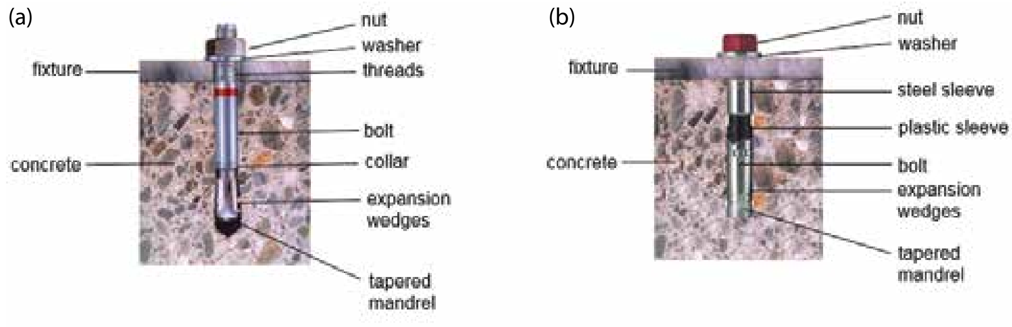

Figure 1. a) Hilti Kwik Bolt-TZ Anchor; b) Hilti HSL-3 Anchor.

How Installation Torque Can Affect Expansion Anchors

By Richard T. Morgan, P.E.

Post-installed expansion anchors are used to attach fixtures to concrete and masonry. Expansion anchor types include *torque-controlled* anchors, which must be torqued to expand wedges, and *displacement-controlled* anchors, which require impact forces on a sleeve or plug to expand wedges. Expansion anchors that rely on torque to expand wedges are referred to as torque-controlled expansion anchors. This article discusses the importance of torque on the installation and performance of torque-controlled expansion anchors installed into concrete.

Why Torque Expansion Anchors?

Figure 1 illustrates the components of a torque-controlled expansion anchor. Applying a torque to the nut activates a mechanism whereby displacement (movement) causes the wedges to expand into the concrete. This mechanism consists of a tapered mandrel that moves up through the wedges. The tapered mandrel can be a part of the bolt shank (*Figure 1a*), or it can be a separate assembly that threads onto the bolt shank (*Figure 1b*). When the wedges are expanded, a tension pre-load develops in the anchor along with a compression clamping load between the fixture and the concrete. Pre-loading reduces the amount of displacement the anchor undergoes when subjected to external tension load. Pre-loading also reduces anchor fatigue under cyclic loads. Clamping eliminates gaps between the fixture and concrete.

What Results from Torquing?

Torquing creates a tension pre-load in the anchor and a commensurate clamping load between the fixture and the concrete. Tension pre-load and clamping load depend on several parameters:

- the amount of torque applied to the anchor
- the friction that develops between the nut and bolt threads
- the friction between the nut and washer
- the friction between the washer and fixture
- the friction between the fixture and concrete surface
- the amount of wedge expansion
- the concrete compressive strength
- the angle between the installed anchor and fixture surface
- the elapsed time after the installation torque has been applied

Figure 2 illustrates the effect an external tension load has on a torque-controlled expansion anchor.

The load corresponding to pre-load in the anchor, and clamping between the fixture and the concrete, is designated N_{torque}. Torquing causes the anchor to undergo a *positive* (i.e. tension) displacement, which is offset by a *negative* (i.e. compression) displacement in the concrete. The amount of pre-load, clamping, and displacement are dependent on the parameters listed above.

Application of external tension load to the fixture reduces the clamping load between the fixture and concrete while adding some tension load to the anchor. Since concrete is typically stiffer in compression compared to the tension stiffness of an anchor, the additional tension load on the anchor resulting from the external tension load is minimized as long as any clamping load remains.

Once the clamping load between the fixture and concrete is completely removed, any external tension load applied to the fixture acts directly on the anchor. *Figure 3* illustrates the effect an external tension load has on a torque-controlled expansion anchor after the clamping load between the fixture and concrete has been removed.

It is necessary to make a distinction between anchor performance in uncracked concrete versus cracked concrete. When a torque controlled expansion anchor is installed in uncracked concrete, the anchor pre-load created by torquing will decrease over time. Relaxation within the interface between the nut and bolt threads and relaxation of the stressed concrete in the areas adjacent to the expansion wedges contribute to this decrease. The anchor pre-load decrease occurs rapidly at first, sometimes within minutes after the initial torque has been applied. The decrease continues over several hours, then days, eventually reaching

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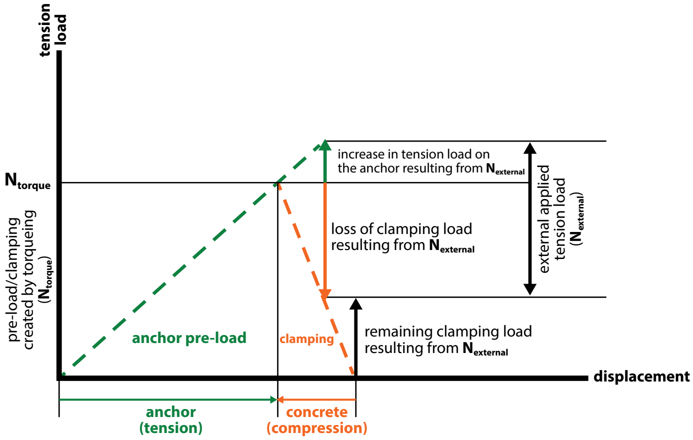

Figure 2. Effects of external tension load with clamping.

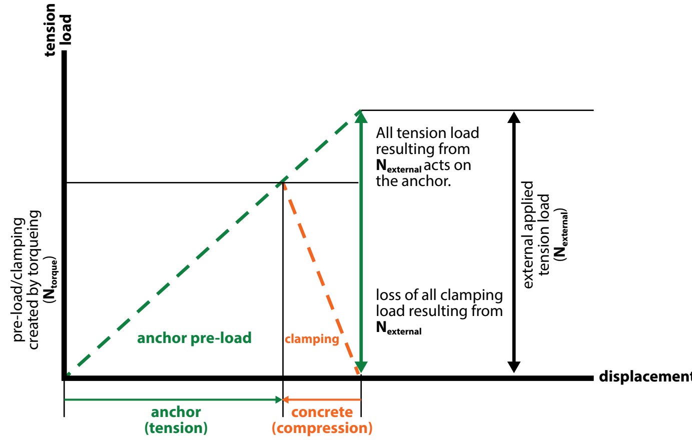

Figure 3. Effects of external tension load without clamping.

a plateau (e.g. 100+ days). The amount of anchor pre-load lost over this time can range between 50-60% of the initial anchor pre-load. Re-torquing permits some of this anchor pre-load loss to be regained. However, a loss of anchor pre-load due to relaxation will continue to occur, albeit to a lesser extent than the original loss. Re-torquing is discussed later in this article.

With respect to cracked concrete conditions, torque-controlled expansion anchors can lose all of the anchor pre-load when a crack propagates to the anchor. The size of the drilled hole is effectively increased, which requires additional wedge expansion, via additional anchor displacement, to accommodate the crack. This additional wedge expansion resulting from the additional anchor displacement is referred to as *follow-up expansion*. Torque-controlled expansion anchor design for cracked concrete conditions requires the anchor to have follow-up expansion capability. Therefore, it is important to select an anchor specifically qualified for use in cracked concrete.

Whether cracked or uncracked concrete conditions exist, pre-load and the commensurate clamping load will decrease. Once these loads are removed, any additional external tension load applied to the fixture will cause additional anchor displacement and "lift-off" of the fixture, whereby a space develops between the fixture and concrete surface. The tension load is now acting directly on the anchor(s). Anchoring-to-concrete strength design provisions for *tension* assume the loads acting on an anchorage act directly on the anchor elements, i.e., no pre-load/clamping load remains. Anchoring-to-concrete strength design provisions for *shear* likewise assume the loads act directly on the anchor elements, i.e., no clamping load remains. Furthermore, the clamping load that does develop from torquing an expansion anchor is not considered sufficient to design an anchorage as a slip-critical connection for resisting shear load.

What is the Result of Improper Torquing?

Expansion anchors must be torqued per the values provided in the Manufacturer's Printed Installation Instructions (MPII) to properly expand the wedges and clamp the fixture. Under-torquing results in under-expansion of the wedges, which reduces the amount of clamping developed. Once pre-load/clamping is removed from an under-torqued expansion anchor subjected to tensile loading, the anchor will displace, resulting in follow-up wedge expansion and lift-off of the fixture.

An anchor group consisting of anchors that are torqued unequally during installation can have an unequal load distribution on the anchors. For example, Section 5.2.2 – *Drill bit requirements* in the American Concrete Institute (ACI) Standard ACI 355.2 (*Qualification of Post-Installed Mechanical Anchors in Concrete*) permits anchor installation at an angle up to 6 degrees from perpendicular. Anchors in a group that are installed at an excessive angle (with respect to perpendicular) will have a different tension pre-load compared to anchors in the group installed perpendicular to the surface. If this unequal load distribution on the anchors is not considered, the calculated anchorage capacity may be unconservative. A non-uniform clamping load will also develop between the fixture and concrete.

Torque-controlled expansion anchors must be qualified per the International Code Council Evaluation Service (ICC-ES) acceptance criteria AC193 (*Acceptance Criteria for Mechanical Anchors in Concrete Elements*) in order to receive recognition under the *International Building Code* (IBC). Recognition is given in an ICC-ES evaluation report (ESR). AC193 also references ACI 355.2; Section 5.2.3 – *Setting requirements for testing* in ACI 355.2 includes provisions for checking the effects of under-torquing. These provisions are given in Section 5.2.3.2.1, and are as follows:

"For the reliability tests performed with reduced installation effort (Table 4.1, Test 3 and Table 4.2, Test 5), install and set the anchor with a setting torque of $0.5T_{inst}$. Do not reduce the torque from this amount."

The parameter T_{inst} is defined in ACI 355.2 Section 2.2 – *Notation* as the "specified or maximum setting torque for expansion or pre-stressing of an anchor." T_{inst} corresponds to the recommended torque value given in the MPII. Setting a torque-controlled expansion anchor with T_{inst} causes anchor displacement/wedge expansion and pre-load/clamping load to develop. Referencing the ACI 355.2 *Commentary* Sections R5.2.3 and R.5.2.3.1, the test provisions given in Section 5.2.3.2.1 are intended to simulate "installation error on the job site" (i.e. under-torquing) and to determine "if the anchor will still properly function if set with a torque substantially below the recommended torque." An under-torqued expansion anchor will have under-expanded wedges. Testing per ACI 355.2 Section 5.2.3.2.1 assesses if a torque-controlled expansion anchor set with a torque less than T_{inst}, and after removal of any pre-load/clamping load, can undergo sufficient follow-up expansion to function in an acceptable manner.

Over-torquing a torque-controlled expansion anchor could result in the occurrence of various failure modes. One possible failure mode is concrete splitting. The ACI 355.2 test 9.3 – *Service-condition test at minimum edge distance and minimum spacing* "is performed to check that the concrete will not experience splitting failure during anchor installation." The test consists of installing two anchors in uncracked concrete at a minimum edge distance (c_{min}) and minimum spacing (s_{min}) established by the anchor manufacturer. Each anchor is installed with a setting torque that is greater than the smaller of ($1.7T_{inst}$) and (T_{inst} + 100 ft-lb). The smallest values for c_{min} and s_{min} that can be achieved without splitting failure represent the minimum edge distance and minimum spacing for the anchor in both cracked and uncracked concrete. Over-torquing can also result in steel failure of the anchor, the anchor pulling through the wedges, or the entire anchor pulling out of the concrete.

Torque-controlled expansion anchors must be installed in holes drilled with matched-tolerance bits. Installing an anchor in an under-sized drilled hole can damage the wedges and inhibit wedge expansion during torquing. Installing an anchor in an oversized drilled hole results in the wedges not able to fully engage the concrete, thereby preventing them from properly expanding when the anchor is torqued or externally loaded.

How is Inspection Accomplished?

The MPII for an anchor provides specified torque values. These torque values must be used when installing the anchor. The IBC requires *special inspection* for "materials and systems required to be installed in accordance with additional manufacturer's instructions" (e.g. reference Section 1705, *Required Special Inspections and Tests*, and specifically Section 1705.1.1 *Special cases* in the 2015 IBC). Special inspection is intended to be an independent evaluation of the work that has been performed. The special inspector is employed by, and acts on behalf of, the owner or through the architect/engineer of record who represents the owner. The special inspector should not be employed by the contractor since this would be considered a conflict of interest. Therefore, special inspection with respect to a torque-controlled expansion anchor is a means to verify, among other things, that the anchor has been properly installed using the manufacturer's specified torque value.

The ESR will note special inspection requirements unique to an anchor. These special inspection requirements can include verification of the "tightening torque" used to install the anchor. Torquing must be performed with a properly calibrated torque wrench. This assures that the manufacturer's specified setting torque is used, and it also helps avoid under-torquing or over-torquing of the anchor. Since the interface between the nut and bolt threads is integral to developing pre-load in the anchor, these threads should be inspected for damage or fouling before torquing, and should never be lubricated.

Verifying a torque value brings up the subject of re-torquing. As previously noted, even without any external load being applied to an expansion anchor installed in uncracked concrete, the pre-load resulting from torquing tends to decrease over time due to relaxation. Expansion anchor pre-load loss in cracked concrete occurs when a crack propagates to the anchor.

Re-torquing an expansion anchor is used to reintroduce a higher preload or clamping load. Re-torquing can also be used to re-set the anchor when the location of a fixture must be adjusted. The nut threads, anchor threads, and area under the washer should be cleaned before re-torquing if the nut is loosened or removed. When re-torquing an anchor, the re-torque value should never exceed the torque value given in the MPII. A rule of thumb is to limit the number of times an expansion anchor can be re-torqued to three times. Consult with the anchor manufacturer for guidance with respect to a particular product.

ACI 355.2 Section 5.2.3.1.1 includes provisions for testing the relaxation effects on a torque-controlled expansion anchor. The recommended torque value (T_{inst}) given in the MPII is applied using a calibrated torque wrench. After 10 minutes, the nut is loosened and a torque of $0.5T_{inst}$ is re-applied using the calibrated torque wrench. This test simulates the loss of pre-load over the service life of the anchor and assesses if the anchor can function in an acceptable manner after relaxation has occurred.

Torquing is sometimes used as a crude means of proof loading an expansion anchor to verify some level of performance and rule out gross installation errors. The use of torque to proof-load an anchor is not precise because the torque-tension relationship can be highly variable from one anchor to another.

A manually operated torque wrench is commonly used to install and proof-load torque-controlled expansion anchors.

The published torque values of a power tool such as an impact wrench do not coincide with a manually applied torque value, and standard impact wrenches do not have the required calibration accuracy. Therefore, an impact wrench should not, as a rule-of-thumb, be used to set a torque-controlled expansion anchor. That said, technological advances by some manufacturers now permit torque-controlled expansion anchors to be set with an "adaptive torque tool" specially calibrated for setting this type of anchor.

Summary

This article discussed the importance of torquing with respect to the installation and functioning of torque-controlled expansion anchors installed into concrete. Installation torque creates a tension pre-load in the anchor and a clamping load between the fixture and concrete. A properly qualified, designed, and installed expansion anchor set with the manufacturer's specified installation torque will function as designed. Under-torquing causes under-expansion of the wedges, which results in lower-than-intended clamping of the fixture and increased anchor displacement when external tension loads are applied. Over-torquing can lead to concrete failure, steel failure of the anchor, or some form of anchor pullout failure.

The MPII and ESR provide specified installation torque values for an anchor. The ESR notes if the anchor is qualified for use in cracked concrete and the special inspection requirements. Special inspection of torque-controlled expansion anchors, conducted by an approved agency acting on behalf of the owner or owner's representative, is required by the IBC. Calibrated torque wrenches or power tools specifically designed for setting a torque-controlled expansion anchor should be used for installation and inspection of the anchor.■