

DuraSquirt® DTIs



DuraSquirt® DTIs, are enhanced ASTM F9591 DTIs that render feeler gauges unnecessary. Like Squirter® DTIs, DuraSquirt® DTIs expel orange indication media when a bolt has been properly pretensioned in accordance with AISC/RCSC specifications. The difference with DuraSquirt® DTIs, is the indication media is permanent, unless actively removed.

This picture illustrates how permanent. Each assembly has been fully tensioned

with a DuraSquirt® DTI. The galvanized bolt on the left is a freshly tightened assembly. The plain bolt on the right, was tightened in November 2014. It is rusty since it was washed in Applied Bolting's lunchroom dishwasher every working day for a year. Afterwards, it was carried loose in a toolbox for another 2 years, unprotected, as our technical personnel traveled around the USA to conduct structural bolting seminars. While the fastener underwent serious abuse and neglect, the DuraSquirt® DTI can still be inspected visually.

Like all DTIs, DuraSquirt® DTIs are single use mechanical load cells that function independent of torque or turn. While a DuraSquirt® DTI is a smart device, they are dumb about how much it will take to tighten a bolt. If a bolt is tightened enough, the DTI will show it, if not, the DTI will show that too. While current specifications considered DTIs an installation method, in reality, they are actually an inspection tool. They indicate success of pretensioning, or the lack of it.

DuraSquirt® DTIs are the only DTIs that can be used as Bolt Tension Measurement Devices, per AISC/RCSC section 7¹ because they are the only "verification lot" of DTIs available. Per AISC/RCSC:

A Bolt Tension Measurement Device is a calibrated device that is used to verify that the bolting assembly, the pretensioning method, and the tools used are capable to achieve the required tensions when a pretensioned joint or slip-critical joint is specified. (AISC/RCSC 16.2-x)

Pre-installation Verification Testing is essential for:

- (1) Evaluating the suitability of the bolting assembly, including the lubrication that is applied by the Manufacturer or specially applied, to develop the specified minimum pretension;
- (2) Verifying the adequacy and proper use of the specified pretensioning method to be used;
- (3) Determining the installation torque for the calibrated wrench method of pretensioning;
- (4) Verifying the initial torque applied achieves at least the required initial tension when using the combined method of pretensioning; and
- (5) Demonstrating the suitability of the bolt tightening equipment to be used during installation.

¹ AISC/RCSC 16.2-59, "Direct tension indicators (DTIs) may be used as bolt tension measurement devices".

(AISC/RCSC 16.2-52)

Further reading AISC/RCSC section 7 describes how verification lot DTIs with Calibrated Gaps are to be used:

Direct tension indicators (DTIs) may be used as bolt tension measurement devices, except in the case of the turn-of-nut method and the combined method. This method is especially useful for, but not restricted to, bolts that are too short to fit into a hydraulic bolt tension measurement device (AISC/RCSC 16.2-59).

Using a verification lot DTI as a bolt tension measurement device has been included in the AISC/RCSC specification since 2009 but the U.S. Department of Transportation's Federal Highway Administration has permitted the procedure since at least 1991².

Once the DTIs are calibrated, they are used on short bolts to set the installation wrenches at the required bolt tension. (FWHA 10-6)

Similarly, the AISC/RCSC states:

The fastener assembly may then be installed in a standard size hole with the additional verification DTI. The prescribed pretensioning procedure is followed, and it [the bolt assembly] is verified...³

To date, DuraSquirt® DTIs are the only DTIs manufactured as verification DTIs per AISC/RCSC⁴. The AISC/RCSC explains tightening with an assembly sufficiently, with a verification lot DTI, can replace Preinstallation Verification testing with a hydraulic tension calibrator. In other words, tightening bolts with verification lot DTIs satisfies section 7 bolt verification testing. Preinstallation testing is conducted "on the fly" as bolting commences. As each verification DuraSquirt® DTI is installed, with enough torque to cause the DTI Squirt™ location to fully emit orange indicating material, the fastener has passed field testing requirements.

Such robustness is not possible with other styles of DTIs because they rely on feeler gauges for pretension confirmation and feeler gauging is susceptible to false positive readings. Feeler gauges will erroneously indicate tension when a hole exceeds standard hole dimensions (oversized, reaming, etc.), flat washer problems, as well as improper DTI orientation i.e., upside down (yes, it happens).

With poor quality flat washers, the DTI's bumps are not compressed but feeler gauges will erroneously indicate they have been flattened. Poor quality washers will imprint themselves onto the DTI. The two images below illustrate this. Obviously, the DTI washer combination shown is not "tight" since there is no bolt, but the feeler gauge is refused entry anyway.



² FHWA-SA-91-031 May 1991.

³ AISC/RCSC 16.2-59.

⁴ AISC/RCSC 16.2-59 DTIs being used for verification testing, termed the "verification lot."

The image on the left is the same washer/DTI combination separated. Observe the cavities imprinted in the flat washer. DTIs are hardened, structural flat washers are supposed to be as well. This one is not heat treated so it formed cavities where it contacted the DTI bumps.

In the case of holes outside of the standard hole dimensions and tolerance, the flat washer will push (not compress) the DTI bumps and force the DTI into the oversized hole. Also, when the DTI is placed upside down, i.e., bumps against the steel work, the DTI will “appear” flat against the adjacent washer, since the hardened bumps imprint into the softer the steel. In both cases, the DTIs’ bumps are intact, and will pass feeler gauge inspections.

DuraSquirt® DTIs solve these problems and more since bump compression is verified by the DTI expelling DuraSquirt® media. If the DTI does not emit orange media at every available Squirt™ location, it should trigger the installer/inspector to determine that something is out of spec and should be corrected immediately. Poor quality flat washers can be replaced or an additional flat washer against the oversized hole (as required by code) can be added to the assembly.

Simply put, a fully deployed DuraSquirt® DTI (i.e., orange visible at all bump locations), indicates adequate bolt tension and confirms holes and washers are per modern construction standards.

Pre-Installation Verification

Per AISC/RCSC section 7 Pre-Installation verification, fastener assembly testing must be conducted, onsite, by the installation crew, using actual installation tools. Contrary to popular opinion Pre-Installation Verification testing **DOES NOT** pass or fail fastener assemblies. Testing is intended to discover possible issues between fasteners, tools and installers, before field bolting operations commence.

The next few sections describe issues that may be highlighted by Pre-Installation testing results.

Fasteners:

Are the fastener assemblies capable of achieving 105%, or more, of minimum required bolt pretension at all?

Torque must be applied to the fastener assembly until the tension calibrator indicates adequate pretension or the bolt fails, whichever occurs first. Failure occurs by either the bolt breaking before minimum pretension, or tensile load climbs and then falls, as indicated by the tension calibrator, without ever achieving minimum pretension. Except for TC bolt⁵, applying additional lubricant may alleviate failure. However, if additional lubricant solves bolt failure, all fasteners represented by lubricated test samples, must be similarly lubricated.

Tools:

Do the installation tools have enough output torque to tighten adequately lubricated fastener assemblies, to at least 105% of minimum required pretension?

If the full effort of an installation tool applied to a fastener assembly, does not result in at least 105% of required minimum pretension, the tool must be replaced for testing as well as for installation. While not

⁵ AISC 348-20, the Research Council on Structural Connections, Specification for Structural Joints Using High-Strength Bolts: Section 2.10.4 “matched bolting assemblies shall not be relubricated by anyone other than the Manufacturer”

always true, an adequate installation tool should have a drive chuck at least as large as the fasteners being tightened. For example, when tightening $\frac{3}{4}$ " bolts, the installation tool should have a square drive chuck of $\frac{3}{4}$ " or more. Also, a tool's manual may claim a higher output torque than the tool can produce. Such claims are usually stated vaguely, such as, claiming the tool's motor **can produce** some high amount of torque. This statement may describe no-load torque output, but once load is applied, the high torque described will not be realized.

Installation crews:

Do the installers understand how to employ the selected method?

The installers must understand that a snugged tightened condition must be achieved before the pretensioning method is employed. Once a snug condition exists, the installers must fully understand the method they employ and not confuse, or combine, fundamentals of individual methods. Such as applying a torque value to rotate the nut to turn angle listed for Turn-Of-Nut or employing a torque wrench as an inspection technique after the turn is complete. Doing so combines elements of Calibrated Wrench and Turn-Of-Nut. In the same fashion, inspecting a DTI installation with a torque wrench combines DTI and Calibrated Wrench methods.

Snug-tightened Joints

Every bolted joint must be snug-tightened before a pretensioning method can be performed. Snug-tighten is defined as the effort applied to bring the steel plies into *firm contact*. AISC/RCSC describes the effort as the full effort of an ironworker or a few impacts of an impact wrench (5.2) until the nut cannot be removed by hand. An attempt at manual nut removal is the only requirement for inspection (9.1). There is no pretension requirement for a "snugged" joint. Per AISC's *Specification for Structural Steel Buildings* (AISC 360) Section J3:

"There are no specific minimum or maximum tension requirements for snug-tight bolts."

Conversely, snug-tightening may result in a pretension near or greater than the minimum required, and the required turn may strip or break the bolt when employed. This is especially true of bolt diameters $\frac{3}{4}$ " and below.

Verification Basics

The following content applies to AISC/RCSC Pre-installation testing only. Individual projects, State DOTs and Federal Highway specifications may differ substantially and will not be covered here. The following represents Applied Bolting Technology's interpretation of AISC/RCSC Pre-installation testing based on *The Research Council on Structural Connections'*, **Specification for Structural Joints Using High-Strength Bolts** (AISC 348) and the *American Institute of Steel Construction's Specification for Structural Steel Buildings* (AISC 360). Anyone interested in a different interpretation is welcome to read the documents themselves.

Verification testing can be summarized as snug-tightening, at least three sample fastener assemblies, in or with, a bolt tension measurement device, applying the selected pretensioning method, and confirming at least 105% of minimum required pretension has been achieved. While each method accomplishes this with different tools, fastener components, or tightening techniques, all 4 tensioning methods follow these basic principles of snug fastener, apply method, and verify conformity to

specification. Lastly, all acceptable methods are expected to permanently deform the fastener into its inelastic region⁶.

Sampling

Pre-Installation verification testing begins with sampling. Per AISC/RCSC section 7.2:

“On a sample of not fewer than three complete bolting assemblies of each combination of diameter, length, grade, and lot to be used in the work; Using bolting assemblies that are representative of the condition of those that will be pretensioned in the work” (AISC/RCSC 16.2-52)

Regardless of method, it is critical that assembly samples be **TRULY REPRESENTATIVE**, that is, in similar condition as fasteners being actively pretensioned. Testing a “new” fastener, removed directly from sealed shipping receptacles, does not constitute a representative sample, unless only new condition fasteners are actively being pretensioned.

Fasteners that have been snug-tightened & exposed to the weather, for any amount time, must be verified as is, if this condition accurately represents the fasteners’ being tightened in the steelwork. **TRULY REPRESENTATIVE** samples are especially important for TC bolts and Calibrated Wrench installation and testing because these methods are negatively affected by weathering and lubrication degradation.

Specification for implementing DuraSquirt DTIs in accordance with AISC/RCSC 2.12: Alternative-Design Bolting Components, Assemblies and Methods

DuraSquirt DTIs, are ASTM F959⁷ DTIs that render feeler gages unnecessary. DuraSquirt DTIs are *verification lot* DTIs, per AISC/RCSC section 7, where the *calibrated gap* has been determined per ASTM F606 testing. DuraSquirt DTIs are designed to expel indication media when torquing efforts reduce the *job inspection gap* below the *calibrated gap*. DuraSquirt DTIs are to be installed & inspected in accordance with the 2020 **Specification for Structural Joints Using High-Strength Bolts** section 2.12.

Since the does not include metric information, additional tables are provided when working with metric fasteners.

Pre-Installation Verification Testing

Three DuraSquirt DTI *bolting assemblies* shall be verified to achieve at least the minimum design tension by the bolting crew and inspector; employing the following procedure: Pre-Installation Verification testing in accordance with AISC/RCSC section 7:

⁶ AISC/RCSC 16.2-47 "In any of the foregoing installation methods, it can be expected that a portion of the bolt assembly (the threaded portion of the bolt within the grip length and/or the engaged threads of the nut and bolt) will reach the inelastic region of behavior. This permanent distortion has no undesirable effect on the subsequent performance of the bolt."

⁷ ASTM F959 3.1.1 *compressible-washer-type direct tension indicator, n*—washer-type element inserted under the bolt head or hardened washer, having the capability of indicating the achievement of a required minimum bolt tension by the degree of direct tension indicator plastic deformation. Hereafter referred to as *direct tension indicator*.

1. Insert and snug each *bolting assembly* into a *bolt tension measurement device*, with the DuraSquirt DTI positioned per AISC/RCSC Figure C-8.1 (b) and AISC/RCSC section 6.2.5.
2. Tighten each *bolting assembly* until the DuraSquirt DTI displays indication media beyond the outer diameter in all bump locations, known as complete indication.
3. Record the achieved tensions compared to AISC/RCSC Table 7.1.
4. A tension that is greater than the value in table 7.1 shall not be cause for rejection.

...it can be expected that a portion of the bolt assembly (the threaded portion of the bolt within the grip length and or the engaged threads of the nut and bolt) will reach the inelastic region of behavior. This permanent distortion has no undesirable effect on the subsequent performance of the bolt.⁸ The ultimate shear strength of a bolt is not affected by the pretension in a bolt. Tests on bolted joints indicated that the initial clamping force had no significant effect on the ultimate shear strength.⁹

Installation

Assemblies shall be installed (per connection) by the following procedure and referenced AISC/RCSC sections:

Insert and snug *bolting assemblies* in accordance with the requirements of Section 8.1, with the DuraSquirt DTI washer positioned per AISC/RCSC Figure C-8.1 (b) and AISC/RCSC Section 6.2.5. If complete indications of the DuraSquirt DTIs are achieved while snugging, the identified assemblies shall be replaced.

Bolting assemblies are then to be fully tensioned from the most rigid part of the joint onward until complete indications are achieved.

Inspection

Routinely inspect DuraSquirt DTIs *bolting assemblies* by the following procedure:

1. Observe the verification testing and adherence to the snug step of installation.
2. After tensioning, confirm complete indication of inspected assemblies. No further evidence or investigation is required in these cases.
3. When prevailing installation methods result in complete bump compression, without complete indication, inspection ratios of complete indication, less than 100%, may be accepted by the site.

Arbitration

Assembly installation and inspection may be arbitrated by the bolting crew and inspector by:

1. Tightening 3 assemblies in *bolt tension measurement device* until the device indicates the minimum value specified in AISC/RCSC Table 5.2.

⁸ RCSC (2020), Specification for Structural Joints Using High Strength Bolts, Research Council on Structural Connections, American Institute of Steel Construction, Chicago, IL. 16.2- 47.

⁹ Kulak, G.L., Fisher, J.W., and Struik, J.H.A. (1987), Guide to Design Criteria for Bolted and Riveted Joints, (2nd ed.), John Wiley & Sons, New York, NY. pg. 47.

- Recording the number of locations where indication media appears beyond the outer diameter of the DuraSquirt DTI. The count of indications then forms the minimum for the arbitrated installation and inspection criteria.ⁱ

The inspector **MUST**:

- Verify the joint has been snug-tightened.
- Verify the DuraSquirt® DTI bumps have not been compressed to complete indication during the snugging operation.
- Verify the DuraSquirt® DTI exhibits complete Indication.
- Accept any fastener with a pretension greater than the minimum required.ⁱⁱ

The inspector **MUST NOT**:

- Inspect DTI assemblies with a torque wrench.
- Compare the amount of turn between the nut and bolt with Turn-Of-Nut table 8.2.
- Reject DTIs that have been completely flattened during pretensioning.

Inch Bolt Tables

Pretension for Pre-Installation Verification Testing per AISC/RCSC Table 7.1, inch series.		
Bolt diameter in.	A325/120 bolts	A490/150/144 bolts
1/2	13	16
5/8	20	25
3/4	29	37
7/8	41	51
1	54	67
1 1/8	67	84
1 1/4	85	107
1 3/8	102	127
1 1/2	124	155

Equal to 105% of minimum bolt pretension, rounded to the nearest kip.

Minimum Bolt Pretension Per AISC/RCSC Table 5.2, inch series.		
Bolt diameter in.	A325/120 bolts	A490/150/144 bolts
1/2	12	15
5/8	19	24
3/4	28	35
7/8	39	49
1	51	64
1 1/8	64	80
1 1/4	81	102
1 3/8	97	121
1 1/2	118	148

Equal to 0.70 times the minimum tensile strength of ASTM F3125 bolts rounded to the nearest kip.

Metric Bolt Tables

Minimum Bolt Pretension for Pre-Installation Verification Testing, metric series.		
Bolt diameter mm	A325M/8.8 bolts	A490M/10.9 bolts
M12	51	76
M16	96	120
M20	149	188
M22	185	232
M24	215	270
M27	280	351
M30	342	428
M36	499	625

Equal to 105% of minimum bolt pretension, rounded to the nearest kN.

Minimum Bolt Pretension, metric series per AISC 360 table J3.1M, metric series.		
Bolt diameter mm	A325M/8.8 bolts	A490M/10.9 bolts
M12	49	72
M16	91	114
M20	142	179
M22	176	221
M24	205	257
M27	267	334
M30	326	408
M36	475	595

Equal to 0.70 times the minimum tensile strength of F3125M bolts, rounded to the nearest kN.

A tension that is greater than 105% of the value in the tables 5.2 or J3.1M, is not cause for rejection when using ASTM, and similar hardware. The ultimate shear strength of a bolt is not affected by the pretension in a bolt (Kulak et al., 1987, pp 47).

ⁱ Lack of indication may be caused by oversized holes, poor quality hardware, uncured or excessively thick steel coatings, etc. Contact Applied Bolting Technology at (802) 460-3100 or info@appliedbolting.com for assistance.

ⁱⁱ AISC/RCSC 9.2.4 "A pretension that is greater than that specified in Table 5.2 or feeler gage refusal in all locations shall not be cause for rejection."