

# Overhead Installation of Injection-Type Adhesive Anchors

An evaluation of two available methods and recommendations for ACI's installer certification program

by John Silva

The installation of adhesive anchors in horizontal to upwardly inclined orientations is the focus of several code provisions in ACI 318-14.<sup>1</sup> These provisions are intended to ensure that adhesive anchors installed in these orientations (referred to as “overhead installation” in this article) are safe and reliable. The provisions also include requirements on the qualification of the anchor system according to the ACI 355.4-11<sup>2</sup> standard, design for sustained tension loads, and the training and certification of workers that perform the installation of such anchors.

A recent laboratory study, in which the two currently available methods for installing injection-type adhesive anchors (the most common adhesive anchor type) in the overhead position are assessed for their effectiveness, is summarized herein. This study was undertaken in the context of mounting anecdotal evidence that overhead installation of injection-type adhesive anchors without the aid of a device such as a piston plug may be unworkable and therefore unsafe.

## Background

On the evening of July 10, 2006, a vehicle entering the I-90 eastbound connector tunnel of Boston's Big Dig en route to Logan International Airport, Boston, MA, was struck by a 20 x 40 ft (6 x 12 m) section of concrete ceiling falling from above, resulting in the death of a passenger in the vehicle and injury to the driver.<sup>3</sup> The ceiling panels had been hung from the concrete tunnel roof using 5/8 in. (16 mm) diameter injection-type adhesive anchors embedded 8 anchor diameters into the tunnel roof. An investigation by the National Transportation Safety Board (NTSB) highlighted the use of an adhesive not suitable for sustained tension loads, but also

noted that poor installation may have played a role in the failure. The investigation and repair resulted in closure of the affected section of the tunnel system for nearly a year. Six years later, on December 2, 2012, a similar collapse of ceiling panels occurred in the Sasago Tunnel in Japan, killing nine motorists. The anchors in this case were capsule-type adhesive anchors, not injection-type anchors.<sup>4</sup>

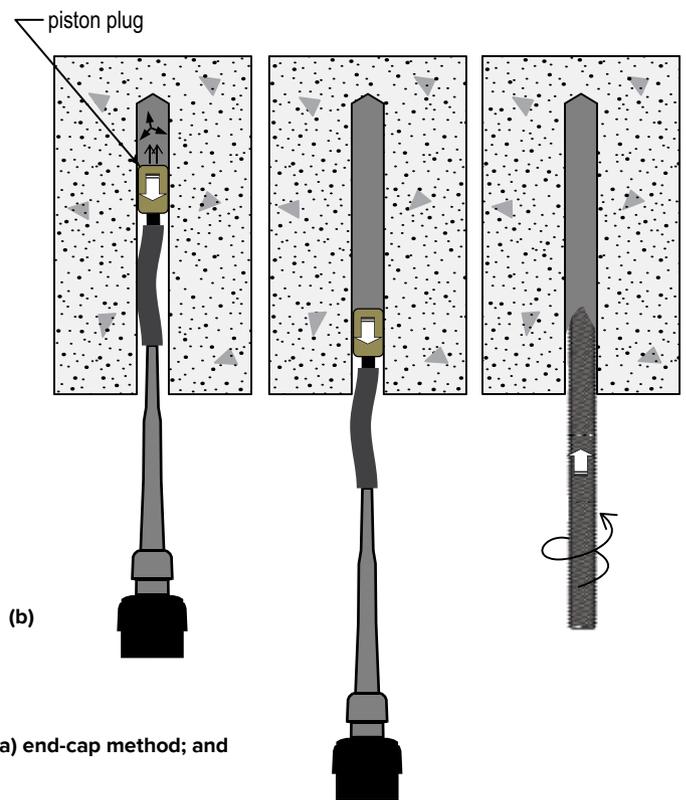
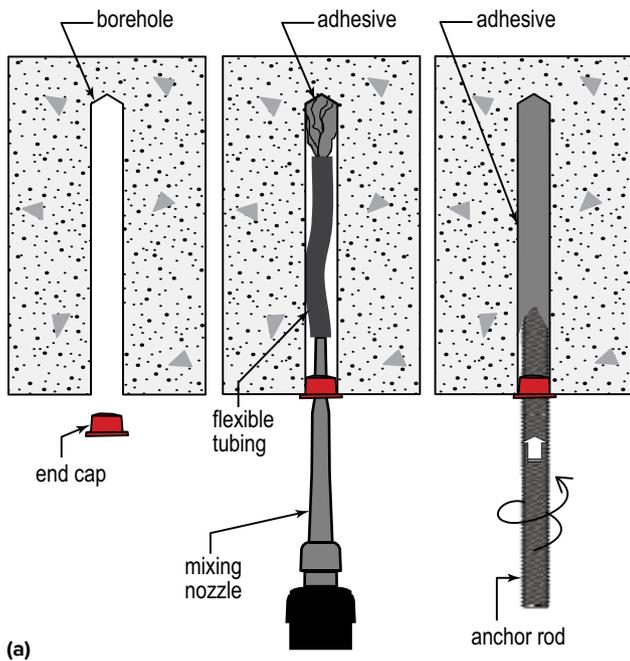
In response to the Boston collapse and the subsequent report of the NTSB, which noted the lack of guidance on the design and use of adhesive anchors in construction, ACI developed design and qualification procedures for adhesive anchors that were implemented in the ACI 318-11 Code<sup>5</sup> and a new ACI 355.4-11 standard. In addition, at the request of ACI Committee 318, Structural Concrete Building Code, the ACI Certification department fast-tracked the implementation of a certification program for installers of adhesive anchors using input from industry subject-matter experts. These efforts have resulted in substantial improvements in the safety of adhesive anchors, which continue to be widely used in construction due to their versatility.

A remaining area of uncertainty concerns the two methods of injecting adhesive into holes in “horizontal to upwardly inclined”<sup>1</sup> (that is, overhead) orientations that are recognized by the ACI/CRSI Adhesive Anchor Installer (AAI) certification program.<sup>6</sup> Both methods are included in evaluation reports issued by ICC Evaluation Service, LLC. The reliability of these two methods is the subject of this investigation.

## End-cap and Piston Plug Methods

The overhead installation procedure used for the Boston tunnel ceiling anchors is generally referred to as the end-cap method. Adhesive injection proceeds through a plastic cap designed to seal the bottom of the hole against adhesive leakage (Fig. 1(a)). Extension of the mixing nozzle—usually with flexible vinyl tubing—is used to reach the back of the

**ci** *Overhead installations of adhesive anchors are shown in a movie, available at [www.concrete.org/CIVideo2](http://www.concrete.org/CIVideo2).*



**Fig. 1: Methods for overhead installation of injection adhesive anchors: (a) end-cap method; and (b) piston plug method**

hole for embedment lengths that exceed the reach of the mixing nozzle. The method requires the installer to withdraw the injection tube at a rate corresponding to the degree to which adhesive has filled the hole. As documented in testing conducted by the Federal Highway Administration (FHWA),<sup>7</sup> this procedure can result in significant voids in the injected adhesive mass, the presence of which can impede the insertion of the anchor rod and reduce the bonded area of the anchor (Fig. 2).

The piston plug method (Fig. 1(b)) uses a cylindrical attachment, usually made of molded plastic, to improve the installation reliability of cartridge adhesive anchor systems. The piston plug method was developed to reduce the likelihood that air voids will be encapsulated in the injected adhesive for the installation of post-installed reinforcing bars (an application that often involves deep embedments). It has since been adapted for anchor applications and is now offered by most manufacturers of adhesive anchor systems. Adhesive injection with a piston plug begins by securing the piston plug to the end of the extension tube and pushing it to the back of the drilled hole. As adhesive is expressed through the injection tubing and the attached piston plug (which is matched to the drilled hole diameter), the pressure of the injected adhesive drives the piston plug back out of the hole (Fig. 1(b)). Unlike the end-cap method, the piston plug automatically meters the withdrawal rate and thus reduces the likelihood that air will be trapped in the injected adhesive mass.

The ongoing use of the end-cap method by some manufacturers of adhesive anchor systems has led to mandatory inclusion of this procedure in the ACI/CRSI AAI certification program.<sup>6</sup> Since its inception in 2011, certification under the



**Fig. 2: End-cap installation with voids (Ocel et al.<sup>7</sup>)**

program has been contingent on the successful completion of at least one blind injection in a clear acrylic tube with both the end-cap and piston plug methods. Although the tube diameter and length (7/8 x 9 in. [22 x 229 mm]) are representative of what should be an uncomplicated installation, anecdotal evidence indicates that the failure rate of test-takers attempting the end-cap installation has been high. This, despite the facts that the installers should have practiced the method prior to the exam; the installation is usually being conducted in a conditioned, well-lit interior environment; the position of the installer is essentially adjacent to the “hole” instead of directly under it; and the installer is permitted to retry the installation if he or she believes the initial attempt was inadequate.

Successful completion of the AAI certification examination authorizes the examinee to install any qualified system in the overhead position using either a piston plug or the end-cap method. It may be inferred that a single successful installation at the diameter and length included in the AAI program qualifies the certified installer to perform these installations for all diameters and embedments.

Currently, two adhesive anchor manufacturers include the use of the end-cap method in evaluation reports issued under ICC-ES AC308<sup>8</sup> for the installation of injection adhesive

anchors overhead for embedments up to 25 in. (635 mm) with, for example, 1-1/4 in. (32 mm) threaded rod. It is, therefore, reasonable to ask whether a single successful attempt of the end-cap method under the AAI performance examination conditions is sufficient to verify the ability of the candidate to repeat this procedure consistently and reliably on a jobsite.

## Investigation

Given the lack of data concerning the relative effectiveness of these two installation procedures, and in the interest of reliability and safety of overhead installations used to carry sustained tension loads (as in the Boston tunnel ceiling), an extensive investigation was conducted in late 2015 at the University of Stuttgart, Stuttgart, Germany. The investigation compares the performance of the piston plug and end-cap installation methods for a variety of installation conditions using two adhesives that have been assessed under ACI 355.4-11 (denoted as Adhesive A and B). (Note: Adhesive A is currently offered for installation with the piston plug method only. Adhesive B is marketed for installation with either the piston plug or end-cap installation method.) In particular, the ability to successfully inject large-diameter, deep holes was investigated. The effect of rod insertion on the quality of installations that contained voids was investigated, and potential weaknesses of the acrylic tube method for verifying installation efficiency as required in ACI 355.4-11 were identified.

The scope of the investigation is described in Table 1. The primary mode of investigation was the blind injection of adhesive in clear acrylic tubing that was subsequently sectioned with a band saw. In addition, tests were conducted in concrete specimens that were split open to check for voids.

The test program objectives were to assess the effectiveness of:

- The end-cap and the piston-plug overhead installation procedures for typical injection adhesive types;

- The current ACI/CRSI certification program for determining the competence of successful candidates to install any qualified adhesive anchor installation system for the full range of qualified anchor diameters, embedments, and installation temperature ranges; and
- The ACI 355.4-11 testing and assessment procedures for overhead installation.

Installation quality of adhesive anchor systems is to some degree dependent on the experience of the installer. The individuals selected to perform the work had substantial experience installing adhesive anchors in laboratory investigations in both the downhole and overhead positions. Nevertheless, for these tests, each installer was pre-qualified for overhead injection using the same procedure employed in the ACI/CRSI AAI certification program.

## Test Program

The test stand used for blind injection in clear acrylic tubes is shown in Fig. 3. The test stand was patterned after that used for the ACI/CRSI AAI certification program. A prequalification series of injections were performed to establish the qualifications of the installer. Testing consisted of both piston plug and end-cap installations in acrylic tubes with inside diameters of 7/8 and 1-3/8 in. (22 and 35 mm), and lengths of 9 and 25 in., respectively. (Note that a 7/8 in. hole diameter corresponds to a 3/4 in. [19 mm] anchor rod diameter and a 9 in. tube length represents a 12 anchor diameter embedment. A 1-3/8 in. hole diameter corresponds to a 1-1/4 in. anchor rod diameter and a 25 in. length corresponds to 20 rod diameters, the maximum embedment permitted under the design provisions of ACI 318-14.) All acrylic tube specimens were saw-cut lengthwise following adhesive cure. Per the AAI certification program rubric, installations are judged based on a maximum void size as well as the location of voids relative to the top of the acrylic tube. The examination and grading of the test specimens in this program used a limiting void amount of

**Table 1:**  
**Outline of test program conducted at the University of Stuttgart**

Phase	Test type	Description
1. Qualification of installer	Injection in 7/8 x 9 in. acrylic tubes mounted in test stand	ACI/CRSI grading criteria – fill one tube successfully
2. Repetitions at room temperature	Injection in 7/8 x 9 in. acrylic tubes mounted in test stand	ACI 355.4-11 criteria – void area less than or equal to 10%
3. Repetitions with cartridges conditioned to maximum and minimum installation temperatures	Injection in 7/8 x 9 in. acrylic tubes mounted in test stand	ACI 355.4-11 criteria – void area less than or equal to 10%
4. Repetitions in maximum diameter and length tubes with cartridges at room temperature and conditioned to maximum and minimum installation temperatures	Injection in 1-3/8 x 25 in. acrylic tubes mounted in test stand	ACI 355.4-11 criteria – void area less than or equal to 10%
5. Repetitions in maximum diameter and length tubes with cartridges at room temperature and conditioned to maximum and minimum installation temperatures	Injection in 1-3/8 x 25 in. acrylic tubes mounted in test stand followed by insertion of threaded rods	Investigation of influence of rod insertion on injections with voids
6. Tests in concrete	Injection in 1-3/8 x 25 in. holes in overhead position, rods inserted	Specimens split open to reveal effectiveness of installation

Note: 1 in. = 25.4 mm

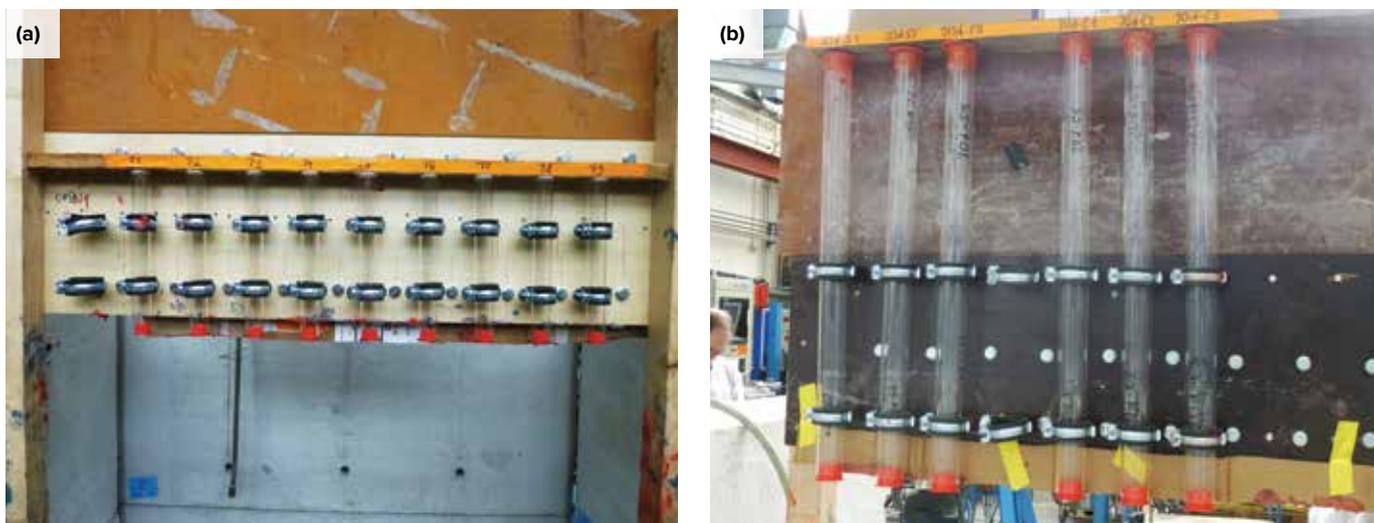


Fig. 3: Test apparatus: (a) 7/8 x 9 in. (22 x 229 mm) acrylic tubes with end caps; and (b) 1-3/8 x 25 in. (35 x 635 mm) acrylic tubes with end caps

10% of the total area of the cross section to distinguish successful from unsuccessful injections.

The evaluation criteria in Section 10.12.1 of ACI 355.4-11 require that “the annular gap around the anchor element is completely filled with adhesive” and that the installation procedures are adequate to “prevent the formation of gaps and/or trapped air in the adhesive along the bonded length of the anchor.” The 10% criterion used in this study was adopted in recognition of the likelihood that some level of void

formation may be acceptable and to permit a numerical rather than strictly subjective evaluation of the specimens. This acceptance criterion is more liberal than the ACI/CRSI acceptance criterion for voids, as the location of voids is not evaluated.

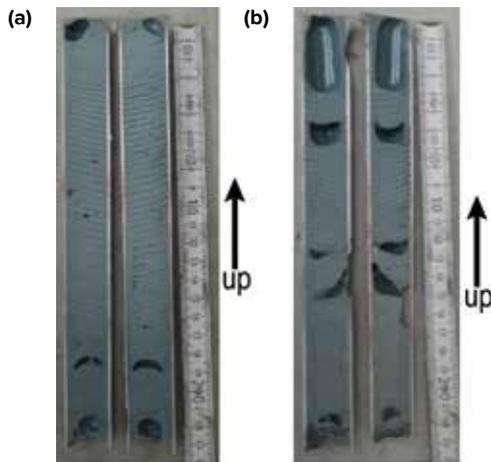
A number of repetitions were conducted with each combination of adhesive type, hole diameter and embedment, temperature, and injection method. The test program for the injections in acrylic tubes is summarized in Table 2.

**Table 2:**  
Injection tests in acrylic tubes, excluding those that included insertion of anchor rod

Tube diameter x length, in.	Adhesive temperature	Filled length	Adhesive A		Adhesive A		Adhesive B	
			Piston plug		End cap		End cap	
			Total number of tests	Dispenser type*	Total number of tests	Dispenser type*	Total number of tests	Dispenser type*
7/8 x 9	Room	Full	9	M	4	E	7	M
	Room	2/3 full	—	—	5	E	—	—
	Room	Full	10	E	5	E	10	M
	Room	2/3 full	—	—	5	E	—	—
	Low	Full	3	E	3	E	3	M
	Elevated	Full	3	E	3	E	3	M
		2/3 full	—	—	—	—	2	M
2/3 full		—	—	—	—	2	P	
1-3/8 x 25	Low	Full	3	P	6	P	1	P
	Low	2/3 full	1	P	—	—	—	—
	Room	Full	2	P	—	—	2	P
	Room	2/3 full	1	P	—	—	1	P
	Elevated	Full	2	P	—	—	1	P
	Elevated	2/3 full	1	P	—	—	1	P

\*M is manual; E is electric motor-driven; P is pneumatic

Note: 1 in. = 25.4 mm



**Fig. 4: Example test specimens: (a) successful injection result (voids  $\leq$  10%), piston plug method; and (b) failed injection result (voids  $>$  10%), end-cap method**

Examples of successful and unsuccessful injections are shown in Fig. 4.

### Influence of temperature

Injections with adhesives at elevated and low temperatures were conducted with pre-conditioned adhesive cartridges. The temperatures corresponded approximately to the installation temperature range reported for each adhesive in the literature. Some installations proceeded until the tube was filled with adhesive, while others were conducted following the typical manufacturer's instruction to fill the tube 2/3 full (to allow room for the anchor rod).

### Influence of rod insertion

Additional tests were conducted to verify the effect of rod insertion on injected holes with entrapped air. These were conducted with M30 (approximately 1-1/8 in. [29 mm] diameter) threaded rods in 1-3/8 in. diameter acrylic tubes. Although the rod diameter was slightly smaller than would be typical for installation in a 1-3/8 in. hole, it was deemed adequate to demonstrate a critical consequence of air voids in adhesive anchor installations. Subsequent investigation revealed that the tubes were not airtight, thus permitting entrapped air to escape from the top of the tube as the rod was inserted. Tests with the end-cap method were therefore repeated with acrylic tubes that had been hermetically sealed and verified for approximately 90 psi (0.62 MPa) under water.

To verify the findings from the injections in acrylic tubes, additional injections, not shown in Table 2, were performed with the end-cap method in hammer-drilled holes in concrete cylinders that were later split open for examination.

Installations were performed, in so far as possible, in accordance with instructions provided with each product.

### Influence of tubing diameter

To permit a direct comparison between the two adhesive types, end-cap installations were performed with flexible

polyvinyl chloride (PVC) extension tubing having an outside diameter of 11 mm (0.43 in.) and inside diameter of 9 mm (0.35 in.). (Note: The manufacturer installation instructions for Adhesive B did not specify an extension tubing type or diameter. The PVC tubing used for these investigations is believed to be representative of current practice.) This tubing diameter was compatible with the injection nozzle that accompanied the adhesive cartridges for Adhesive B. To check whether the extension tube diameter could affect the outcome, additional tests (not shown in Table 3) were performed in 1-3/8 in. diameter tubes with Adhesive A using PVC tubing having an outside diameter of 16 mm (0.63 in.). Piston plug installations were performed with the same flexible PVC extension tubing attached to the piston plug, whereby the outside diameter of tubing was 16 mm in accordance with the manufacturer instructions.

### Limitations

Recognized limitations of the test program include:

- Injection in smooth acrylic tubes is not representative of injection in rough-sided holes drilled in concrete with a rotary-percussive (hammer) drill. It is, however, somewhat representative of core-drilled holes;
- Injections with cartridges conditioned to high and low temperature in acrylic tubes do not completely simulate the condition of injecting adhesive into concrete at these temperatures (temperature limitations refer to the temperature of the concrete and adhesive at the time of injection, not the ambient air temperature). However, the thermal mass of the concrete would likely amplify the effects on adhesive viscosity observed in these tests;
- Injection of adhesive using a test stand in a laboratory environment cannot duplicate site conditions. In practice, overhead injection typically places the installer in a position beneath and to the side of the hole in the concrete, and intermediate verification of the effectiveness of the technique being used is obviously not possible. Installations conducted in concrete on a jobsite will likely experience greater variability than recorded in this test program;
- The acrylic tubes were sealed at the top to prevent adhesive from escaping the tube. It was discovered that the seal was not completely effective in preventing air from escaping through the seal under the conditions associated with rod insertion. This had a marked effect on the results of tests where the threaded rod was pushed into the tube after adhesive injection. Subsequent tests with tubes hermetically sealed to prevent air escape even under the high pressures developed by rod installation yielded representative results. This was confirmed by subsequent injections in concrete specimens; and
- The test program did not investigate all possible combinations of anchor diameter and embedment.

In spite of these limitations, the observations recorded over the course of the investigation are believed to be sufficiently definitive to provide the basis for a general recommendation.

## Results

A total of nearly 100 individual injections in acrylic tubes were carried out. Additional injections in concrete specimens were performed. A summary table of the investigation results using clear acrylic tubes is shown in Table 3.

The piston plug method was 100% effective in all tests using the criteria established for the assessment (Fig. 4(a)), regardless of adhesive temperature or tube diameter or length. This procedure also required significantly less effort on the part of the installer because the process of filling the hole with adhesive proceeds automatically. For injections that were intended to fill the acrylic tube only 2/3 full (in accordance with typical installation instructions), a mark on the flexible tubing corresponding to  $2/3h_{ef}$  facilitated this objective.

The end-cap method was partly effective in the 7/8 in. diameter tube. Adhesive A had a 100% success rate at room temperature, whereas Adhesive B was successful in approximately 60% of the attempts at room temperature. Adhesive B had a greater success rate at elevated temperature, indicating that the viscosity of the adhesive at lower temperatures was not as conducive to the end-cap installation method. Adhesive A had a zero success rate with the end-cap method at elevated and low temperatures. Clearly, the viscosity of the adhesive as affected by temperature is significant for the outcome when using the end-cap installation method.

The end-cap method was completely ineffective in the larger tubes. Of the 12 attempts made with the end-cap method in 1-3/8 x 25 in. tubes (see in Table 2), none could be rated as successful, and most were complete failures, with

**Table 3:**  
Results of injection tests in acrylic tubes

Series	Tube diameter x length, in.	Adhesive temp., °F	Filled length	Adhesive A			Adhesive A			Adhesive B		
				No. of tests and method	Dispenser*	Successful installations, %	No. of tests and method	Dispenser*	Successful installations, %	No. of tests and method	Dispenser*	Successful installations, %
Prequalification tests	7/8 x 9	70 (A&B)	Full	9 piston plug	M	100	4 end-cap	E	100	7 end-cap	M	57
			2/3 full	—	—	—	5 end-cap	E	100	—	—	—
1A	7/8 x 9	70 (A&B)	Full	10 piston plug	E	100	5 end-cap	E	100	10 end-cap	M	60
			2/3 full	—	—	—	5 end-cap	E	100	—	—	—
1B	7/8 x 9	41 (A) 50 (B)	Full	3 piston plug	E	100	3 end-cap	E	0	3 end-cap	M	33
			2/3 full	—	—	—	—	—	—	2 end-cap	M	100
		104 (A&B)	Full	3 piston plug	E	100	3 end-cap	E	0	3 end-cap	M	100
			2/3 full	—	—	—	—	—	—	2 end-cap	P	0
1C	1-3/8 x 25	41 (A) 50 (B)	Full	3 piston plug	P	100	6 end-cap	P	0	1 end-cap	P	0
			2/3 full	1 piston plug	P	100	—	—	—	—	—	—
		70 (A&B)	Full	2 piston plug	P	100	—	—	—	2 end-cap	P	0
			2/3 full	1 piston plug	P	100	—	—	—	1 end-cap	P	0
		104 (A&B)	Full	2 piston plug	P	100	—	—	—	1 end-cap	P	0
			2/3 full	1 piston plug	P	100	—	—	—	1 end-cap	P	0

\*M is manual; E is electric motor-driven; P is pneumatic

Note: 1 in. = 25.4 mm; °C = (°F - 32) × 5/9

little or no adhesive retained at the top end of the tube (Fig. 4(b)). This can be explained by the inability of the adhesive mass to support its own weight through adhesion to the tube wall in apertures of larger diameter. The surface area of the tube per unit length is directly proportional to the tube diameter, whereas the volume of adhesive per unit length increases with the square of the tube diameter. In addition, the injection tube diameter used for this method is typically kept constant, so as the hole diameter increases, the adhesive is less likely to contact and adhere to the tube wall (Fig. 5). As observed in tests conducted in acrylic tubes, adhesive expressed from the injection tube at the top of the hole falls to the bottom of the hole and fills the hole from the bottom (end-cap side), trapping air at the back (top) end of the hole.

In contrast to the piston plug method, the end-cap method provided the installer with little or no visual or haptic information regarding the correct rate at which to withdraw the injection tube. This is a significant deficiency associated with this procedure that was noted by the installers throughout the investigation. (Note: Additional tests conducted in 1-3/8 in. diameter tubes with a length of 12 in. [10d] whereby the installer was given no instruction other than to fill the tube

2/3 full, resulted in significant under-filling of the tubes. These tests are not reflected in the tables.)

Typical results of injection with the end-cap method in the 1-3/8 in. diameter tubes are shown in Fig. 6. Most of these attempts resulted in an almost total lack of adhesive at the back end of the hole. In contrast, all 10 attempts made with the piston plug method had void areas less than 10% (far less in most cases).

### Effect of rod insertion

The ACI 355.4-11 criteria do not specify whether to include the insertion of the anchor element in tests performed with acrylic tubes (for example, in accordance with ACI 355.4-11, Fig. 7.3) for the assessment of installation effectiveness. Insertion of the threaded rod into the injected adhesive mass can force air voids out of the hole. If the voids are small, this occurs without incident during the rod insertion process. If the voids are large and are concentrated at the back end of the hole, significant force may be required to overcome the natural buoyancy of the air in the adhesive mass and to force this air past the rod and out the bottom of the hole. The application of increasing force to push the anchor rod into the hole often leads to explosive eruption of air and adhesive from the hole. This is not only hazardous for the installer (many commercial construction adhesives can cause severe injury to the eyes and skin) but also typically results in a significant residual void at the top of the hole.

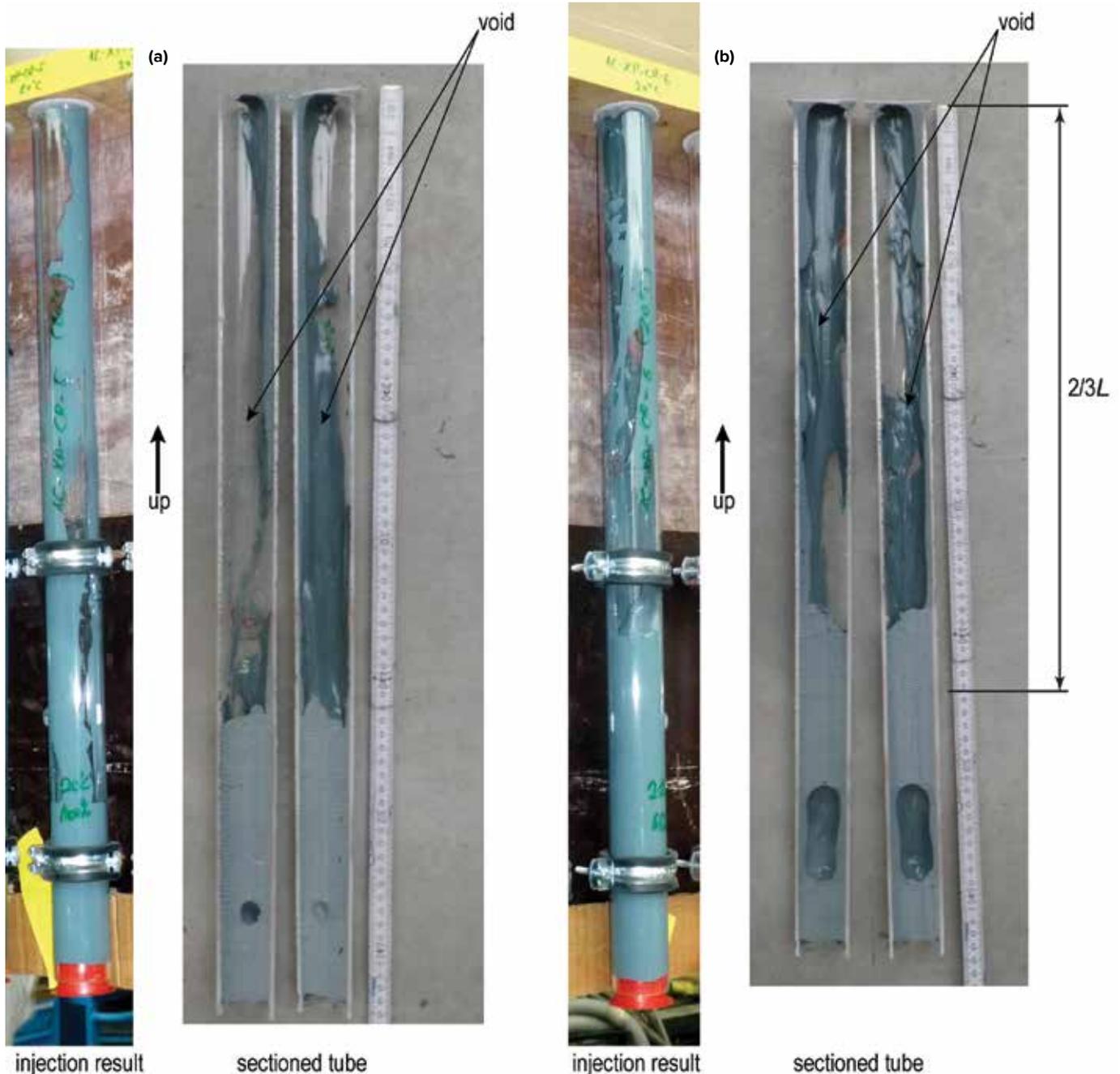
This phenomenon was confirmed by tests with Adhesive A in acrylic tubes provided with an airtight seal (Fig. 7). Initial tests in tubes that were sealed to prevent adhesive from leaking through the top of the tube, but not for the large internal pressures that developed as the adhesive mass and rod compressed the air at the top of the tube, resulted in air escaping from the top of the tube. In these initial tests, the adhesive mass was pushed by the anchor rod to the back of the hole and filled the void without significant effort. Subsequent tests in hermetically sealed tubes required much more force to drive the rod to the end of the hole, a process that was accompanied by explosive eruption of air and adhesive from the bottom of the tube and resulted in voids at the far end of the embedment (Fig. 7(b)).

### Tests in concrete

To verify the effects noted in tests with properly sealed acrylic tubes, overhead injections using the end-cap method with Adhesive A were performed at room temperature in holes drilled in concrete cylinders that were subsequently segmented and split open to reveal the effectiveness of the installation. All injections were conducted in 33 mm (1.30 in.) holes drilled to depths of 20 and 10 rod diameters with a hammer drill and carbide bit. Threaded rods with a diameter of 30 mm (1.18 in.) were pushed into the injected holes. In some cases, great effort was required to accomplish this. The deep holes evidenced the same explosive ejection of air found with the acrylic tubes, and although the process of splitting the concrete specimens does not necessarily reveal all of the



**Fig. 5: Close-up of adhesive injection at the top of a large-diameter acrylic tube. The adhesive is not in contact with the full perimeter of the acrylic tube**



**Fig. 6: Sample test specimens (1-3/8 in. x 25 in. tubes, end-cap method): (a) injection over full length of a 25 in. long tube; and (b) injection over 2/3 length of a 25 in. long tube**

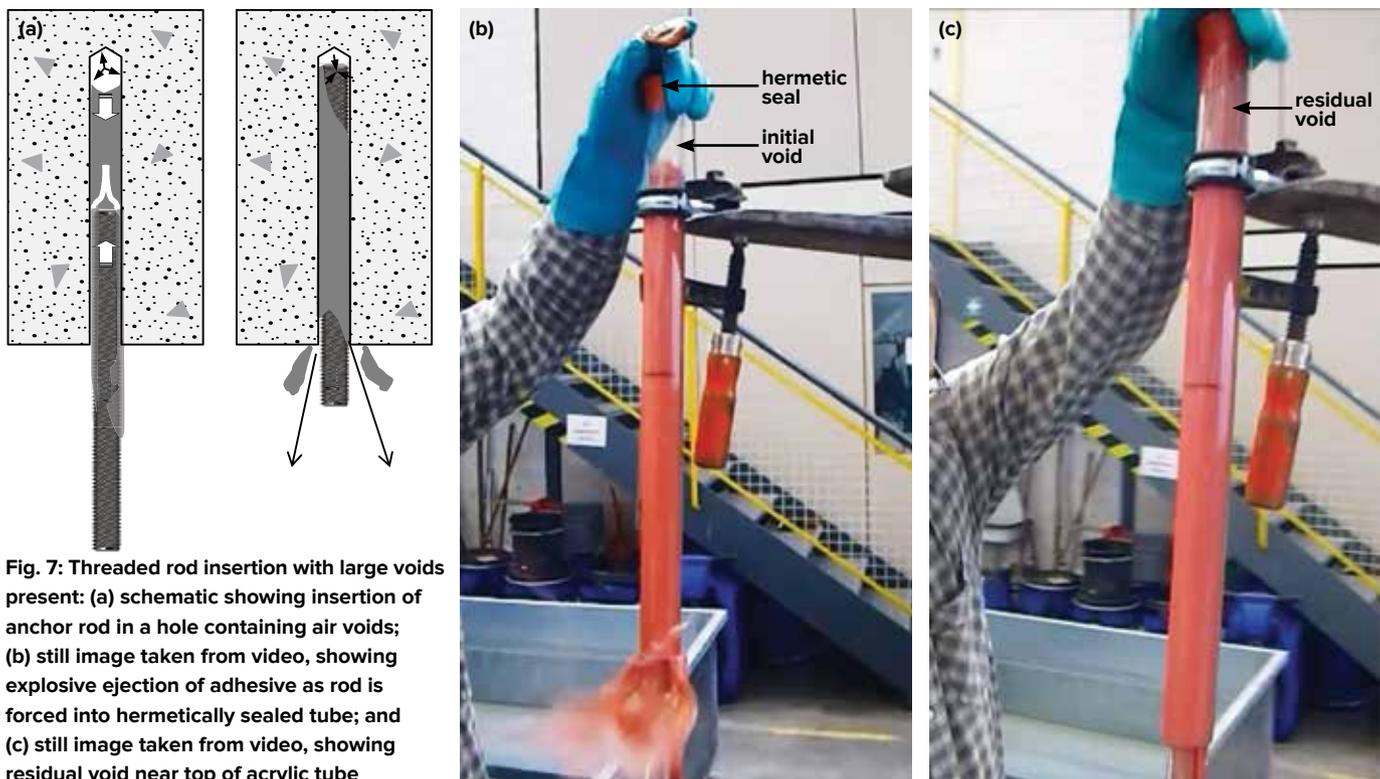
voids in the injected adhesive, the longer embedments showed the same type of voids (Fig. 8) found with the end-cap injections in acrylic tubes in which rods were installed.

The three injections conducted in concrete with Adhesive A at 10 diameters appeared to show good results when the specimens were split open. (Note: The injections in concrete were primarily intended to verify the effect of trapped air on rod insertion. As a method of verifying the presence of voids, this procedure is limited by the fact that the crack plane can only reveal one potential plane of voids, and that voids may be masked by concrete adhering to the adhesive mass.) While this is not inconsistent with the results observed for

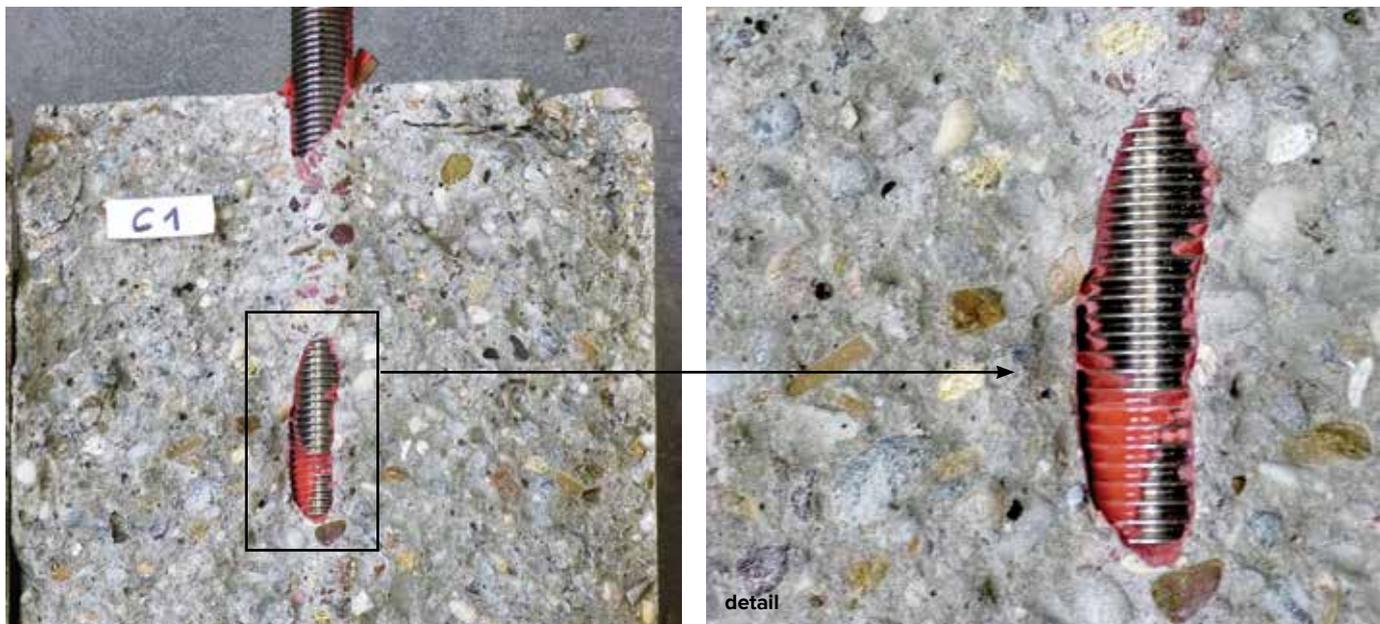
this adhesive in the prequalification tests and in Test Series 1A at room temperature, it should be noted that Adhesive A demonstrated poor performance with the end-cap method in Test Series 1B—that is, when the cartridges were conditioned to elevated and reduced temperatures (Table 3). Furthermore, the three injection tests in acrylic tubes conducted at this diameter and embedment at room temperature resulted in significant voids.

### Findings

Two methods for overhead installation of injection-type adhesive anchors were investigated for their effectiveness.



**Fig. 7: Threaded rod insertion with large voids present: (a) schematic showing insertion of anchor rod in a hole containing air voids; (b) still image taken from video, showing explosive ejection of adhesive as rod is forced into hermetically sealed tube; and (c) still image taken from video, showing residual void near top of acrylic tube**



**Fig. 8: An example of a concrete test cylinder used for overhead installation using the end-cap method. After adhesive installation, a threaded rod was inserted. The cylinder was later split to examine the quality of adhesive installation. This sample exhibits extruded adhesive on the exposed end of the rod and voids at and near the embedded end of the anchor rod**

The following conclusions can be drawn from this study:

- For all tested hole diameters, anchor embedments, and adhesive temperatures, the piston plug method proved to be reliable for injecting adhesive overhead without introducing significant voids;
- The end-cap installation method provided inconsistent results at the shorter embedments (9 to 10 diameters)

investigated. The end-cap injection method showed some sensitivity to adhesive viscosity, which varies from adhesive to adhesive and which is temperature-dependent. The end-cap method appears to be uniformly ineffective for 1-3/8 in. diameter holes at 20 anchor diameter embedment (the maximum permitted for adhesive anchors in ACI 318-14);

- The end-cap method provides little or no feedback to the installer regarding how much adhesive has actually been injected and whether air has been encapsulated in the injected mass, even for the shorter embedment lengths;
- The forcing of an anchor rod into a hole containing air voids is likely to result in a compromised installation with at least partial loss of bonded length. Under some circumstances, adhesive can be expelled in an explosive manner and pose a hazard for the installer;
- Certification under the ACI/CRSI AAI certification program, in and of itself, is unlikely to qualify an installer to reliably and consistently perform end-cap installations for the range of diameters and embedments currently recognized in anchor evaluation reports issued by, for example, the ICC Evaluation Service on the basis of testing and assessment in accordance with ACI 355.4-11. On the contrary, it can be inferred from this investigation that candidates who successfully complete the certification program with the end-cap installation method are unlikely to be effective with this method under the conditions they could reasonably expect to encounter on a jobsite; and
- The procedures in the ACI 355.4-11 qualification standard for verifying the installation effectiveness may be insufficient to properly assess the effectiveness of the system for overhead installations. If rod insertion is included in the test, acrylic tubes that are not sealed against air leakage during this procedure will likely yield misleading results. For injection tests with acrylic tubes where rods are not installed, saw-cutting of the injected tubes, as performed in the ACI/CRSI AAI certification program, is essential for revealing hidden voids. Given the effectiveness of this procedure for verifying installation quality, it is recommended that this type of test be added to the required tests in ACI 355.4-11.

## Recommendations

Adhesive anchors are a versatile method of anchoring in concrete, but their performance is highly dependent on installation quality. Therefore, the equipment and methods used to install adhesive anchors, particularly in applications where they may be subject to sustained tension loads, should be sufficiently robust to obtain consistently acceptable installations over a wide range of concrete temperatures, hole diameters, embedment depths, anchor orientations, installer position, and other jobsite conditions. An installation method that yields inconsistent results under laboratory conditions is likewise unlikely to fulfill this condition on a jobsite.

In summary:

- This investigation strongly suggests that the installation of injection adhesive anchors overhead with the end-cap method produces highly variable results and should be

discontinued. This is particularly true for cases involving sustained tension loads;

- The procedures in ACI 355.4-11 for assessing installation effectiveness in the overhead position should be reviewed and revised as appropriate to ensure that the use of qualified systems in the overhead position will reliably result in a minimum of voids in the injected adhesive; and
- The ACI/CRSI AAI certification program should discontinue certification on the end-cap installation method.

## References

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Received and reviewed under Institute publication policies.



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