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ASSURING QUALITY ADHESIVE ANCHOR INSTALLATIONS IN THE AMERICAS

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ABSTRACT

Anchorage to concrete design provisions were first incorporated into the ACI 318 Code in 2002[1] as Appendix D. In 2011, the design provisions for adhesively bonded anchors were added to the ACI 318-11 *Building Code Requirements for Structural Concrete*.[2] ACI took a proactive position in response to the recommendations/criticisms from the National Transportation Safety Board (NTSB) resulting from an adhesive anchorage failure in the "Big Dig" tunnel accident in Boston, Massachusetts. Additionally, Adhesive Anchor Installer Certification was made a requirement in ACI 318-11 Code for anchorages with sustained tension loading and installation orientations from horizontal to vertically upward (overhead).

This paper provides an introduction and background to the adhesive anchor certification requirements incorporated into ACI 318 Code (now Chapter 17 in ACI 318-14[3]). The ACI 318 code committee mandated a certification program for adhesive anchors. The program was fast-tracked with the aid of a certification development consultant, which worked with ACI Committee 601A - *Adhesive Anchor Installer.* ACI assembled a group of Subject Matter Experts (SMEs) knowledgeable about adhesive anchors, who identified the criteria and developed examination protocols that installer candidates must follow to obtain certification as ACI Adhesive Anchor Installer (AAI). The result of this fast-tracked effort is an operational certification program with both written and performance examination requirements that has been accepted by the industry and specified by code.

1 Introduction

In July 2006, tragedy struck a newlywed couple traveling on the Interstate 90 connector tunnel in Boston, MA, when precast concrete ceiling panels detached from the tunnel ceiling and crushed their car (Fig.1). The impact killed the wife and injured the husband. This unfortunate tragedy lead to immediate investigations into the cause(s) of the failure.

Findings in the National Transportation Safety Board (NTSB) Highway Accident Report – *Ceiling Collapse in the Interstate 90 Connector Tunnel, Boston Massachusetts,*[4] released July 2007, provided recommendations as well as considerations to prevent future failures where life safety is of concern.

This report motivated many within the construction and anchoring industry to evaluate potential improvements and needed actions to further educate those using adhesive anchor systems.

Fig. 1: Twenty-six (26) tons of precast concrete panels release from ceiling and crush car[6].

The American Concrete Institute (ACI) was proactive in its desire to address some of these issues by implementing changes to the following codes and standards; ACI 318-11 *Building Code Requirements for Structural Concrete* and ACI 355.4-11 *Qualifications of Post Installed Adhesive Anchors in Concrete*[5] specifications. In addition, ACI developed a certification program for Adhesive Anchor Installers, online educational programs, and hosted symposiums on anchorage to concrete. This paper focuses on the development and implementation of the Adhesive Anchor Installer certification program.

2 NTSB Investigation into Big Dig Failure

Conclusions in the NTSB report indicate the primary cause of the ceiling failure in Boston was related to the creep characteristics of the adhesive. The adhesive formulation used on this project was not approved for sustaining long-term loads. Displacement (movement) of the anchorage system was observed in a number of locations prior to the failure (see Figure 2). However, contractors, inspectors, manufacturers, and the Department of Transportation (DOT) were all learning "on the job" in their efforts to resolve this issue and avoid its recurrence. The NTSB report also indicated that a general lack of knowledge related to creep issues with adhesive anchors was apparent and the industry needed to take immediate action to understand and measure this important property.

Fig. 2: Photograph of hanger plates with displaced anchors adjacent to the failure area[6]

Another finding in the NTSB report was related to difficulties associated with overhead installations – Finding 17 states; *"Installing adhesive anchors in overhead applications appears, by the nature of the task, to introduce voids into the adhesive that can reduce the ultimate load capacity of the anchor and thus the overall reliability of the anchoring system."*

In fact, many of the installed anchors examined from the scene of the collapse exhibited deficiencies with the installation. Of the 20 failed anchors, 19 were found to have void areas from 1 to 40% over their embedment length. The anchor used was a 5/8-inch (16mm) diameter threaded stainless steel rod (316 SS) with a required 5-inch (127mm) embedment depth. A total of 85 anchors were removed and examined from the tunnel. Twenty of the 85 anchors came from the collapse area and 65 were taken from outside the failure area. Sixty-two (62) of these 65 anchors were found to have void areas around the threaded anchor ranging from 1 to 70% of the total embedment area (see Figure 3). Forty (40) of these anchors had displaced from the tunnel roof before removal; reported displacements ranged from 0.625 to 2.65 inches (16 to 67 mm). It appears that installation practices could have contributed to the failure. If an anchor is installed to fasten a hanger plate and 40% of its embedment depth not fully engaged with adhesive, this would reduce the maximum load capacity of that anchor.

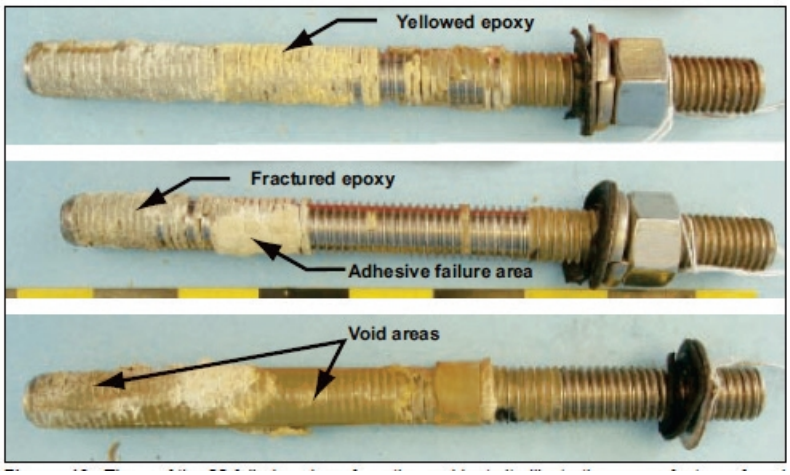

Fig 3: Anchors from the failure area exhibiting installation deficiencies[6].

Losing one anchor of many may not be critical, but the load has to redistribute and would transfer additional load on the adjoining anchors as well as the next hanger-plate installation. Considering that the anchors in the next hanger plate may also have installation deficiencies, this compounds the issue. Now add that the adhesive had poor creep properties…. failure.

The NTSB recommendations to the American Concrete Institute were: *Use your building codes, forums, educational materials, and publications to inform design and construction agencies of the potential for gradual deformation (creep) in anchor adhesives and to make them aware of the possible risks associated with using adhesive anchors in concrete under sustained tensile-load applications. (H‑07‑32)*

2.1 ACI Committee 318 Action

Members of the ACI 318 building code committee want assurances that those installations with sustained long-term loads would not be problematic in the future. The code committee first took the position that adhesive anchors not be allowed in the code in an overhead, sustained-load condition.

Extensive code committee discussions lead to agreement that ACI would develop a certification program for Adhesive Anchor Installers. If ACI developed a program accepted by the industry, the ACI 318 committee members were willing to write code language allowing adhesive anchors, however, installers had to be certified for overhead, sustained-load condition installations by the time the ACI 318 2011 code was published.

2.2 ACI Committee 355 Action

Overall, the ACI 355 committee agreed that creep was a contributor to the ceiling failure in Boston, but also believed that the greater problem was with the inability of the installer to provide consistent, high-quality installations in the overhead orientation. At the request of Committee 318, Committee 355 was charged with the task of leading the development of a certification program with ACI's Certification Department. The certification program had to be developed and available to the construction industry by the issuance of the 2011 code, which at the time, was just 2.5 years away. Additionally, the committee had to have a balloted and approved adhesive anchor qualification standard, ACI 355.4 *Qualification of Post-Installed Adhesive Anchors in Concrete,* completed in the same 2.5-year time period. Through the great effort of the ACI 355 committee, the ACI Certification Department and a certification development committee, both efforts were completed and implemented by the publication of the ACI 318-11 Code.

3 Development of the AAI Certification Program

ACI Committee 355 Chairman Meinheit (2006-2012) also chaired the AAI certification development committee. Subject matter experts (SMEs) from Committee 355 also volunteered to participate on the development committee. It was apparent from the beginning of this process that ACI would receive strong industry support for this important program as representatives from Hilti, ITW Redhead, Powers Fasteners and Simpson Strong-Tie, already members of 355, joined the AAI certification development committee. Additionally, the Concrete Reinforcing Steel Institute (CRSI) partnered with ACI in support of this program. This development committee would move into ACI's certification committee structure and follow established protocols for developing new certification programs.

Initial meetings of the certification committee focused on: "What does the committee want to accomplish with a certification program? What do we, as engineers, expect the installer to know? What does the certification program want to 'measure'?" Also discussed was whether the program should be accredited or not. ACI decided to follow ANSI/ISO Guidelines in the certification development process for this new program, in the event ACI wanted to seek accreditation of the program at a future date. ACI also hired Professional Testing[6], Orlando, Florida, to serve as a facilitator to fast-track program development.

3.1 Protocols for Program Development

The facilitator provided an outline of the process that would be followed by the committee. The process included the following:

1. Development of a Body of Knowledge
2. Development of written exam questions
3. Development of practical exam checklists
4. Vetting of the examinations
5. Passing Score Study
6. Pilot Programs

First the certification committee had to agree on what they expected to accomplish with the certification program. Is it just a written exam that measures the technical knowledge of the installer? Is it a performance exam that will measure installers' ability to properly install an anchor in a horizontal and overhead installation? Or…does it include both? The committee agreed it must include both written and performance-based exams. They also agreed on the scope of this new program. The installer should have a general knowledge about adhesive anchors, understand that there are multiple systems available in the marketplace, that installation procedures and product accessories are different, and most importantly, they must read the directions provided for each product; this is covered by the objective (written) exam. The performance part of the examination was designed to measure the installers ability to Read, Comprehend, and Execute a set of installation instructions.

Development of the Body of Knowledge is a critical first step in this process. This document becomes the blueprint for the program and directs the certification committee in developing the written and practical examinations. The Body of Knowledge for the installer is usually based on reference documents that the committee members select, review, and agree upon. Interestingly, in this instance, the only "reference documents" available would be the instructions the manufacturers provide with their products. These are commonly referred to as the Manufacturers Printed Installation Instructions (MPII). The certification committee could also have obtained additional product information from each manufacturers website, if desired. However, there was no one source the committee could point to as a generic guide or workbook for the potential installer to study. The focus of the committee then became the MPII and how it would be addressed in the program. Would the MPIIs of all manufactures be used in the training and examination? Would the installer be expected to know specifics about all products? How many installation procedures would the installer need to demonstrate? It was agreed that a generic MPII would be developed by the Concrete and Masonry Anchor Manufactures Association (CAMA) and provided to ACI for use exclusively in this certification program. It was also agreed that an ACI-developed workbook would be written by the SMEs. However, the workbook development effort would take place after development of the certification program. The workbook would also use the Body of Knowledge document as its outline.

The key items in the Body of Knowledge for this program included; Preparing for Installation, Drilling Anchor Holes, Cleaning Anchor Holes, Injecting Adhesive Using Cartridge Systems, Installing Adhesive Capsule Systems, Installing Anchors. Each of these key subject areas had related subsections. The document is available at *www.concrete.org/certification/certificationprograms.aspx*.

3.2 Development of Written and Performance Examinations

A 2-day meeting hosted at the Chairman's firm, Wiss, Janney, Elstner Associates located in suburban Chicago, Illinois, was held to develop the "pool" of examination questions and the performance procedure checklist items. Participants included the ACI 355 committee members, ACI staff, and invited industry guests. The invited guests included major construction contractors that utilized and had knowledge of adhesive anchors. The facilitator assigned the members to small work groups after which each was assigned specific sections of the Body of Knowledge on which to write exam questions. The written exam was intended as a multiple-choice examination and was to contain 60 questions. The facilitator provided the SMEs with guidelines on how the questions must be written, and how to create good answer detractors. Additionally, each work group had to assign a difficulty rating to each question they created. Over the 2-day program, the teams created 120+ exam questions and a draft of the performance checklists for a vertical down and overhead installations utilizing a piston-plug system and a retaining-cap system.

Vetting the exam questions – This process includes the group review of all the examination questions to verify the following: the intent of each question; if the question is technically correct; and if there is one clear answer. It also includes a review of the proposed distractors provided in each answer set. Lastly, the review team had to agree upon the difficulty rating of the questions, as assigned by the creators, 1 being easy and 5 difficult. The goal being a blend of the difficulty levels in the eventual examination.

With this exercise complete, a written examination was assembled from the pool of questions. Committee efforts then focused on hosting a Passing Score Study for the written exam. A Passing Score Study requires actual participants from the intended target market to take the written examination. In this case, actual adhesive anchor installers with previous experience took the written exam. ACI identified major contractors across the United Stated and invited them to participate in this exercise. A group of ten (10) installers representing seven states and various experience levels attended the Passing Score Study hosted at the Concrete Reinforcing Steel Institute (CRSI) headquarters in suburban Chicago, in December, 2010. At this Passing Score Study, all 10 potential certified installers took the examination, rated the difficulty of each examination question, and were debriefed on the content of each examination question. Results from this independent study resulted in requiring a minimum score of 74% to pass the Adhesive Anchor Installer written examination.

Concurrently, the certification committee continued to work on the performance examination. Final requirements included installation of a 6-inch (150 mm) long, ½-inch (12.5 mm) diameter threaded anchor to a drilled hole of 4-inch (100 mm) depth. This included drilling and cleaning, injecting the adhesive, and installation of the anchor. The overhead test set-up included injecting adhesive into a 7/8-in (22 mm) diameter by approximately 8 ½ -inch (216 mm) long polycarbonate tube that the installer could not see while injecting the adhesive (Fig. 4). The requirement was to fill the tube nearly void-free utilizing both the piston-plug and retaining-cap systems. The certification committee identified the pass/fail criteria for the overhead installation to be no single void larger than 3/8 x ½-inch (9.5 x 12.5 mm) in the deepest 2/3rds of the polycarbonate tube.

Fig. 4: Typical blind test set-up for overhead installation with a piston plug system being used[7].

3.2 Pilot Programs

A Pilot Program is a session where the written and practical exams are administered to participants that have been identified as having experience with the subject matter. No training, review, or practice session is included in a pilot program. For this pilot program the facilitator suggested 30 participants attend. ACI hosted two pilot programs in the Chicago, Illinois, area in the Winter and Spring of 2011; a total of 35 participants attended. Participants for the program were from the greater Midwest area and were identified by their employer as someone who installs anchors for their firm. Experience of the participants varied from 1 to 20+ years, with a mix of men and women and an age group from 22 to 55+ years old. Participants were asked to rate the difficulty of each examination question and agreed to be interviewed upon completion of the practical exam.

A majority of the participants believed the written exam was appropriately basic and straight forward but were not happy with the practical portion of the Pilot Exam. The primary complaint was that the participants were not given an opportunity to practice with the different equipment and systems prior to being "tested." The participants believed they would have done much better on the performance examination and had a greater opportunity to pass the performance examination if a practice session had been offered. Many failed because they did not read the MPII directions. At the test station, each participant was given a generic MPII provided by CAMA, and was told to use those instructions for the performance examination. Some struggled to follow instructions. Issues like putting the wrong accessories on extension tubing, not expressing out an initial amount of material when starting with a new cartridge, or overfilling of the drill hole or plastic tubes were observed (see Figure 5). Recall that all had experience with anchor installation, yet 80% of them failed the practical exam and 30% of them failed the written exam. The average score on the written exam was 81%.

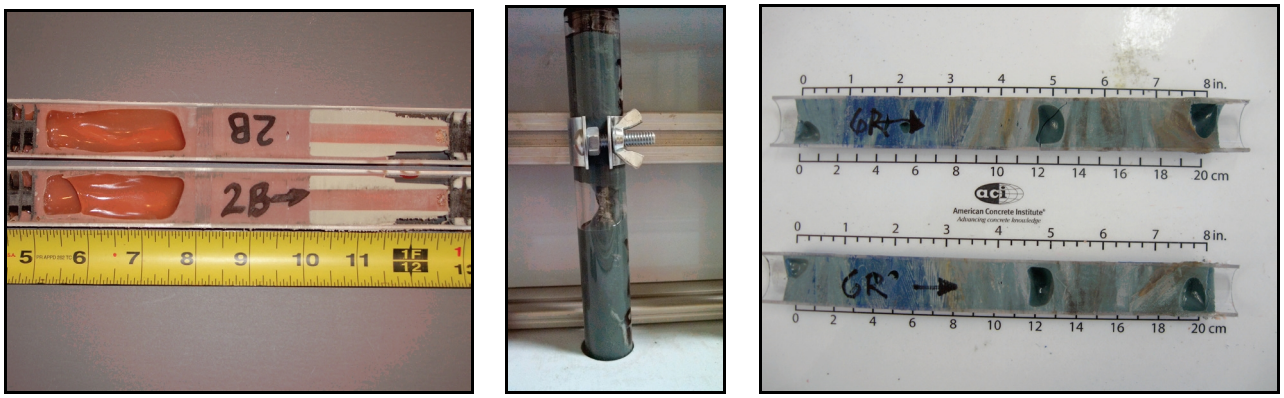

Fig 5: Examples of failures with overhead methods. Left to right, Piston Plug upside down and left in tube, Retaining Cap with 1+ inch void in center of tube, voids at top and middle of tube[7].

A grading guide, or rubric, for evaluation of the filled overhead tubes was created and used to evaluate the tube samples from the pilot programs. This rubric was subsequently distributed to all ACI test administrators offering the AAI program.

With only minor changes to the performance examination set-up and execution, the program was officially declared ready to go, and roll-out was set to begin in the summer of 2011, several months ahead of the publishing of the ACI 318-11 Code.

3.2 Development of AAI Workbook

In late 2011, ACI staff and SMEs from the AAI committee again began work this time on an Adhesive Anchor Installer workbook. The Body of Knowledge document was used as the outline of the workbook, the committee also utilized the MPII's from the manufacturers, other general technical information from the industry, and two *Concrete International* magazine articles about Adhesive Anchor Installations. The workbook (see cover page in Figure 6) was completed in August 2012. The 95-page workbook contains 9 chapters, review questions after each chapter, performance checklists, a practice exam, and a 22-minute training video on proper procedures for both downward and overhead adhesive anchor installations.

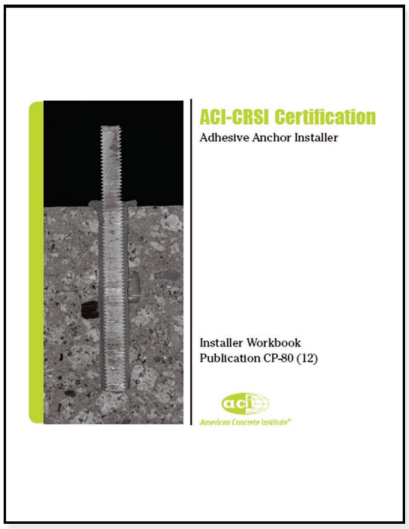

Fig. 6: ACI/CRSI Adhesive Anchor Installer workbook[8].

With the delivery of the AAI workbook, passing rates for the written exam improved and the average score on the written exam also improved to 87%. Currently, the workbook and exams are available in English, Spanish, Mandarin, and French.

4 Program Rollout via ACI Sponsoring Group Network

ACI's Sponsoring Group network provides excellent coverage throughout North America. In most instances Sponsoring Groups are connected with a local ACI Chapter and the local chapter members organize, staff, and execute ACI Certification programs for their local concrete community. With ACI offering over 20 concrete-related certification programs, the Sponsoring Group network is critical in getting these programs to the end users. ACI Certification programs cover a wide area of services including Concrete Field and Laboratory Technicians, Inspectors, Supervisors and Craftsmen. Each Sponsoring Group offers select programs that are needed in their market and schedule such programs throughout the year. Generally, programs offered by the Sponsoring Groups are typically 2-days long and include a review and hands-on practice session on Day 1 followed by the written and practical examination on Day 2. As learned from the AAI Pilot Programs, ACI requires all Sponsoring Groups offering the AAI program provide a review and hands-on practice session prior to administering the examinations. With 120 Sponsoring Groups worldwide, and 97 Sponsoring Groups operating in North America, the ACI Certification Department has prepared 40+ to offer the AAI program.

Fig. 7: Examiner reviews filled tubes with an Installer at practice session[7].

A Sponsoring Group must show an interest in offering the AAI certification program. Members of the group are required to go though an ACI orientation program including written and performance exams. The program policy for the AAI program requires the Examiners to be AAI-certified and to achieve a passing score of 90% or greater on the written exam. ACI Certification Department staff provide on-site training to the hosting Sponsoring Group and lead an initial AAI training and examination session explaining all the critical issues associated with the program. Included in the orientation program is instruction on how to conduct a review session, test station set-up, product lines and accessories, and inspection of the tubes after curing (see Figure 7). These orientation programs usually have between 5 and 8 representatives from the local sponsoring group that volunteer to participate in bringing the program to their market area. ACI also invites local technical-

service representatives from Hilti, ITW Redhead, Powers, and Simpson, to participate, and all are very supportive of this program. An AAI program guide was developed for a potential Sponsoring Group so they can plan for everything involved with set-up and execution of this certification program prior to deciding to add it to the list of certifications they offer.

Mandated certification by code - 318-11, *Building Code Requirements for Structural Concrete* was published in July 2011. In Appendix D, Section 9.2.2 (and Chapter 17 Section 17.8.2.2 of ACI 318-14) states;

D.9.2.2 (17.8.2.2) — Installation of adhesive anchors horizontally or upwardly inclined to support sustained tension loads shall be performed by personnel certified by an applicable certification program. Certification shall include written and performance tests in accordance with the ACI/CRSI Adhesive Anchor Installer Certification program, or equivalent.

From July 2011 to March 2015, ACI staff completed 40 Sponsoring Group/Chapter orientation programs throughout North America (see Figure 8) as well as South America and Taiwan. During this time, numerous articles, seminars, presentations were also scheduled and executed. Additionally, in January of 2014, the ICC Evaluation Services updated all their Engineering Service Reports for adhesive anchors to include language to reflect design provisions of ACI 318-11. Specifically, the ICC calls out the ACI/CRSI Adhesive Anchor Installer program.

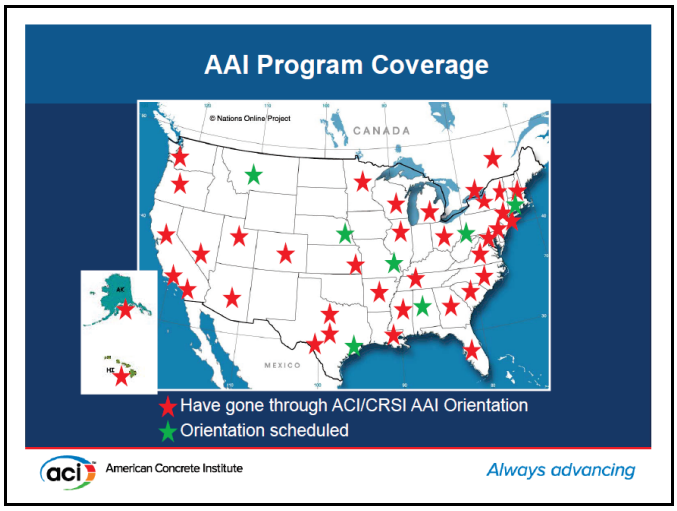

Fig. 8: ACI Sponsoring Groups currently offering the AAI certification program.

5 Need for AAI Inspector Program

As the AAI certification program began to generate interest, it became apparent to many of the program Examiners as well as ACI 318 committee members, that a needed component was a program for Special Inspectors. A number of Inspectors were going through the AAI program in an effort to gain specific knowledge about adhesive anchors and to know what the installers were supposed to be doing as certified installers.

During Spring 2014, the ACI C680 *Adhesive Anchor Installer* committee discussed this topic and a task group was formed to investigate the potential need and content of an inspector program. By Fall 2014, C680 submitted a request to develop an inspector program. A new certification program development committee was created, resulting in a new AAI Inspector certification. All the subject

matter experts came from the C680 committee, and in less than 30 months, the Inspector program was completed and available to the industry. Program development followed the same protocols as the AAI program with the exception that no workbook was required to be developed. All the reference documents were previously published and used on a regular basis by inspectors, making it much easier for the SMEs to develop the Body of Knowledge for the Inspector program. Four (4) Pilot Programs were organized for the Inspector program with over 80 inspectors participating. Sessions were held in New York City, Philadelphia, Chicago, and the Oakland/San Francisco Bay Area. The pilot programs were successful with very positive feedback from the inspectors. Inspectors particularly liked the required hands-on demonstration part of the program. Interest in this program is very high, and growing rapidly including government agencies seeking to specify it.

6 Lessons Learned

Assembling this program and conducting the orientation sessions served as an eye opener for all involved regarding potential difficulties with overhead installations. This program experienced some difficulties during development and the members worked hard to correct the procedures to make the program viable. Particularly the overhead installation procedures had to be modified from their original concepts.

7 Conclusion

ACI and its members actively responded to an important industry need. ACI committees reviewed the situation and acted on multiple levels to prevent recurrence of the errors leading to the Boston tragedy. Changing codes and standards, developing and hosting educational seminars, and development of a thorough certification program that measures the physical skill set as well as the technical knowledge of the installer is taking the industry in the right direction. This certification program ensures that the installer is fully aware of their responsibilities when using adhesive anchors.

Unfortunately, as important as it is, this program has been met with some resistance in North America. Even though it is required in the ACI 318 Code, many contractors do not have certified installers in their labor pool, viewing this required certification only as an “added cost.” As yet, few are policing this important issue. If contract documents don’t include requirements, or if included requirements aren’t enforced, anchors will continue to be installed by unqualified personnel. How shortsighted…do we have to wait for another failure, another death to enforce this?

With availability of the new Adhesive Anchor Installation Inspector certification program, ACI anticipates an increase in demand for the AAI program generated by increased awareness and enforcement. Further assisting the increase will be the adoption of updated codes requiring certified installers and inspectors.

8 Acknowledgements

The authors would like to thank all the members of the ACI Committee C 601-A *Adhesive Anchor Installer*, the members of ACI Committee 355 *Anchorage to Concrete* and ACI staff for their commitment and diligence in developing these important new standards and programs. They would also like to acknowledge the support received from the adhesive manufacturers, specifically: Hilti,

ITW Redhead, Powers Fasteners and Simpson Strong-Tie as well as the Concrete Reinforcing Steel Institute.

References:

1. ACI 318-02 Building Code Requirements for Structural Concrete.

2. ACI 318-11 Building Code Requirements for Structural Concrete.

3. ACI 318-14 Building Code Requirements for Structural Concrete.

4. National Transportation Safety Board (NTSB) Highway Accident Report – Ceiling Collapse in the Interstate 90 Connector Tunnel, Boston Massachusetts, released July 2007.

5. ACI 355.4-11 Qualifications of Post Installed Adhesive Anchors in Concrete.

6. Figures 1, 2, 3 - National Transportation Safety Board (NTSB) Highway Accident Report – Ceiling Collapse in the Interstate 90 Connector Tunnel, Boston Massachusetts, released July 2007.

7. Photographs by the authors.

8. ACI / CRSI Adhesive Anchor Installer workbook, ACI Publication CP-80 (12).