mix and initiating the chemical reaction that hardens the adhesive.

Adhesive anchors are available in a variety of chemistries, each with its own specific characteristics and capacities. The adhesive materials include epoxies with many different formulations, acrylates, vinyl esters, polyesters, and hybrid mortars. The specifier, installer, and end user should become familiar with the requirements of each specific application to ensure the selected anchor and adhesive materials are appropriate for the given application.

SELECTION OF ADHESIVE ANCHORS

Selection of the appropriate adhesive anchor system requires an understanding of the loads to be resisted. Not only the direction of the load (tension, shear, or a combination of tension and shear), but also the duration (sustained or short-term loads) and the source (gravity, wind, or seismic). Proper selection also requires matching the adhesive material to the environment of the application. This includes consideration of such factors as the expected ambient environment, elevated temperatures, and protection from adverse weather.

PREQUALIFICATION OF ADHESIVE ANCHORS

Prior to 1995, there were no written criteria for testing and qualifying adhesive anchors. The International Conference of Building Officials Evaluation Service (ICBO ES) recognized adhesive anchors through AC01, "Acceptance Criteria for Expansion Anchors in Concrete and Masonry Elements,"[1] as a basic test protocol and acceptance criteria with some additional special requirements applicable to adhesive anchors. Recognizing

the need for stand-alone adhesive anchor criteria, ICBO ES requested recommendations from the anchor industry. In 1994, an ad hoc committee began work on draft acceptance criteria for adhesive anchors. The committee developed a set of testing protocols that could be used to prequalify adhesive anchors for use with the design provisions contained in the Uniform Building Code (UBC).[2]

In January 1995, ICBO ES adopted AC58, "Acceptance Criteria for Adhesive-Bonded Anchors in Concrete and Masonry."[3] This document contained the testing methods (based on ASTM E1512[4]) and acceptance criteria for evaluating and qualifying adhesive anchors for structural use in accordance with the provisions of the UBC. The Concrete Anchor Manufacturers' Association (CAMA) was subsequently established by members of the ad hoc committee to assist with future criteria and code development.

Since the merger of the three major building code organizations into the International Code Council (ICC) and the subsequent creation of the ICC Evaluation Service (ICC-ES), AC58 has remained in use. With the publication and adoption of the 2003 International Building Code (IBC 2003),[5] however, new qualification criteria were required to address the requirements of ACI 318-02,[6] Appendix D: Anchoring to Concrete, which is referenced in the IBC. Although ACI 318-02 excluded adhesive anchors from the design procedures, CAMA provided recommendations for a new design procedure and acceptance criteria in AC308, "Acceptance Criteria for Post-Installed Adhesive Anchors in Concrete Elements,"[7] to address the requirements in Appendix D. AC308 was adopted by ICC-ES in June 2005 and now supersedes AC58 for concrete installations. AC308 contains acceptance criteria for adhesive anchors used in both cracked (tension zone) and uncracked concrete in accordance with the provisions of the IBC.

After testing by an independent third party according to the protocols in AC308, ICC-ES evaluates the testing and issues an Evaluation Service Report (ESR) that contains all the information necessary to properly use the adhesive anchor system including technical data, installation procedures, the category of the anchor system for design, and any limitations on the adhesive anchor system.

INSTALLATION REQUIREMENTS

Once the correct adhesive anchor system has been selected, installation is the next critical aspect to be considered. As part of the prequalification procedure, anchors are tested after they're installed according to the manufacturer's published installation procedures. It's of great importance to follow these instructions to obtain the published anchor capacities and performance characteristics. Installation instructions specify the drilling method, hole cleaning procedure, how to install the adhesive and the metal anchor in the drilled hole, and the care to be taken until the adhesive has cured. Let's look at each of these aspects.

Drilling method

The usual method for drilling concrete is to use a rotary-hammer drill with a carbide drill bit of a specified diameter, creating a roughly cylindrical hole. Prequalification tests are typically based on such a drilling system.

Other drilling methods sometimes used include rock drills and diamond coring. Rock drills usually produce holes with walls that are somewhat rougher than those drilled with rotary hammer drills, whereas diamond core bits usually produce holes with walls that are somewhat smoother. Both of these drilling methods affect the capacity of adhesive anchors—rock drilling generally increases the capacity, whereas core drilling generally decreases the capacity. The user should check whether the anchor capacity is affected if other than rotary hammer drilling is used. Because diamond core drilling is

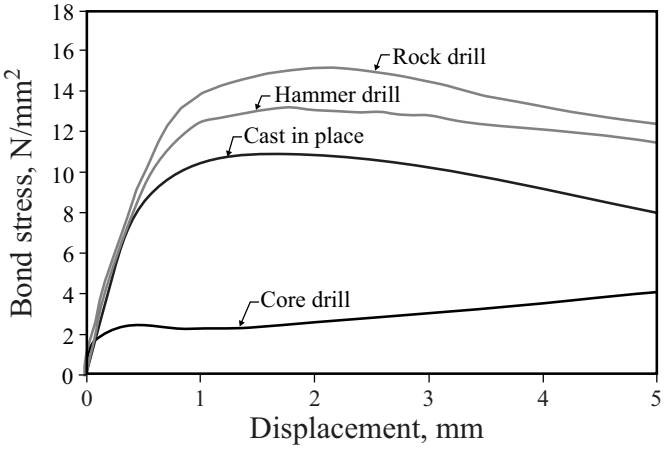


Fig. 1: Bond stress-displacement curves for 20 mm (0.8 in.) diameter adhesive anchors installed in holes made by various drilling methods. Anchors in core drilled holes had 300 mm (11.8 in.) embedment in 50 MPa (7250 psi) concrete. All other anchors had 200 mm (7.9 in.) embedment in 20 MPa (2900 psi) concrete (based on Reference 8) (1 in. = 25.4 mm, 1000 lb/in.² = 6.89 N/mm²)

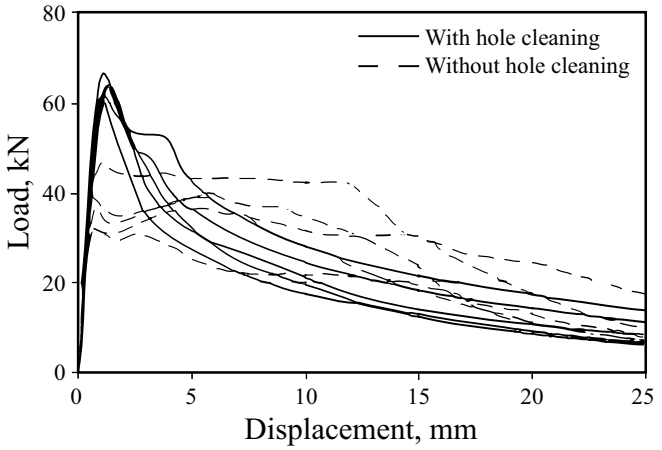


Fig. 2: Load-displacement curves for 12 mm (0.5 in.) diameter anchors with 110 mm (4.3 in.) effective embedment depth in 24 MPa (3500 psi) concrete bonded using an adhesive that is sensitive to hole cleaning (based on Reference 8) (1 in. = 25.4 mm, 1000 lb = 4.45 kN)

usually accomplished using water, the method creates a slurry. This slurry is not removed while drilling, so the residual material must be flushed from the hole before it dries to prevent it from affecting the anchor tensile capacity. Figure 1 illustrates the reduction in bond strength that may be obtained from different drilling methods compared to a cast-in reinforcing bar. The adhesive used was a low-adhesion resin system.

Some anchor systems are sensitive to the size of the annular gap between the anchor rod and the wall, while others are not. The correct bit type and diameter must be used in accordance with the anchor manufacturer's instructions.

Because the performance of the anchor depends on a specified embedment into the concrete, the hole must be drilled to the depth recommended by the manufacturer.

Hole cleaning

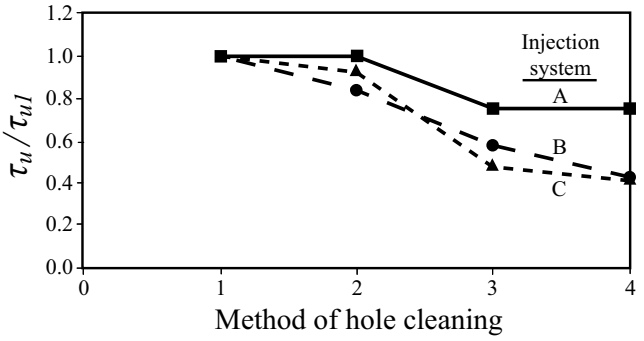
Proper hole cleaning is critical to almost all adhesive anchor installations and the lack thereof is frequently a major source of poor adhesive anchor performance. Figure 2 demonstrates the influence of lack of hole cleaning on the load-displacement curves of adhesive anchors. The specified procedures must be followed for the adhesive to properly adhere to the concrete. The usual method involves brushing with a stiff metal or nylon brush and blowing out the hole with sufficient compressed air. This must be done in the sequence and manner that best removes the debris and dust particles from the hole. Figure 3 illustrates the influence of the degree of hole cleaning on bond strength for three different injection systems.

Any standing water from rain or construction activity should be thoroughly removed and the hole should be dry during anchor installation, unless the anchor system has been qualified for installation under damp or wet conditions. Figures 4 and 5 show the possible effects of installing anchors in wet concrete using a resin that is sensitive to moisture. The correct installation procedures will vary by product but will be specified in the manufacturer's literature and the ESR.

Installation of the adhesive and anchor

For cartridge adhesive systems, the manufacturer's complete system should be used. When a new cartridge is used, manufacturers universally recommend that some adhesive be dispensed and wasted on a disposable surface until a consistent adhesive color is obtained. This ensures that the adhesive materials are properly mixed and will set and harden properly. If this procedure is not followed, the first anchor installations with the new cartridge may not achieve full performance. In some cases, the anchors can be removed by hand because the adhesive is not adequately mixed. After hole cleaning, this is one of the most common and serious errors that occur with cartridge systems. Anecdotes are told about installations where every tenth (or some other multiple) anchor could be easily removed by hand, corresponding to the use of a new cartridge.

The mixing nozzle is inserted into the bottom of the hole and slowly withdrawn as the adhesive is pumped into the hole while avoiding the introduction of air voids into the adhesive mass. It's important to fill the hole with enough adhesive so the annular space is completely filled when the anchor rod is installed. The manufacturer's installation instructions typically state how much adhesive should be dispensed into the hole to completely fill the annular space. Insertion of the anchor element should be



Method of hole cleaning	
1	2 x blowing 2 x brushing 2 x blowing
2	1 x blowing 1 x brushing 1 x blowing
3	2 x blowing
4	No cleaning (drilling machine retracted 3 times)

Fig. 3: Influence of the intensity of hole cleaning on the bond strength (τ_u) of 12 mm (0.5 in.) diameter injection anchors in dry concrete (τ_{u1} = bond strength using cleaning method 1) (based on Reference 8)

with a twisting motion to ensure that the adhesive flows into the threads of a rod or around the deformations of a reinforcing bar. It's very important that the anchor element is inserted to the bottom of the hole so the required embedment is achieved. The presence of air voids, incomplete hole filling, and short embedment reduce the area of adhesive bond to the anchor rod or the wall of the hole and are detrimental to adhesive anchor performance.

Capsule systems are much less sensitive to installation procedures. The manufacturer's installation procedure, however, should be followed. The capsule is inserted into the drilled hole. The anchor, usually a threaded rod, is inserted to the full depth of the hole with a rotary hammer drill, mixing the adhesive contents of the capsule, as well as scouring the wall of the hole. The depth of the hole is specified by the manufacturer and corresponds to the capsule diameter and desired embedment length. The total length of the anchor rod depends on the embedded length and the amount of the anchor that will protrude above the concrete. Once the insertion of the anchor is completed, the anchor should not be touched until the adhesive has set.

Curing

After the anchor is inserted into the adhesive, it should not be disturbed until the adhesive has cured. Set times are listed in the ESR or the manufacturer's instructions. Curing takes more time at lower temperatures and less time at higher temperatures. Some adhesives can be loaded in tension within an hour of installation, while others may require as long as 24 hours. Refer to the ESR or the manufacturer's literature for product-specific information.

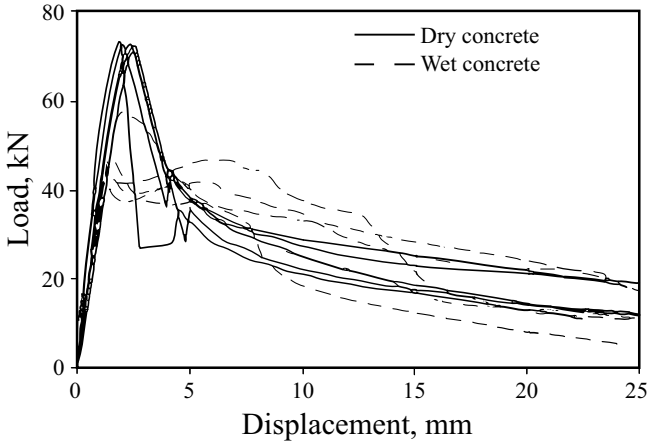
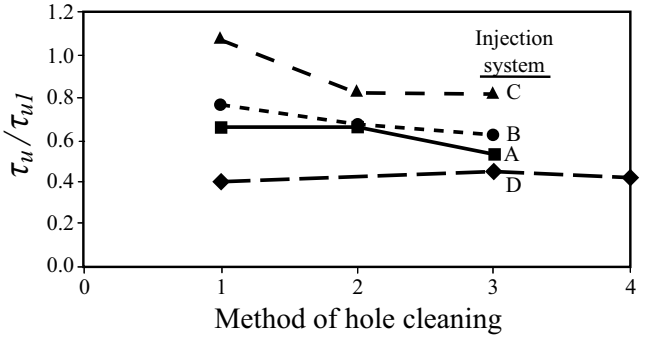


Fig. 4: Load-displacement curves for 12 mm (0.5 in.) diameter anchors with 110 mm (4.3 in.) effective embedment depth in 24 MPa (3500 psi) concrete. Anchors installed in thoroughly cleaned holes and bonded using an adhesive that is sensitive to moisture in concrete (based on Reference 8) (1 in. = 25.4 mm, 1000 lb = 4.45 kN)



Method of hole cleaning	
1	2 x blowing 2 x brushing 2 x blowing
2	1 x blowing 1 x brushing 1 x blowing
3	2 x blowing
4	No cleaning (drilling machine retracted 3 times)

Fig. 5: Influence of the intensity of hole cleaning on the bond strength (τ_u) of 12 mm (0.5 in.) diameter injection anchors in wet concrete (τ_{u1} = bond strength using cleaning method 1 in dry concrete) (based on Reference 8)

SPECIAL INSPECTION

Installation of adhesive anchors under the IBC requires special inspection to ensure that the installation is correctly performed in accordance with the design and the ESR requirements. Special inspection is continuous observation of construction activities requiring unique expertise or where additional assurance of quality is deemed necessary. The requirements are found in IBC Sections 1702, 1704, and 1901.5. The owner or the licensed design professional, acting as the owner's agent, must employ the special inspector. The special inspector must be approved by the building official and has a

responsibility to the building official in the performance of special inspection.

Special inspection is mandated by the ESRs for all adhesive anchor systems. This is due to the correct perception by ICC-ES that proper installation is critical to achieving the desired performance. The special inspector must verify that the installation is in accordance with the requirements of the approved plans, ESR, and manufacturer's instructions. This generally means verifying the location of the anchor, any edge distance and spacing requirements, drilling equipment, drill bit type and size, hole depth, hole cleaning procedures, anchor type and material, size, embedment, and installation procedure including checking adhesive expiration date and proper dispensing meet the specification.

Although special inspection is defined as continuous observation of the construction activity, there is a provision in the IBC for periodic inspection with the approval of the building official. Because critical requirements can be verified at certain phases of the installation, the installation of adhesive anchors can effectively be inspected periodically. For instance, the special inspector can verify appropriate requirements after the holes have been drilled and cleaned but prior to installation of the adhesive and anchors. The inspection of the adhesive dispensing and anchor installation can be done immediately after the verification of hole drilling with the special inspector present. In any case, the special inspector must be able to directly witness and verify all aspects of the installation.

Proof loading alone is not recognized as meeting special inspection requirements. While proof loading may be specified as a supplemental requirement to special inspection, visual inspection of the anchor installation procedures must still be provided because it's not possible to verify embedment and other important installation requirements after the anchors have been installed. From a practical standpoint, it's not always possible to load an anchor to a level that will adequately stress the adhesive due to limitations of the anchor material properties, such as the steel strength. For instance, a proof load of 50% of the adhesive bond strength is considered a reasonable maximum load that will not damage the adhesive bond of a properly installed anchor. This load level, however, may not be possible if a mild steel anchor rod is used because it would load the rod close to or above its yield strength. Nevertheless, proof loading can be an effective incentive to promote good installation practices.

For an in-depth article about special inspection for both mechanical and adhesive post-installed anchors, refer to the CAMA Web site, **www.concreteanchors.org**, where a comprehensive paper[9] on this subject can be found under the "PUBLICATIONS" link.

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Selected for reader interest by the editors.

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