Special Inspection Guidelines for Post-installed Anchors

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1.0 Scope

1.1 Purpose

The purpose of this document is to provide background and a frame of reference about special inspection in general and to provide specific information regarding the special inspection of post-installed mechanical and adhesive anchors installed in hardened concrete. This document is based on the requirements for special inspection in the International Building Code (IBC) published by the International Code Council as well as in the California Building Code as amended by the Office of Statewide Health and Planning Development (OSHPD). This document is intended to provide guidance on the special inspection process. It is based on historical information, existing public documents and the experience of the authors with post-installed anchors. Any opinions or recommendations expressed are solely those of the authors and not of the Concrete Anchor Manufacturers Association.

1.2 Types of Post-installed Anchors

Mechanical anchors comprise undercut anchors, expansion anchors and screw anchors. In their usual form, undercut anchors interlock with the concrete at the base of the drilled hole. They derive tension resistance by bearing. Expansion anchors derive tension resistance via the friction generated by expansion forces against the wall of the drilled hole. Two types of expansion anchors, torque-controlled and displacement controlled, are identified. Torque-controlled expansion anchors are set by the application of a defined torque to the anchor bolt. This generates the necessary expansion force in the anchor and preloads the bolt. Torque-controlled expansion anchors re-expand upon the application of tension loads in excess of the preload in the bolt, a mechanism referred to as follow-up expansion. Displacement-controlled expansion anchors are set by driving the expansion cone or the anchor sleeve through a defined displacement which results in a corresponding level of expansion force. Displacement-controlled expansion anchors do not generate additional expansion force upon loading. Screw anchors derive tension resistance via the interlock of the screw threads with the concrete.

Adhesive anchors derive tension resistance via the bond of the adhesive with the concrete surface in the drilled hole and with the steel anchor element. Hybrid anchors, such as torque-controlled adhesive anchors, combine the working principle of expansion and adhesive anchors.

2.0 Background

2.1 History of Special Inspection

The Uniform Building Code first included requirements for special inspection of certain types of construction in 1937. Special inspection requirements have not always been vigorously or uniformly enforced. They were conceived at a time when testing of construction materials was more prevalent and necessary due to variations in quality and the labor force was more skilled and less costly. Subsequently, the quality of construction materials has become more consistent while the cost of labor has risen dramatically, both absolutely and as a percentage of total construction cost. The result has been a reduction in the testing of construction materials and more emphasis on inspection of the labor portion of the work.

These trends, along with periodic earthquakes in California highlighting the need for better quality control of construction and the emergence of the IBC as the national building code, have focused attention on the special inspection requirements within the last twenty years. This has spawned national interest in special inspection, particularly among engineers who see special inspection as an extension of their construction phase overview services.

The IBC contains special inspection requirements that are specifically tailored to the principal construction material types (steel, concrete, masonry, wood), as well as to foundations and other types of specialized construction.

2.2 Future of Special Inspection

Work is ongoing in the code development process to better define the role of the special inspector and the levels of special inspection required for particular aspects of the construction. Since the advent of the IBC, emphasis has been placed in the past on the frequency of inspection (continuous vs. periodic). There is now a recognition that this simple distinction may not be adequate to capture the necessity of inspecting work at the time of installation, but not necessarily on a continuous basis. For example, reinforcing steel requires inspection prior to concrete placement, but the intensity of the inspection can be periodic. Similarly, the inspection of adhesive anchors should be conducted as they are being installed, but the overall intensity of inspection can be periodic (continuous inspection is appropriate for adhesive anchors installed overhead to carry sustained tension loads).

In general, the number of construction operations requiring special inspection has been increasing, particularly in connection with work associated with earthquake resistance and earthquake bracing of nonstructural components.

2.3 Special Inspection Definitions

Special inspection is the inspection of construction activities requiring unique expertise or where additional assurance of quality is deemed necessary. Concrete placement, masonry construction, structural welding and high strength bolting are common special inspection items. These inspections are in addition to the normal progress inspections performed by the building department inspectors.

The IBC distinguishes between continuous and periodic special inspection. The most recent revision to these terms occurred in the 2010-2011 code cycle:

SPECIAL INSPECTION, CONTINUOUS – The inspection of construction or work that requires special inspection in accordance with the statement of special inspections and, due to the nature of the work, is inspected by an approved special inspector who is continuously present in the area when and where the construction or work is being performed.

SPECIAL INSPECTION, PERIODIC – The inspection of construction or work that requires special inspection in accordance with the statement of special inspections and, due to the nature of the work, is inspected by an approved special inspector who is intermittently present in the area when and where the construction or work has been or is being performed.

The statement of special inspection is submitted by the Engineer of Record (EOR) and is made part of the building permit. Special inspectors are approved on the basis of criteria established by the authority having jurisdiction (AHJ), which may be a city, country, or state agency. See Section 2.4 for additional information.

2.4 Qualification of Special Inspectors

A special inspector is a specially qualified person with both inspection and practical experience in the construction operation requiring special inspection. The individual must submit his qualifications to the local building official for approval. Approval is sometimes done on a case by case basis or is granted to local testing agencies who employ inspectors with the particular expertise. In many cases the approval is informal, based on previous experience with firms and individuals. The International Code Council (ICC) has a certification program that includes many of the common special inspections. Also International Accreditation Service (IAS) has an accreditation program for special inspection agencies. Engineers may be qualified as special inspectors, however an engineering degree or license does not automatically qualify a person as a special inspector.

2.5 Employment of Special Inspectors

Section 1704.1 of the 2009 IBC states the following:

> **1704.1 General.** Where application is made for construction as described in this section, the owner or the *registered design professional in responsible charge* acting as the owner's agent shall employ one or more *approved agencies* to perform inspections during construction on the types of work listed under Section 1704.

Thus it is the owner of the construction project or the engineer or architect of record, acting as the owner's agent, that employs the special inspector(s). Contractors may not employ the special inspector(s), since this would constitute a conflict of interest and is not in accordance with the intent of special inspection as an independent evaluation.

2.6 Duties and Responsibilities of Special Inspectors

The special inspector observes the work for conformance with the approved design drawings, specifications and workmanship provisions of the building code, brings discrepancies to the immediate attention of the contractor and to the design authority and the building official if not corrected. Periodic and final inspection reports are required to be submitted to the building official and engineer or architect of record.

The special inspector is considered an extension of the building official by virtue of the code requirements for inspections by the building official and special inspection. The City of Los Angeles formalizes the relationship with special inspectors in this regard, and they are called "deputy inspectors".

3.0 Special Inspection Requirements for Post-Installed Anchors

Table 1704.4 of the IBC provides special inspection requirements for concrete construction. Anchors installed in hardened concrete are listed as requiring periodic special inspection. The inspection level for cast-in anchors for which the higher allowable loads in the code were used was continuous. In the 2009 IBC, the inspection requirement was broadened to all cast-in anchors designed in accordance with the strength design procedures of ACI 318 Appendix D. In the 2012 IBC, this requirement was reduced to periodic inspection due to the similarity with special inspection of reinforcing steel.

4.0 Special Inspection Procedures

4.1 General

Visual special inspection of cast-in anchors is conducted prior to concrete placement. Special inspection of post-installed anchors can occur both at the time of anchor installation and subsequent to anchor installation (e.g., for proof loading).

4.2 Special Inspection of Cast-in Anchors

Where required by the building code, cast-in anchors are included in the Statement of Special Inspections and are inspected together with other elements in the formwork such as reinforcing bar placement. To meet the requirements of continuous inspection when special inspection is specified, the special inspector must verify that the installation is in accordance with the requirements of the approved plans, evaluation report and manufacturer's instructions. This generally means verifying the location of the anchor including any edge distance and spacing requirements, as well as anchor type, size, and embedment.

4.3 Special Inspection of Post-installed Anchors

The inspection requirements for post-installed anchors are generally derived from the manufacturer's published installation instructions (MPII) and from the relevant evaluation report (ICC-ES ESR or other) for the product. Typical inspection procedures consist of reviewing the type of anchors that will be installed prior to the commencement of work and determination of what aspects of the installation are critical from an inspection standpoint. This varies from anchor type to anchor type. Generally, inspection focuses on verification that the anchor is in accordance with the project specifications, that the installation procedure is in accordance with the MPII, and that the anchor size, placement and embedment are in accordance with the contract documents.

Where required by the contract documents, procedures to avoid existing reinforcing bars in the concrete during drilling are reviewed by the inspector. Where core drilling is used, this is particularly important. Measures to be taken if reinforcing bars are encountered or damaged may include relocation of the anchor and will usually involve consultation with the EOR.

4.3.1 Post-installed Mechanical Anchors

The special inspector must verify that the installation is in accordance with the requirements of the approved construction documents, applicable evaluation report and the MPII, including verification of the location of the anchor, edge distance and spacing requirements. Pre-installation inspection of post-installed mechanical anchors usually consists of verification of anchor type, material, size and length, drilling method, drill bit type and size, hole cleaning procedures, and anchor installation and setting procedures. Special attention to aspects of the installation may be required depending on the job conditions. For example, where anchors installed in a slab on grade, it may be necessary to check that the hole drilling procedures do not result in breaking through to the underside of the slab. Use of a properly calibrated torque wrench is required for setting of many types of anchors, and is also required to avoid over-torquing of anchors during subsequent assembly. Prior to application of torque, anchor threads are inspected for damage or fouling. During setting of torque-controlled expansion anchors, the inspector will note the number of full turns required to achieve the required torque. Where anchors fail to set within the maximum permitted number of turns, procedures to remove and replace the anchor are developed with the EOR. Where large numbers of anchors are being installed, the inspector may observe the initial installations continuously, and thereafter perform periodic inspections as the installation proceeds. Subsequent continuous inspection of the installation for a time is required where there is a change of personnel performing the installation or where the anchor type is changed. ICC-ES acceptance criteria include a requirement for a length identification letter code to be stamped on the ends of anchors recognized for multiple embedments (usually wedge anchors). This makes it possible for the special inspector to determine, in conjunction with a knowledge of the specific anchor make, the embedment of these types of anchors after they have been installed.

Verification of proper set is conducted according to the anchor type. Torque-controlled expansion anchors such as wedge anchors and sleeve anchors are generally checked by application of torque with a calibrated torque wrench. Drop-in anchors (displacement-controlled expansion anchors) are checked by placing the setting tool into the anchor body to verify full set prior to installation of the bolt or threaded rod. Undercut anchors generally incorporate a method of visual verification of full set (full engagement of the anchor in a fully-developed undercut). Verification of proper set of screw anchors is performed during installation by ensuring that the minimum torque resistance is achieved, that the maximum torque is not exceeded, and that the anchor has achieved the required embedment.

Where specified, proof loading of mechanical anchors may be conducted by placing a loading shoe under the anchor head or threading a coupler onto the anchor stud. Proof loading of screw anchors may be performed in the case of anchors that have been pre-qualified for re-setting, however this must be approached with caution since testing may damage the screw threads in the concrete.

4.3.2 Adhesive anchors

The special inspector must verify that the installation is in accordance with the requirements of the approved construction documents, applicable evaluation report and the MPII, including verification of the location of the anchor, edge distance and spacing requirements. Pre-installation inspection of adhesive anchors usually consists of verification of anchor type, material, size and length, drilling method, drill bit type and size, hole cleaning procedures, and anchor installation and setting procedures. In addition, the inspector must verify the expiration date of the adhesive and the manner in which it has been stored. Anchor elements (threaded rod, reinforcing bars, internally threaded sleeves) must be inspected for the presence of substances that might interfere with bond (e.g., dust, mud, oil) and that the threads are undamaged and not fouled. Reinforcing bars must be free of loose rust. In cases where the concrete temperature may be higher or lower than normal room temperature, the concrete temperature in-situ must be verified prior to installation for conformance with the requirements of the MPII and to establish the cure time for the adhesive.

Since the design bond strengths for adhesive anchors are often associated with the use of specific drilling techniques (based on the resulting hole roughness), it is important that the specified hole drilling technique is used.

Verification of hole cleaning procedures in accordance with the MPII is critical. Where holes are drilled and cleaned in advance of anchor installation, it must be verified that the holes are protected from intrusion of contaminants or moisture (e.g., rainwater) during the interim period, or that the cleaning steps are performed immediately prior to anchor installation.

Prior to anchor installation, hole depths must be verified to ensure the correct embedment and to determine, in the case of injection systems, that the correct amount of adhesive is dispensed into the hole.

Injection adhesive systems have special requirements to ensure that the adhesive injected is correctly metered and mixed. These usually include, for each new cartridge, dispensing a quantity of adhesive from the mixing nozzle prior to beginning injection of adhesive in the hole. The objective of adhesive injection is to avoid entrained air. For long holes and holes drilled horizontally or overhead, the MPII may specify special equipment such as extension tubes, stoppers and end caps to achieve a void-free injection. The presence of air bubbles in the adhesive may be detectable as a tendency of the anchor element to spring back after being pushed into the adhesive mass or a popping sound is heard as air bubbles are displaced upward. Inspection of the installed anchor includes verifying that the anchor position is true (angle with respect to the concrete surface), that the anchor is secured against movement during the cure time, and that adhesive has not fouled the threads.

The inspector should verify that personnel performing adhesive anchor installation are experienced and qualified to use the specific adhesive anchor system being employed. ACI 318-11 Appendix D requires that all horizontal and upwardly inclined installations of adhesive anchors that resist sustained tension must be performed by certified adhesive anchor installers. A certification program is offered by ACI that includes both written and performance components.

4.4 Proof Loading

Proof loading is the application of tension load or, in the case of torque-controlled expansion anchors, torque moment to an installed anchor to verify proper set of that anchor. The load level is selected sufficiently high to provide assurance of correct installation but not so high as to result in damage (e.g. in the form of yielding or permanent slip) to a correctly installed anchor.[a]

Although no standard exists in the U.S. for the conduct of proof loading, it has been in use, predominantly in the western U.S., as an adjunct to anchor installation quality control for many decades. The state of California agencies responsible for hospital and school construction have historically included proof load requirements in their documented interpretations of the state building code.[b]

Proof loading alone is not recognized as meeting special inspection requirements. When included as a requirement in contract documents, it most commonly appears on the general notes sheet of the structural drawing set. The basic components of a proof load requirement are the size and type of anchors to be tested, the percentage of each type and size to be tested, the proof loads to be applied for each type and size, and the general requirements of acceptance (e.g., no discernable movement of the anchor). In addition, consequences for the case where an anchor fails the proof load test are specified. Note that the requirements for the proof load program may vary significantly from case to case. For example, while it is typical on a large job to require that anywhere from 10 to 20 percent of the installed anchors of a given type and size be proof loaded[c], this requirement must be adjusted where, say, only four large anchors in a baseplate are to be verified. In such a case, it is not unreasonable to require that all four anchors be proof loaded, particularly if the consequences of failure are significant.

4.4.1 Essential Elements of a Proof Load Program

Type and size of anchors to be tested – All safety-related post-installed anchors may be subject to proof loading. The requirements for mechanical anchors (expansion and undercut anchors) are generally distinct from those for adhesive anchors. Screw anchors present specific challenges with respect to proof loading and are addressed separately. Since the level of proof load is specified as a percentage of the tension capacity of the anchor, it is necessary to categorize anchors by type, diameter, and embedment depth where actual proof loads are used (as opposed to torque testing).

Frequency of testing – There is no set rule regarding the percentages of anchors to be tested, nor is there any existing statistical basis for the percentages usually specified. Clearly, the number of anchors to be proof loaded is dictated by structural safety as well as practical considerations. The typical phrase "test X percent of each anchor type and

[a] Note that testing of installed anchors as a means of establishing in situ strength is often confused with proof loading. While the test methodologies are similar, testing to establish values for design is conducted with different objectives and therefore with different acceptance criteria, sampling rates, etc.

[b] The Division of the State Architect (DSA) responsible for schools K-12 as well as community colleges, maintains IRs, or Interpretation of Regulations, while the Office of Statewide Health Planning and Development (OSHPD) which oversees hospital construction throughout the state, uses Code Application Notices, or CANs.

[c] OSHPD requires 50%.

size" may result in complications where there is not a clear distinction made between anchor "types" and "sizes". For highly redundant applications and less critical applications such as rebar doweling for shotcrete applications or slab on grade doweling, proof loading of a minimum random sampling of 5% of the anchors may suffice. The EOR may require higher sampling rates for installations with less redundancy or that are considered more critical.

Acceptance criteria – Proof loading should be performed only after the minimum cure time specified in the MPII for ambient temperature conditions has elapsed. Proof loads should be maintained long enough to enable a determination of no anchor movement. When torque testing torque-controlled expansion anchors, the installation torque should usually be achieved within one turn of the nut or as specified in the MPII.

Proof loads – The establishment of proof loads should recognize the primary objective of proof loading as stated above, i.e., sufficiently high to provide assurance of correct installation but not so high as to result in damage. Given this objective, it should be clear that proof loads are set as a percentage of the tested tension capacity of the anchor, not the anchor design tension load. Historically, proof loads have been set at twice the allowable tension load. Given that the global safety factor used for anchor tension strength in allowable stress design has historically been set at 4.0 (inspected construction), the proof load represents approximately 50% of the mean ultimate anchor tension strength uninfluenced by edges, member thickness, etc. Note that, depending on the embedment to diameter ratio and the steel grade, this load might or might not subject the anchor to yield level stresses. For most mechanical anchor types using high-strength steels and typical embedment to diameter ratios (7 to 9), this is not a problem. Where lower yield steels are used, it should be verified that the proof loads do not exceed 80% of the nominal yield stress of the steel anchor components. Since the purpose of proof load is to verify proper installation, proof loading equipment may have load reactions close to the anchor but with sufficient clearance so any movement would be visible.

4.4.2 Special Requirements of the State of California Office of Statewide Health Planning and Development (OSHPD)

The state of California has for many years required proof loading of anchors used in school and hospital construction. These requirements originated with the Division of the State Architect (DSA) and were later adopted by OSHPD specifically for hospitals. The OSHPD requirements are defined in documents issued as clarifications or interpretations of the adopted code language, originally via Interpretation of Regulations (IR 26-6, referring to Chapter 26 of the UBC) and currently in a Code Application Notice (CAN 1925.1). DSA requirements, which apply to schools K through 12, community and state colleges and universities, are provided in IR 19-1. Historically, OSHPD (and DSA) set allowable loads for post-installed anchors at 80% of the tabulated allowable loads provided in ICBO ES evaluation reports. Therefore, proof loads represented 2 x 0.8 = 1.6

times the ICBO ES allowable load, or 1.6/4.0 = 0.4 times the mean ultimate tension strength.

4.4.3 Example

The following is an example of a periodic inspection and proof loading program specified by the author and used on an actual construction project:

Initial inspection is required for each different subcontractor. The inspector will verify location and configuration of the anchors based on the project plans including any edge distance and spacing requirements, drill bit type and size used, hole depth, hole cleaning technique, anchor type, size, embedment and installation procedure including adhesive expiration date and proper dispensing.

Subsequent inspection of installation will be required only when there is a change of personnel doing the installation. The general contractor shall call for such inspection in the event of a change, defined as any one or more persons drilling, preparing holes or installing anchors.

Initial inspection and proof load testing are required for the following. Anchor type drawing detail reference, test frequency and tension loads are:

#4 Rebar Dowels at shotcrete walls (7/S1.2) - 5%/9000 lbs

#4 Rebar Dowels at lower level ramps (5/S1.1) - No testing

#5 Rebar Dowels at roof infill (2/S1.3) - 10%/14,000 lbs

3/4" Epoxy Rods at steel moment frames (1-7/S5.1) - 5%/20,000 lbs

1" Epoxy Rods at steel moment frames (9/S5.1) - 5%/28,000 lbs

1-1/4" Epoxy Rods at steel moment frames (8/S5.1) - 1 at each frame/50,000 lbs

Test loads are based on either 80% of steel yield or 50% of expected ultimate adhesive bond tension capacity, whichever is less, to avoid permanent distress. Anchors shall have no visible indications of movement during or after the application of the proof load.

4.4.4 Derivation of Proof Loads for Strength Design

Anchors are designed using strength values calculated as the 5% fractile or "characteristic" resistance (defined as the value that would be exceeded by 95% of the population with a confidence of 90%). In Appendix D, it is assumed that the characteristic value is 0.75 times the mean ultimate resistance (based on an assumed COV = 15%).

$$N_{cb} = k\sqrt{f_c'}\,h_{ef}^{1.5} = 0.75\bar{N}_{cb} \quad \text{.......(1)}$$

Taking the previous rule of "twice the allowable":

$$N_{allow} = \frac{\bar{N}_{cb}}{4} = \frac{N_{cb}}{3} \quad \text{.......(2)}$$

$$2 \cdot N_{allow} = \frac{2}{3}N_{cb} = \frac{N_{cb}}{1.5} \quad \text{.......(3)}$$

That is, the characteristic resistance divided by 1.5 yields twice the "allowable".

However, if we use the current definition for the allowable load based on LRFD:

$$N_{allow} = \frac{\phi N_{cb}}{LF(weighted\ avg)} \quad \text{.......(4)}$$

In the simplest case:

$$N_{allow} = \frac{0.65N_{cb}}{1.4} = \frac{N_{cb}}{2.15} \Rightarrow 2 \cdot N_{allow} = \frac{N_{cb}}{1.08} \cong N_{cb} \quad \text{.......(5)}$$

For the general case (variable strength reduction factors)[d]:

Proof load = $2 \cdot \frac{\phi N_{cb}}{1.4} = 1.43 \cdot \phi N_{cb}$ ....(6)

Per subpara. 1.1.1 of the CAN, OSHPD takes this as $1.5\phi N_{cb}$ which implies a weighted average load factor of 1.33 instead of 1.4.

Where the resistance has been reduced by 0.75 for seismic in accordance D.3.3.3, OSHPD asks that the proof load be calculated using a factor of 2.0 instead of 1.5 as follows:

Proof load = $2.0 \cdot 0.75 \cdot \phi N_{cb} = 1.5 \cdot \phi N_{cb}$

[d] Note that ACI defines "design strength" as ϕ (nominal strength), ref. ACI 318-08 R9.1

For adhesive anchors, standard practice has been to establish proof loads at 50% of the mean bond strength or 80% of the rod yield, whichever is less (For obvious reasons, proof loads should never result in steel yield).

Taking 50% of the mean bond strength:

$$\bar{N}_u = \frac{N_k}{0.75} \qquad (7)$$

$$\frac{\bar{N}_u}{2} = \frac{N_k}{1.5} = 0.67N_k \qquad (8)$$

which would be appropriate for a global safety factor of 4 on the mean resistance.

5.0 Equipment and Calibration

Inspection equipment may include:

1. A borescope for inspection of deeper drilled holes.
2. A probe thermometer or other temperature measuring device to verify in-situ concrete temperature for adhesive anchors.
3. Measuring devices for hole diameter and depth as well as anchor position and member dimensions. Hole depth can also be verified using the anchor element.
4. Proof loading equipment as described below.

5.1 Hydraulic Systems

Hollow core rams with pressure gages are used when proof loading is part of the special inspection procedures. Each combination of ram and gage must be calibrated together as a system in a testing machine or other device that is traceable to the National Institute of Standards and Technology (NIST). It is not acceptable to calibrate the gage alone and calculate the load by multiplying gage pressure time the ram area.

When testing anchors to ultimate failure, the load reactions from the bridging system should be at least two times the anchor embedment away from the anchor. However when using the OSHPD or DSA procedure, it is permissible to have the reactions close to the anchor as long as the fixtures do not restrict the anchor from pulling out or restrict visibility so any movement can be seen. The reason for this is that only the anchor installation is being verified using a relatively low proof load.

5.2 Torque wrenches

Torque wrenches are used when torque testing is part of the special inspection procedures. They must be calibrated by a standard traceable to NIST.

5.3 Other

Torque bridges, levers and other custom devices must be carefully conceived and calibrated to insure that the required proof load is applied to the anchors. Torque bridges are particularly tricky since the calibration procedures in testing machines using rigid connections may not be valid for anchors that move when loaded (are less rigid than the calibration set up).

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