

A Field Study of Adhesive Anchor Installations

Theory and practice

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For every fastening application, the starting point is choosing the correct product. This requires understanding the loads to be resisted and following a defined design method. It also requires establishing the exact location of the fixing point, anticipating the environmental conditions during installation and service, and knowing the installation procedures for the fastener or anchor.

For adhesive anchors, the designer must select a product that is adequate for the conditions in service and that has been evaluated for compliance with code requirements.

Once an appropriate system has been selected and designed, the installation process has to be considered. To ensure correct installation, the installer must follow the manufacturer's instructions precisely. Furthermore, the installer must follow the requirements of the relevant evaluation service report (ESR)—refer to the sidebar. Detailed information on the installation and inspection of adhesive anchors is given by Wollmershauser and Mattis,¹ and information on factors influencing the behavior of adhesive anchors can be found in Reference 2.

In theory, the knowledge is available to ensure reliable fastenings with adhesive anchors and to give designers and installers confidence and flexibility in myriad applications. With the failure of adhesive anchors in Boston, MA, however, the installation and use of these types of anchors has been called into question. To figure

out what can be improved with regard to the use of adhesive anchors, adhesive anchor installations with injection systems were monitored on 23 job sites in five locations scattered over the U.S. Critical aspects were examined to determine gaps between actual and recommended practice and to come up with proposals to improve installation practices.

FIELD RESEARCH PROJECT

The installation of adhesive anchor systems was investigated at construction sites in California, Florida, Illinois, New York, and Pennsylvania. In total, 23 sites were visited, 26 applications were monitored, and 31 installers were interviewed (Table 1). Thirteen different adhesive systems (either epoxy-based or hybrid mortars) were installed. Nine of these products had an ESR. The steel anchors were continuously threaded steel rods or deformed steel reinforcing bars. Anchors were used for strengthening bridge structures, seismic retrofits, connecting structural elements to structural walls, anchoring steel elements to existing concrete members, anchoring pavement dowels, installing hurricane protection, or anchoring façade elements. The anchors were installed downward in 13 applications, horizontally in 11 applications, and overhead in two applications.

All information relevant to the installation was monitored on site by the first author, and the detailed findings were recorded in a protocol. Installers were interviewed to determine their professional and educational backgrounds, training and experience

levels with post-installed anchors, general anchor installation experience level, and general opinions concerning the pros and cons in regard to the installation of adhesive-bonded anchors.

TABLE 1:
DETAILS OF THE SURVEY

Location	Illinois	Florida	California	Pennsylvania	New York	Total
Job sites	6	7	5	2	3	23
Applications	7	8	5	3	3	26
Surveys	8	6	8	5	4	31

Ensuring code compliance

In the U.S., the International Building Code (IBC) is generally the governing building code.³ To verify compliance with IBC requirements, the supplier of a proprietary fastening system must obtain an evaluation service report (ESR) from an accredited independent evaluation service. The ESR will show compliance with predefined acceptance criteria describing test and quality assurance protocols. In the case of adhesive anchors, IBC compliance can be shown through an ESR issued by the ICC Evaluation Service (ICC-ES), following the acceptance criteria specified in ICC-ES AC308.⁴

The designer selects a product based on information contained in the relevant ESR. In addition, the designer must take into account several different aspects that influence the correct application of adhesive anchor systems, such as the drilling method, temperature and state (cracked or uncracked) of the base material, condition of the borehole, and installation direction.

Section 1704 of the IBC stipulates special inspection of adhesive anchor installations for many applications, and special inspections are also required in ESRs. The special inspector observes the work for conformance with the construction documents and provisions within the building code. The IBC requirements for special inspection originated in the Uniform Building Code (UBC),⁵ which was the adopted building code in much of the western U.S.

General observations

Figure 1 summarizes the general observations made at the construction sites. All manufacturers' product installation instructions (MPIIs) were analyzed to evaluate whether the required information to ensure a correct installation was given. Nine out of the 13 products (five with ESRs and four without ESRs) did not deliver all information that's necessary for the correct installation of adhesive anchors (Fig. 1(a)).

Some MPIIs were ambiguous, some had incomplete instructions, and others had pictograms that did not match the information in the text. With some products, the instructions were only printed on the cartridge and with a very small font—this information couldn't be read after the cartridge was placed in the dispenser. Whereas most systems required that the adhesive be stored in a dry, relatively dark, and well-ventilated area at temperatures within a specified range, it was found that some MPIIs

gave no information about storage requirements. Some MPIIs provided no information about the diameter of the drill bit relative to the anchor size, and none of the MPIIs indicated that a depth stop was required. Table 2 contains a brief summary on the various ways the MPIIs statements failed to provide adequate detail.

In most of the applications, the MPIIs for the adhesive systems were available on site, but many installers didn't refer to the instructions. In one application, the product was past its expiration date, but it was used anyway. The adhesives were found to be stored in various places that ran counter to the storage requirements (Fig. 1(b)).

Figure 2 provides specific observations made during anchor installations, including borehole drilling, cleaning, and condition; adhesive dispensing and injection; and curing time. These observations are discussed in detail in the following sections.

Borehole

Depending on the product, the anchor capacity might be reduced if the borehole has the wrong depth, location (Fig. 3 and 4), or diameter (Fig. 5). Installers should use a drill bit meeting the tolerances stated in the MPIIs, but it was observed that an incorrect drill bit was used in many applications. In 23% of the applications, the drill bit was too large (the maximum deviation was 33%), and in 15% of the applications, the drill bit was too small. In one extreme case, the drill bit was about the same size as the nominal anchor rod size (Fig. 5). As indicated previously, some MPIIs didn't define the proper bit size, so the use of improper drill bits isn't entirely surprising.

In most of the installations, a depth stop (depth gauge) wasn't used (Fig. 6). While none of the MPIIs included a requirement to use a depth stop, all stated that the borehole must be drilled to the correct size and depth; this is only possible when using adequate accessories and aids.

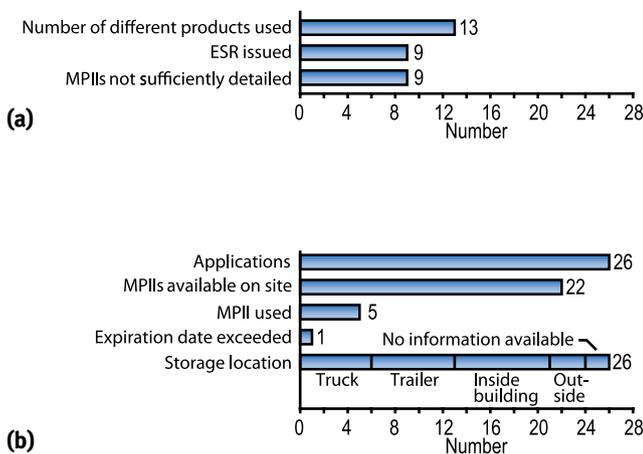


Fig. 1: General observations made on job sites: (a) number of different products used and information regarding ESR and MPIIs; and (b) monitored applications and observations regarding use of MPIIs, age of adhesive, and storage of adhesive

TABLE 2:
INFORMATION MISSING FROM THE MPIIs. NONE OF THE PRODUCTS HAD ALL OF THE INFORMATION REQUIRED TO ENSURE PROPER INSTALLATION

Product	1	2*	3	4*	5*	6	7*	8*	9
Storage	X	X	X						X
Temperature of cartridge during installation	X	X	X			X			X
Temperature of base material during installation					X				
Drilling method	X		X	X	X	X	X	X	X
Drill bit size				X	X	X	X		X
Condition of borehole (dry, wet, water-filled)	X		X	X	X	X		X	
Cleaning procedure						X			X
Gel time as a function of temperature			X						
Installation torque	X		X		X	X		X	X

*Product with ESR

All product instructions required blowing out the drilled hole with either a hand pump or compressed air (Fig. 7). All instructions also required additional brushing of the borehole. In general, however, the correct tools required for cleaning the boreholes were not available on site (Fig. 8). The boreholes were properly cleaned in only a small number of installations (Fig. 2). Most adhesive systems require that the boreholes are free of standing water, dust, debris, ice, grease, oil, or other foreign materials. In two applications, however, the anchor was installed in a water-filled hole, whereas the ESR stated that the product was not suitable for this installation condition.

Adhesive installation and curing

The MPIIs require the installer to dispose of the initial mixture of hardener and resin pushed through the mixing nozzle (the mixture dispensed into the borehole should have a uniform color). This procedure ensures that the correct ratio of hardener and resin is used. These requirements were often not met (Fig. 2). Many installers reused the mixing nozzle from a previous cartridge. The old adhesive within the nozzle was discarded, but the first part of the adhesive from the new cartridge was dispensed into the borehole. It can be assumed that the actual ratio between hardener and resin for this material is different from the mixing ratio required for full conversion, so this practice likely reduces the capacity of the installed bonded anchor.

To fill the hole with adhesive (and avoid air pockets), the adhesive should be injected from the bottom of the hole and the nozzle should be withdrawn as filling progresses. In some applications, however, the adhesive was not injected from the bottom of the hole. In these cases, the borehole wall and steel part may not be fully covered by the adhesive and voids may be present in the hardened mortar. Both effects yield a significant reduction in capacity and durability. Furthermore, depending on the product, oxygen inhibition might interrupt the curing process of the adhesive and therefore negatively influence the anchor capacity.

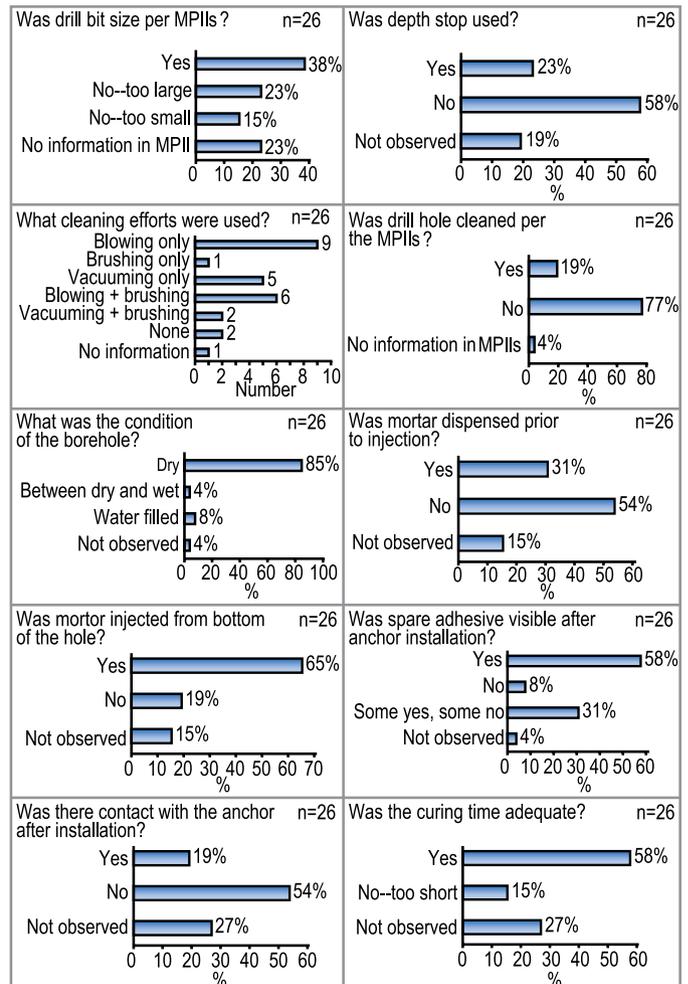


Fig. 2: Results of the field study of adhesive anchor installations. (n = number of observed applications)

After inserting the anchor rod or bar, there must be spare adhesive visible all around the mouth of the hole to ensure that the borehole is fully filled with mortar. Spare adhesive wasn't visible, however, in most of the applications. Because of the missing mortar, the anchor rod is not



Fig. 3: To avoid interference problems, reinforcing bars must be located before drilling and provisions must be made in the details to allow adjustment of anchor locations. Otherwise, bars would be drilled through reinforcement and affect the capacity of the structure. Here, the installer attempted to clear initially undetected bars by inclining the boreholes. The long extensions on two of the threaded rods show that the attempt was a failure



Fig. 4: Details must set limits on how anchor locations are adjusted. In this installation, a second borehole (as well as a new hole in the base plate) had to be drilled because the drill bit contacted a reinforcing bar at the original location. The anchorage capacity will be reduced, however, because the resulting anchor spacing is too small



Fig. 5: After the boreholes were filled with adhesive, these threaded rods were hammered into place because the hole was too small. The size of the drill bit required for a given anchor diameter should be clearly communicated in the MPIIs



Fig. 6: The correct method for creating a borehole. The installer is drilling through a template using a hammer drill with a depth stop

bonded to the borehole wall over its full length and its capacity will be reduced.

Also, after inserting the anchor into the adhesive, each system requires a curing time that depends on the temperature of the base material. During this time, it's necessary to ensure that the rod is not disturbed or loaded. Figure 9, for example, shows a correctly installed overhead application. Early contact or premature loading could partially destroy the bond between the concrete and mortar. In some applications, however, rod contact was observed and loading was applied during the curing time.

Special inspection

Continuous or periodic inspection for anchor installations was only found in the five applications in California and one of the eight applications in Florida (Fig. 10). No special inspections were observed in the seven applications in Illinois, the three applications in Pennsylvania, or the three applications in New York. Whereas all boreholes were cleaned properly and all anchors were installed correctly in the California applications, this was not the case in Florida. The authors highly recommend that the engineer in charge of a project reviews the performance of the inspectors observing anchor installations.

Installers

After monitoring the installations on site, we had 31 installers fill out a questionnaire. The completed questionnaire gave information on adhesive anchor installations on other sites and the educational background of the installers.



Fig. 7: The correct method for cleaning a hole. The installer is blowing dust out of the hole according to the relevant MPIIs using compressed air directed through a nozzle



Fig. 8: Cleaning brushes were seldom used at the survey sites. In this case, a brush was used, but it was old and worn and thus less effective. Criteria setting the maximum acceptable wear were not provided in the MPIIs available at the job site



Fig. 9: This overhead installation was completed correctly. Excess adhesive around the anchor indicates the borehole was properly filled, and the installer used wedges to hold the anchor in place during curing

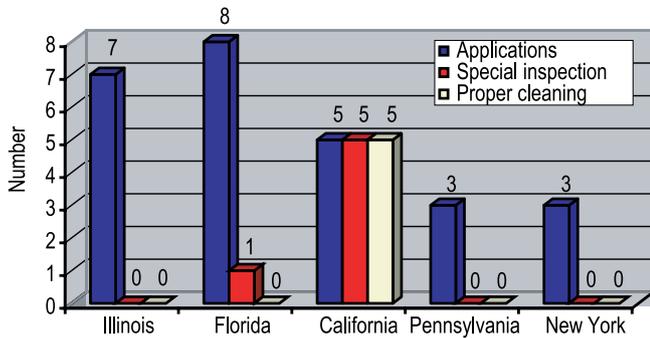


Fig. 10: Influence of special inspection of anchor installations. Proper borehole cleaning was only observed in California, a state with a long history of special inspection dating back to the UBC

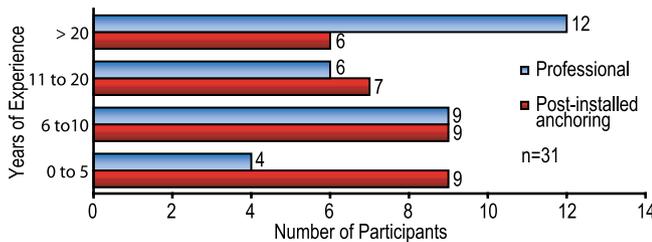


Fig. 11: The installers had significant experience in construction and with post-installed anchor installations. (n = number of installers interviewed)

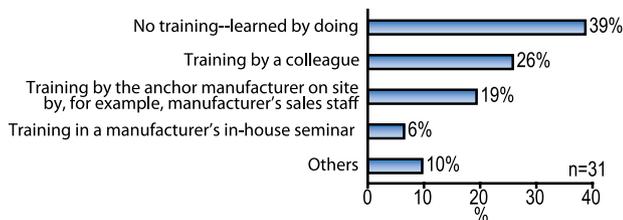
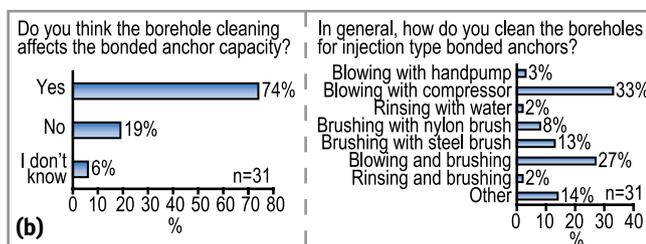
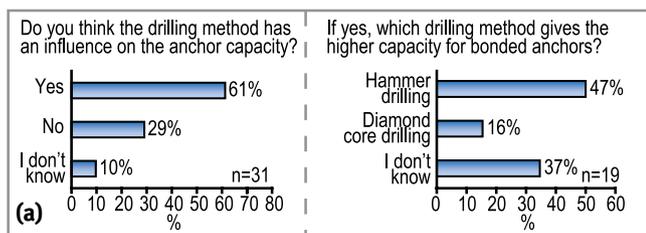


Fig. 12: Training of installers. Although the installers wanted to do a good job, their training was inadequate. (n = number of installers interviewed)



Almost all of the installers had technical backgrounds—the majority had been carpenters, millwrights, ironworkers, or general construction workers. Most of the installers had installed anchors for several years. Figure 11 summarizes the years of experience in their trades and in post-installed anchoring technology.

It was evident that the majority of installers wanted to do a very good job, tried to handle the installation process carefully, and were eager to improve their knowledge in fastening technology and installation procedures. In general, however, they were not informed about improvements in knowledge and procedures. The evaluation of the questions with regard to installation training is given in Fig. 12. Sixty-five percent of all installers stated that they gained their knowledge in post-installed anchoring technology either from “learning by doing” or from a colleague. One-quarter answered that they were trained by a manufacturer on site or in an in-house seminar, and only 10% answered that they got their knowledge from other sources such as schools.

Installers were also asked for their opinions regarding the influence of their practices on the capacity of adhesive anchors. The results are shown in Fig. 13. Whereas most of the installers interviewed knew that the drilling method has an influence on the anchor capacity (Fig. 13(a)), only half of them knew that the rougher borehole wall provided by hammer drilling gives a higher tensile capacity than the smooth borehole wall provided by diamond core drilling. Some of the installers did not know about the influence of borehole cleaning (Fig. 13(b)) on capacity. Note that correct borehole cleaning was mainly found in California, which might be attributed to the effective special inspection observed at those job sites. Most of the installers answered that the storage temperature has an influence on the anchor capacity; however, many stated that they store the adhesive on site or somewhere else, where storage temperature cannot be controlled (Fig. 13(c)).

Fig. 13: Many installers were not aware of the influences of significant factors on anchor capacity: (a) Although about 60% of the installers thought that the drilling method was significant, only half of these knew which drilling method provided higher capacity; (b) Although almost three out of four installers thought that the borehole cleaning method has an effect, less than a third were using blowing and brushing; and (c) Although over three out of four installers thought that storage temperature has an influence, only about a third were keeping the cartridges cool during storage. (n = number of installers interviewed)

FURTHER ACTIONS

The critical factors influencing the load-bearing behavior of adhesive-bonded anchors are well known. The findings summarized herein, however, demonstrate that there might be room for improvement to ensure high installation quality.

Training and certification

This study indicates that installers are generally very eager to do a good job, but much of the information available in ESRs isn't being used. Installers either haven't been properly trained, or they have been given inadequate installation instructions. There is an urgent need to improve the installation process for adhesive anchors on site, so installers need more detailed education in installing these types of anchors. Therefore, ACI Committee C601-A, Adhesive Anchor Installer, is working jointly with the Concrete Reinforcing Steel Institute (CRSI) on a new certification program. The development of the ACI-CRSI Adhesive Anchor Installation Certification Program has been on an accelerated schedule, and its rollout is scheduled for early 2011.

Other measures

In addition to proper training, other measures might help improve the quality of adhesive anchor installations. All parties have an incentive to demand that the manufacturer's product installation instructions are written and illustrated in a uniform, clear, and unmistakable way, and that those instructions are readily available to the installer and inspector.

For critical applications, effective special inspection seems to be necessary to ensure that anchors are installed correctly. Training of inspectors would help ensure effective special inspection.

Proof-loading can be effective in improving installations because it allows detection of installations with significant reductions in capacity. The contractor will have a strong incentive to ensure correct anchor installation and avoid problems that will develop if proof-loading criteria are not met.

Acknowledgment

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