Approved Methods of Tensioning High-Strength Bolted Connections

The Caltrans approved methods for tensioning of common high-strength (HS) bolt systems consist of two standard methods and two alternative methods. The two standard methods are known as the *turn-of-nut* method and the *calibrated wrench* method. The two alternative methods are known as the *twist off-type tension control bolts* and the *direct tension indicator* method. The basic steps for field testing, installation, and performing final inspection of the standard methods are very similar to those of the alternative methods.

All fastener systems must pass the required pre-installation test, calibration testing, and rotational capacity (RoCap) testing, before being installed in a structure. These tests are performed at the job site by the Contractor and are witnessed by the Engineer. The faying (contact) surfaces of all joint plies must be clean and flat. In many instances, a thin coating of qualified paint or hot-dip galvanized zinc coating may be allowed on faying surfaces. The components to be assembled must fit properly such that the faying surfaces between plies in a joint must have full contact when bolts are installed at a snug tight condition only. All fasteners in a joint must first be tightened to a snug tight condition before the final tightening process can begin. In both the snugging and final tightening process, a systematic pattern must be used to tighten each joint, using a crisscross sequence to ensure that bolts are evenly tensioned. The final tensioning of A325 fasteners in slip-critical bolted connection must have the minimum tension values shown in Table 5.2, *Minimum Bolt Pretension, Pretensioned and Slip-Critical Joints*, of the *Research Council on Structural Connections* (RCSC) Specification (see reference 4 in Attachment 2, *Inspection Procedure for Checking Tension in High-Strength Bolts*).

Once all fasteners in a joint have been fully tensioned, the joint is inspected. This requires 1) a visual check to ensure that plies are in full contact, and thread stick-out is in the proper range and is uniform for all fasteners, and 2) the “job inspecting torque” is applied to 10 percent of all fasteners in each joint; note that Section 10 of the RCSC Specification calls it the “arbitration torque”. Joints should always be inspected immediately after being completed. These same basic procedures are common for all of the approved fastener systems.

1 - Standard Methods for Installing HS Bolts

The following discussion gives specific information about the two standard methods, turn-of-nut and calibrated wrench, allowed by Caltrans for installing and checking HS bolts:

1-1 Turn-of-Nut Method

a. **First snug-tighten all bolts:**

When the turn-of-nut method is used, each bolt in a joint must be first brought to a snug-tight condition. At this point, all joint plies should be in firm contact and match marking is done.

b. **Match-mark all bolts:**

When the turn-of-nut tightening method is used to install HS bolts, match-marking is an important mandatory part of the tightening operation. After snugging, the turned element of all fasteners and the outer plate in the joint are match-marked with a felt marker or marking pencil as shown in figure 1 so that the installer and inspector can see that the nuts have been turned a sufficient amount to adequately tension the fastener. Figure 1 shows the four initial marks made, and the final position of the marks after tightening has been completed.

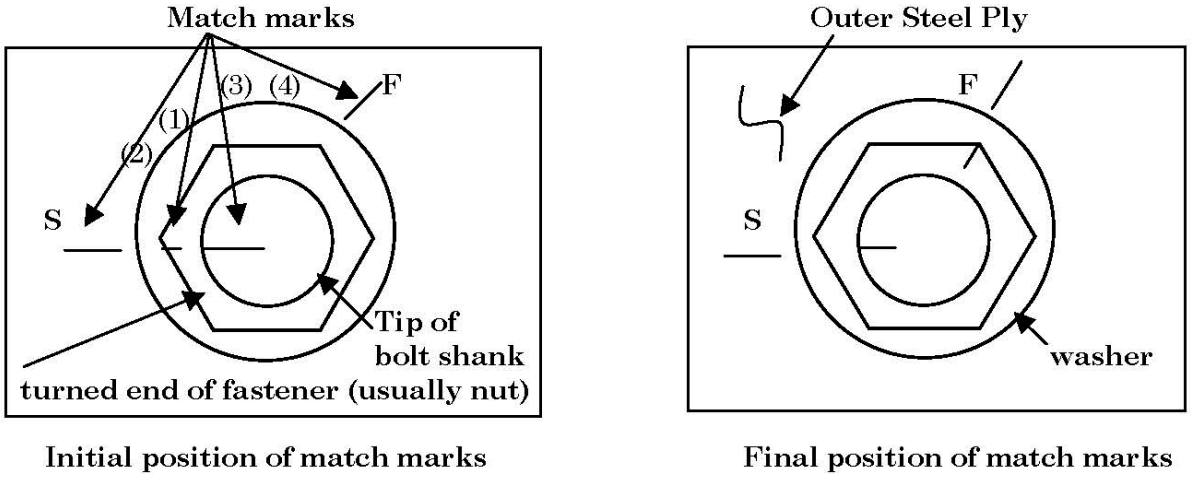

Figure 1. Match-Marking

Note: The two lines on the outer steel ply indicate the start (S) and finish (F) point of the turned element. In a properly match-marked joint, four marks are made at the turned end of each fastener. These are:

i. **A mark on one corner of the nut**. In addition to this mark on one corner of the nut, the outside of the socket used to tighten the nut is usually also marked with a line on its exterior which will be visible during the tightening operation. This mark on the outside of the socket should overlay the hidden mark on the nut corner.

ii. **A start line, S, put on the outer steel ply** after all bolts have been snug tightened, and which aligns with the corner mark on the nut.

iii. **A radial line through the end of the bolt tail**, in line with the start line on the outer steel ply and the nut mark. This radial mark through the bolt tail is important, as it gives a clear indication whether the bolt head turned during tightening (i.e., was properly backed up and kept from rotating during the tightening operation).

iv. **A finish line, F, on the outer steel ply** at the appropriate amount of either 1/3, 1/2 or 2/3 of a turn clockwise past the S mark. The location of this (F) mark will vary and depends on the length of the bolt being tightened.

c. **Final Tensioning of Fasteners:**

The final tightening of the bolt is done as follows:

The socket is positioned so that its exterior mark is aligned with the start mark S on the outer steel ply and the mark put on the corner of the nut. The nut is then turned a prescribed amount, depending on the bolt length as shown in Table 8.1, *Nut Rotation from Snug-Tight Condition for Turn-of-Nut Method Pretensioning*, of the RCSC Specification, until the initial mark made on one corner of the nut lines up with the final mark, F, on the outer ply of the joint. While the nut is being turned, the bolt head (or component of the bolt that will remain stationary) is held with a back-up wrench. The radial mark through the end of the bolt tail should still be aligned with the start mark, S, on the outer ply. If not, this is a clear indication that the bolt head turned during tightening, and the bolt tension may be below the minimum required. This completes the tightening.

The final position of the nut has an allowable tolerance of several degrees with respect to the final mark, F, depending on the size and length of the HS bolt. The acceptable tolerances are shown in Table 8.1 of the RCSC Specification.

d. **Final Check:**

Each joint should be inspected as soon as all bolts in the joint have been tensioned. The “job inspecting torque” check should verify that the bolts in a connection, tightened by the turn-of-nut method, are not below the required minimum tension. Loose bolts may indicate that the bolt heads were allowed to rotate during tightening, or the plies of the joint were not in full contact after snug tightening was completed. Therefore, when installing several bolts in a single joint, it is best to snug bolts in at least two tightening stages, and to use a systematic, alternating tightening pattern, starting near the middle of the joint. This process will ensure even tension in all bolts when complete.

If the members being joined cannot be brought into firm contact by snugging all bolts, verify that the bolt is the correct length, and that the plies are not misaligned, warped, and do not have burrs and/or irregularities. If plies are misaligned and bolt holes do not line up, the cause of the misfit must be determined and corrected. Further tightening of bolts will generally not correct

gaps between plies and around the bolts after they have been snugged and may result in severely elongated bolts and/or distorted plates.

1-2 Calibrated Wrench Method

This tensioning method may be used only when the Contractor's equipment and installation procedures are calibrated daily for each diameter, length, grade, and production lot of bolts.

Torque and/or impact wrenches must also be recalibrated when significant difference is noted in the surface condition of the bolt or nut threads, or washers.

Calibrated wrenches used for installation must be set to provide a bolt tension not less than five percent in excess of the minimum tension.

All bolts must be installed with hardened washers under the turned element and must be brought to a snug condition prior to applying the final pretension. Snug tightening must begin from the middle (or most rigid part) of the connection and progress to the free edges. The tightening operation should be performed such that a systematic (crisscross or alternating) pattern is followed, and the same consistent pattern is used for both snugging and final tightening. In some cases, proper tensioning of the bolts may require multiple cycles of systematic partial tightening prior to achieving adequate and even pretension in all the bolts.

When using a torque wrench, the Contractor is required, and the Engineer should verify, that the torque used on bolts in the structure is consistent with the values determined during the calibration/pre-installation tests done at the beginning of the work shift. In addition, the length of bolt should be checked for compliance to thread stick-out limits.

Using a suitable wrench with proper torque capacity for the desired bolt diameter and grade is very important. When the correct size of pneumatic impact wrench is used, it should take the operator about 10 seconds (after snugging) to achieve the required minimum bolt tension. Please be aware of the detrimental effect if the time required to tighten a bolt to the minimum required tension is very short (4 seconds or less). It is undesirable to use a wrench which is too powerful for tensioning a particular size or grade of bolt because it can easily result in a fastener whose threaded shank is severely necked down and has been plastically stretched near ultimate capacity; this removes most of the bolt's residual capacity to stretch and deform plastically without breaking. Using too small, or a worn or broken impact wrench, on the other hand, will not produce the minimum bolt tension required at the recommended 10-second tightening period. Excessive hammering on nuts, resulting from attempting to tighten a bolt with an inadequate impact tool (or too little air pressure or volume), can distort nuts and damage any protective coating, yet still not provide sufficient bolt tension.

The following steps are typical ones used to properly test structural bolts when using a calibrated wrench:

a. The Contractor should do calibration/pre-installation testing on a minimum of three bolts, nuts and washers for each diameter, length, grade, and production lot to be used for that day. Testing must be performed in an appropriate model bolt tension calibrator, according to requirements in the RCSC Specification, Section 8.2.2., *Calibrated Wrench Method Pretensioning*. The Contractor must order and use the proper length bolt for a particular joint thickness. Bolts from the same lot that are used in the structure must also be used for verification testing. Additional spacers with the proper center hole diameter must be used to adjust the grip in the bolt tension calibrator, so that two to three threads of stick-out is flush with the face of the nut when the nut is finger-tight. Final stick-out permitted is between flush and 1/4 inch past the face of the nut. Appropriate steps, as outlined in the *Structural Bolting Handbook,* should be followed for testing short bolts.

   If short bolts are required in the structure and cannot fit into a bolt tension-measuring device, direct tension indicators (DTIs) must be used to verify adequate tension in the bolts. To determine the appropriate calibrated gap for a particular lot of DTIs, the Contractor must furnish longer bolts of the same diameter and grade to be used in the structure and use them in a bolt tension-measuring device along with DTIs. Once an appropriate calibrated DTI gap is established, the same lot of DTIs must be used to determine torque or impact wrench setting for the short bolts installed in steel plate shimmed to the appropriate thickness to simulate the actual joint. The short HS bolts must then be tensioned in a simulated joint to produce the same calibrated gap verified with DTIs from the same lot (see Section 2-2, *Direct Tension Indicators*), and a torque value read at that gap. The average of the three torque values must be the installation torque for that lot of short bolts and for that day.

b. First, the bolt must be brought to a snug condition. For the initial snugging, a spud wrench, impact wrench, or bar and socket may be used. The same tools used when installing HS bolts in the actual structure must be used during installation testing.

c. Final tightening should follow one of the two following procedures:

   i. Procedure to be used with impact wrench:

      1. Tighten the bolt by turning the nut until the wrench “cuts out”. Verify that the tension achieved, as read on the bolt tension-measuring device, is at least 1.05 times the required bolt tension.

2. Check the degree of turns on the nut to make sure it does not exceed the corresponding tolerance for the “turn-of-nut” rotation. If the amount the nut has been turned has exceeded the maximum rotation allowed, discard the assembly. A new assembly should be tested with the impact wrench torque value adjusted to correspond to the required bolt tension.
3. The HS bolt assembly must be tested to ensure that the minimum tension is attainable by the installation crew and the tools being used, without exceeding the prescribed rotation.

ii. Procedure to be used for torque wrench:

1. Tighten the bolt by turning the nut until the tension on the bolt is at least 1.05 times the required bolt tension.
2. Reading the dial on the torque wrench, measure the moving torque while turning the nut an additional 5 degrees in the tightening (clockwise) direction. This is the torque value that should be recorded.
3. The average of the three values or the highest acceptable value should be used as the installation torque for this day.

2 - Alternative Methods for Installing HS Bolts

The following discussion gives specific information about the two alternative methods, *twist off-type tension control (TC) fastener assembly* and *direct tension indicator*, allowed by Caltrans for installing and checking HS bolts:

2-1 Twist Off-Type Tension Control Fastener Assemblies

All twist-off type TC fastener assemblies consist of a unique bolt having a splined end, a nut, and a hardened washer. The head on the bolt is commonly domed or rounded but may be manufactured with a hex shape. TC fastener assemblies are produced and shipped by the manufacturers as a precisely engineered and fully tested system. They must comply with requirements in the ASTM F1852 specification. Lubricant types and amounts and machining tolerances may be different from one lot to another, and consequently, the component parts may not be interchanged or altered in any way. Each assembly lot must be used only in the as-delivered, factory-lubricated condition. TC fasteners are installed using an electric wrench having a specially designed planetary chuck. This planetary chuck has dual sockets that engage both the nut and splined tail of the bolt at the same time and turn one relative to the other chuck until the splined tail on the end of the bolt breaks off.

When inspecting a TC fastener installation to ensure that a quality job is being done, a number of things must be checked: the initial job-site testing of the fasteners must be carefully observed and checked, the installation procedure required by the manufacturer

must be reviewed, proper storage of the fastener assemblies out of the elements must be constantly checked, the tensioning operation must be carefully monitored while in progress, and the final tension of at least 10 percent of the fastener assemblies must be checked using a “job inspecting torque”. Just verifying at the end of the job that the splined end of each bolt has sheared off is not adequate. This only signifies that at some time during installation, the assembly was subjected to a torque adequate to cause the shearing of the splined tail, not that the final tension in each fastener is adequate.

As with other fastener assemblies, representative samples of TC fastener must be taken from each lot and pre-installation tests run at the beginning of the job. Successful completion of these pre-installation tests will ensure that:

a. The installer knows the proper procedure to install the fasteners and follows the manufacturer’s instructions.

b. The actual equipment being used to install the fasteners works properly, and

c. The fasteners provide the minimum tension as specified in Table 7.2, Minimum Initial Tension for Pre-Installation Verification of Installation in Accordance with Section 8.2.5 (Combined Method), of the RCSC Specification.

When observing pre-installation tests, the following should be verified:

a. A representative sample of not less than three bolts of each diameter, length, grade, and lot must be installed and tensioned by the Contractor at the job site in a bolt tension calibrator. The Contractor’s installer must demonstrate that each assembly develops a tension not less than five percent greater than the tension required by Table 7.1, *Minimum Bolt Pretension for Pre-installation Verification*, of the RCSC Specification.

b. When testing a TC bolt having a domed head in a bolt tension meter, a flat bushing specifically made for testing the domed TC bolts must be used under the domed head. These special bushings are not normally furnished as standard parts with bolt tension calibrators. A different size of bushing is required for each bolt diameter being tested and can be purchased through the manufacturer (such as Skidmore-Wilhelm) of the bolt tension calibrator.

c. The TC fastener assembly must be tested using one flat hardened washer (furnished by the manufacturer of the TC fastener assembly), under the nut (turned element).

   Each TC fastener assembly must first be snugged using the same effort and snugging equipment that will be used on the final structure. During the snugging operation, if the spline breaks off, the bolt must be removed and the bolt tension at snug tight checked. If the tension at snug tight exceeds 50 percent of the

minimum required tension load, the effort used to snug tighten the fastener should be reduced and new pre-installation tests run.

d. If when running the pre-installation tests, the TC bolts are too short to fit into a bolt tension-measuring device, DTIs must be used to verify the proper tension. First a calibrated DTI gap needs to be determined using three bolts long enough to fit into a Skidmore, tightening each until a load of 1.05 times the minimum preload value has been attained, and then, using tapered feeler gages, determining an average gap value for the compressed DTIs. Once an average calibrated gap value has been determined for three DTIs, the same lot of DTIs must be used in conjunction with short TC bolts in a simulated joint having the same grip as in the actual structure. When short TC bolts have been installed (tail has been snapped), the DTI gap must be equal or less than the calibrated value determined by using long bolts in a Skidmore bolt tension calibrator. This confirms that the fastener tension is equal to or greater than the minimum required.

   RoCap testing is also currently required by Caltrans for this system and for this testing; conventional installation tools should be used (to prevent the splined end from being sheared off).

When TC fastener assemblies are installed in a structure, the following procedure must be followed:

a. TC fastener systems must always be properly stored out of the weather and maintained in the original condition as supplied by the manufacturer, or else the fastener tension will change, and problems will arise.

b. When assembling a TC-bolted connection as with other fastening systems, a TC fastener assembly must be installed in each of the holes of the connection.

c. The bolts must be systematically snugged (preferably using a conventional tightening tool commonly used for a snugging operation – not an electric TC fastener installation tool) to bring all plies of the joint into firm contact and without yielding or fracturing the splined tails of the fasteners. If the TC fasteners are incorrectly installed and fully tensioned in a single continuous operation, they will give a misleading indication to the inspector that all the fasteners are properly tightened. However, some of the initially tensioned fasteners may not be. If the plies of the joint are not in firm contact after snugging bolts, then the cause needs to be determined and corrected.

d. Finally, during the final tightening (tail snapping operation), each assembly is tightened following a systematic, crisscross pattern starting from the center of each joint.

   After installation has been completed and there is any question about whether there is adequate tension in the TC fasteners, the following must be done:

i. Uniform and proper thread stick-out must be checked. After the spline has broken off, a partially threaded section (approximately 1/8 inch) typically remains; these partial threads at the broken end of the TC bolt are not to be considered as part of the thread stick-out. Therefore, after installation, the actual length of the projecting bolt stub should extend at least 1/8 inch beyond the outer face of the nut to a maximum of 3/8 inch.

ii. The Contractor must determine a job inspecting torque value.

iii. A minimum of 10 percent of the TC fasteners must be checked using a torque wrench for adequate minimum preload.

2-2 Direct Tension Indicators (DTIs)

A direct tension indicator (DTI) is a special device used in conjunction with each HS bolt to ensure proper tension in the bolt has been attained. DTIs have a number of evenly spaced bumps protruding on one side that are compressed against a hardened surface in a controlled manner. As the bolt is tightened, the bumps are crushed. When they reach a prescribed crushed gap (0.005 inch for bridge and sign structures), the HS bolt has been sufficiently tensioned.

Basic steps for field testing of DTIs in a bolt tension calibrator (e.g., Skidmore) are as follows:

a. Test three DTIs of each diameter, grade and production lot, plus three sample bolts, nuts, and washers. It is not a requirement that this test be conducted on each separate lot of bolts and nuts. Each DTI, along with sample fasteners, is called a “test assembly”.

b. Testing DTIs in a bolt tension calibrator requires the use a special flat bushing and flat hardened washer. The bushing available from the bolt tension calibrator manufacturer (Skidmore-Wilhelm) must be used under the nut (or turned element). DTIs are normally placed under the bolt head, with the bumps bearing directly against the underside of the bolt head (non-turned element).

c. Add spacers and washers under the nut, as necessary, to adjust thread stick-out from zero to two threads beyond the face of nut, when the nut is finger-tight.

d. Testing or installing DTIs in a bolt tension calibrator is a two-person operation. While tightening the nut, the bolt head must be prevented from turning.

e. First, snug the bolt with a DTI, as will be done in the actual structure. In the snug condition, no gap on a DTI may be less than 0.015 inch. Use a 0.015 inch feeler gage to check for gaps less than 0.015 inch at snug.

f. Then tighten the nut until the bolt tension as read on the bolt tension calibrator is equal to 1.05 times the minimum required bolt tension. Check how many gaps

around the perimeter of the DTI the tapered feeler gage enters. It should enter 1/2 or more of the total number of gaps around the DTI.

g. Continue tightening the fastener until the number of gaps which a 0.005 inch feeler gage won't enter equals or is greater than half of the protrusions. The tension in the bolt as measured by the calibrator must be less than the minimum tensile strength of the bolt.

On the actual structure, verify that bolt heads are held stationary with a back-up wrench when nuts are being turned. In addition, check that all of the bolts in the connection are systematically snugged starting from the center of each joint, and the faying surfaces of all joint plies are in firm contact prior to performing the final tensioning of the bolts.

When installing a DTI, the protrusions must always be positioned so that they bear against a hardened surface (normally the underside of the bolt head) that must be held stationary as the bolt is being tightened. Before bolts are permitted to be installed in the structure, a representative sample of at least three assemblies of each diameter, grade, and lot must be tested in a calibrated bolt tension-measuring device. The test assembly must include a flat, hardened washer under the turned element. By doing the pre-installation test, the installation crew must demonstrate that using the same bolts, snugging and installation tools, and techniques to be used on the actual structure, and compressing the DTI protrusions to an average gap of 0.005 inch, will achieve a tension no less than 1.05 times the specified minimum bolt tension.
When HS bolts are installed in the structure in conjunction with DTIs, the fasteners must be installed in all holes of the connection and tightened starting from the center (most rigid part) of a joint in a systematic pattern, until all plies of the joint are in firm contact.

When an actual joint is being assembled, the fasteners should be checked to ensure they are uniformly snug. A snug tight condition is indicated by partial compression of the DTI bumps. After snugging bolts, any DTI which has been compressed to a gap less than 0.015 inch, must be removed and replaced with a new indicator.

Once all fasteners in a joint have been snugged, the fasteners must then be systematically tensioned, as was done during snugging. In some cases, proper tensioning of the bolts may require multiple cycles of systematic partial tightening prior to achieving even final bolt tension to bring bumps in all DTIs to a uniform gap. When inspected after installation, the minimum number of gaps refusing a 0.005 inch tapered feeler gage must be as follows: If all gaps have been reduced to zero (0.000 inch) after installation has been completed, the DTI must be removed, and a new DTI and fastener installed.

DTIs should not be used when over-sized holes are present, unless approved by the Engineer and manufacturer of the DTI. If approved, special flat hardened washers must be used.

If a DTI cannot be placed under the bolt head (stationary element) due to unusual field conditions, contact the HS fastener specialist (Mechanical Testing Committee Chair) at the Materials Engineering and Testing Services (METS) for assistance. For DTIs approved for installation under the turned element, special hardened washers with a small inside diameter may be necessary and can be obtained from the DTI manufacturer.

To follow are answers to frequently asked questions regarding associated tools and equipment used in HS bolting.

3 - Common Questions and Answers Concerning Tools Used in HS Bolting

3-1 Bolt Tension Calibrators

Question 1: What type of equipment should be used to perform torque and tension checks on HS Fasteners?

Answer: Skidmore-Wilhelm (models MS, M, or ML) or Norbar bolt tension calibrators are assigned to some ACMs to do quality assurance testing. See Figure 2 for a typical bolt tension calibrator.

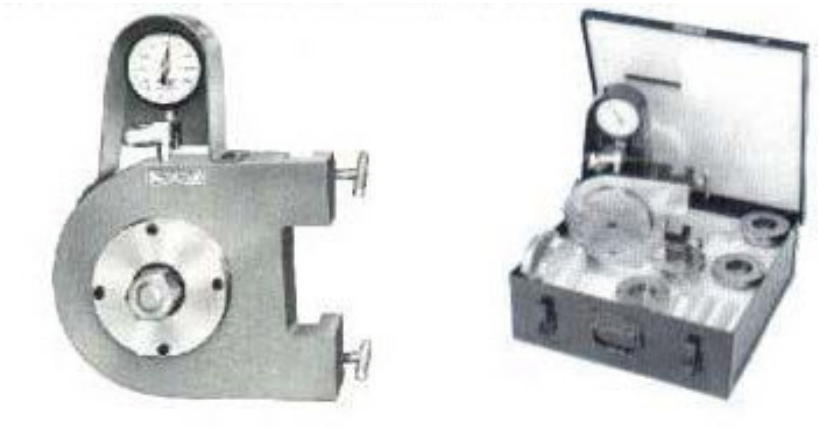

Figure 2. Typical Bolt Tension Calibrator and Steel Case

The appropriate model Skidmore should be used, depending on the shortest length bolts to be tested (see Table 1).

Table 1. Minimum Bolt Length (Inches) which Can be Tested in Models M, ML, MS, H and K, of Skidmore- Wilhelm Bolt Tension Calibrators

Nominal Bolt Size	M	ML	MS	H	K (Bench Model)
1/2 – 13	2.25	2.250	2.000		
5/8 – 11	2.50	2.500	2.000	2.750	
3/4 – 10	2.75	2.750	2.000	3.000	
7/8 – 9	3.00	2.750	2.250	3.000	
1 – 8		3.000	2.500	3.250	
1 1/8 – 7		4.750	3.250	5.250	
1 ¼ – 7		5.000	3.375	5.500	5.500
1 3/8 – 6				5.500	5.500
1 ½ – 6				5.750	5.750
Max. Tension Capacity	80K max.	110K max.	90K max.	170K max.	225K max.
Weight	65 lbs.+	65 lbs.+	65 lbs.+	65 lbs.+	180 lbs.

There are some older Norbar bolt tension calibrators available; check to make sure equipment has been calibrated within the past year, and is within the required accuracy limits.

Question 2: Are all of the necessary parts available with the basic bolt tension calibrators?

Answer: Probably not. To test domed head TC bolts and all DTIs, a special set of flat bushings is required which is not normally furnished with the standard calibrator equipment. Flat bushings are readily available from the Skidmore-Wilhelm Mfg. Co. and are shown in Table 2.

Table 2. Special Flat Bushings Required to Test TC Bolts and DTIs with Skidmore- Wilhelm Bolt Tension Calibrators

Nominal Bolt Size, inch	M and ML Bushing #	MS Bushing #	H Bushing #
1/2	MT-608	MS-608	HT-708
5/8	MT-610	MS-610	HT-710
3/4	MT-612	MS-612	HT-712
7/8	MT-614	MS-614	HT-714
1	MT-616	MS-616	HT-716
1 1/8	MT-618	MS-618	HT-718
1 ¼	MT-620	MS-620	HT-720
1 3/8			HT-722
1 ½			HT-724

Note: The model MS Skidmore bolt calibrator was developed to test bolts which are shorter than can be tested in the Models M or ML calibrators. In Skidmore-Wilhelm's development/design process, the front plates of the Model MS were made thinner. Skidmore-Wilhelm has pointed out that when testing TC bolts, the thinner MS plates will dish slightly when tensioning the fastener. This dishing may reduce the contact area between the nut face and washer and may cause a slight increase in the torque required to rotate the nut. This may cause a reduction in tensile load read on the bolt calibrator dial at which the spline shears off. Skidmore recommends ordering and using the thicker plates for the MS model if the TC fasteners are not meeting minimum tension requirements by 5 to 10 percent. The Skidmore-Wilhelm Mfg. Co. should be contacted immediately (216-481-4774) if use of their Model MS calibrator results in too low-tension values when the spline shears off.

In addition to bushings, spacers of the proper length and inside diameter may also be required when testing long bolts to adjust thread stick-out to between 0 inch (flush) and 1/4 inch.

Question 3: Should Caltrans provide the bolt tension calibrator for use on construction projects?

Answer: No. The Contractor is to perform all pre-installation testing, RoCap testing, and inspection of completed joints at the job site, and must provide all necessary tools and appropriate calibrated equipment, including torque wrenches (dial or digital readout only), bolt tension calibrators, impact wrenches, sockets, and torque multipliers to do so. The Engineer is to witness preliminary calibration, testing, select fasteners to be inspected in a completed joint, and witness joint inspection. Caltrans has Skidmore-Wilhelm bolt tension calibrators available for use by Caltrans employees doing quality assurance inspection.

Question 4: How often should the bolt tension calibrator be recalibrated and adjusted and who is qualified to do this?

Answer: Recalibration and adjustments should be performed at a minimum annually, by a certified testing facility using equipment that is traceable to the National Institute of Standards and Technology at the Contractor's expense. Required accuracy, after calibration is within ± 2 percent of the actual load. The following is a list of acceptable manufacturers and laboratory test facilities that are qualified to recalibrate and repair bolt tension calibrators:

1. Technical Services Group
   2900 Main St.
   Alameda, CA 94501
   Phone: (510) 522-8326
2. Advanced Witness Series, Inc. *(Local representative and calibration/repair center for Norbar equipment)*
   910 Bern Ct. #100
   San Jose, CA 95112-1237
   Phone: (408) 453-5070
   awitness.com
3. Skidmore-Wilhelm ManufactCo. *(Manufacturer)*
   30340 Solon Industrial Parkway, Unit B
   Solon, OH 44139
   Phone: (216) 481-4774
   www.skidmore-wilhelm.com
4. Mountz, Inc.
   1080 North 11th Street
   San Jose, CA 95112
   Phone: (408) 850-9978
   www.mountztorque.com
5. Norbar Torque Tools Ltd. (Manufacturer)
   Wildmere Road, Banbury,
   Oxfordshire, OX16 3JU, United Kingdom
   Phone: 44(0) 1295 270333
   enquiry@norbar.com

Question 5: Where can a field Engineer get more information about bolt tension calibrators?

Answer: Information and literature can be attained directly from the manufacturers or their representatives (see the listing in Question 4 above).

3-2 Torque Wrenches

Question 1: May the Contractor perform testing or installation of HS bolts with a “click-type” torque wrench?

Answer: No. Either a dial or digital gauge torque wrench (illustrated in Figure 3) is required to accurately determine installation torque, perform RoCap tests, and determine job inspecting torque for inspection of a completed joint. When performing a RoCap test or determining proper job inspecting torque at the jobsite, the Contractor cannot read the particular torque value at a given bolt tension when a click-type torque wrench is used. Also, generally the accuracy of a click-type torque wrench is not adequate to meet Caltrans accuracy requirements.

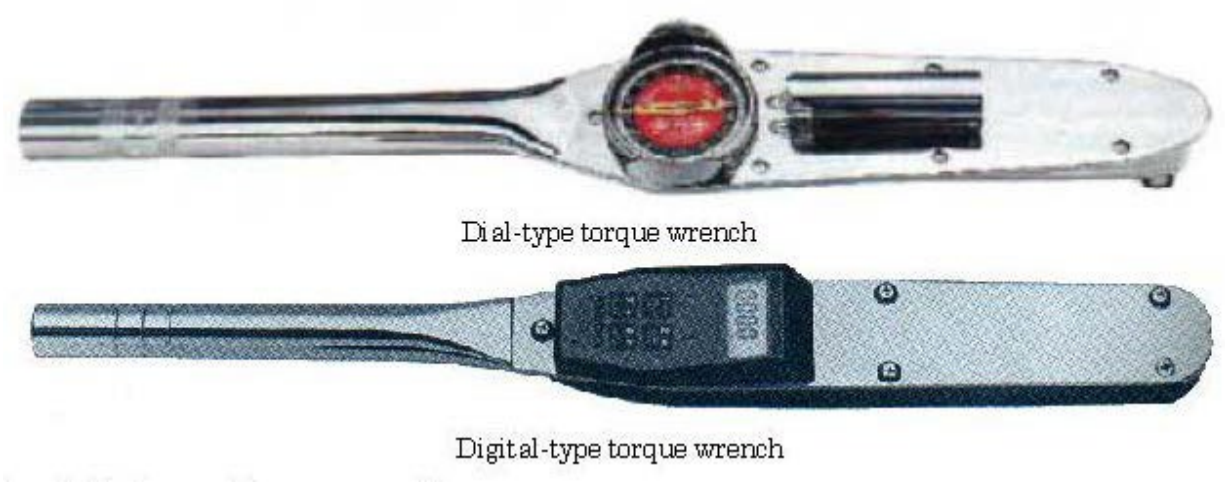

Figure 3. Acceptable Types of Torque Wrenches

Question 2: What is the “best practice” when using torque wrenches?

Answer: A torque wrench is properly used when the following concepts are followed:

a. Proper installation procedures must be verified, and torque values reestablished at least once each working day for each bolt diameter, length, and lot. A hardened washer must be used under the nut (turned end).

b. Always use a proper size torque wrench with adequate torque capacity or use a smaller wrench in conjunction with a torque multiplier, when necessary. Never use a torque wrench that is too small for the job. If the torque limit of a wrench is exceeded, the wrench is generally ruined and cannot be repaired.

c. Operating a large torque wrench is generally a two-person operation – one person to pull on the handle and one to read the dial. The person pulling should use a smooth motion. An extender handle of adequate length should be utilized to reduce effort required to turn nuts and to ensure a smooth turning motion (a “jerky” motion generally results when the lever arm is too short). Difficulty attaining adequate tensile loads on large HS bolts (i.e., 1-1/8 inch to 1-1/2 inch)

generally indicates the need to use a torque multiplier in conjunction with a torque wrench.

d. It is generally not good practice to use a torque wrench to undo a bolt. A torque wrench is a delicate instrument, and the mechanism of some is not designed to be loaded in the reverse (counterclockwise) direction. It is much better to use an impact wrench or breaker bar for loosening or unloading tensioned fasteners.

e. When performing RoCap tests, never use a torque wrench to perform the final portion of the test that requires that the bolt be rotated a specified large number of turns. This portion of the test may require a torque level that will severely overload a torque wrench normally used for routine fastener tensioning and cause irreparable damage. A breaker bar or pneumatic wrench in combination with a torque multiplier should be used for this last phase of the RoCap test.

Question 3: Where can I obtain information about or purchase a satisfactory torque wrench?

Answer: From one of the companies from the following list:

1. Proto
   1015 North Market Blvd #2
   Sacramento, CA 95834
   Phone: 800-800-TOOL (8665)
   inquiry@sbdinc.com
   www.protoindustrial.com
2. Snap-on Incorporated
   2801 80th Street
   Kenosha, Wisconsin 53143
   Phone: 877-762-7664
   www.snapon.com
3. Advanced Witness Series, Inc.
   910 Bern Ct. #100
   San Jose, CA 95112-1237
   Phone: (408) 453-5070
   awitness.com
4. Mitutoyo
   2915 E. Washington Blvd
   Los Angeles CA 90023
   Phone: (323) 908-6064
   www.mitutoyo.com
5. Mountz, Inc.
   1080 North 11th Street
   San Jose, CA 95112
   Phone: (408) 850-9978
   www.mountztorque.com

Question 4: How often should a torque wrench be recalibrated and adjusted?

Answer: At least once a year. It must be recalibrated and adjusted more often if dropped/mishandled.

Question 5: Who is qualified to perform the recalibration and adjustments, and what information/certificates are required?

Answer: A certified testing facility must have calibration equipment traceable to National Institute of Standardized Testing (NIST) standards and must perform calibration checks and any adjustments on equipment. If equipment cannot be adjusted so that its accuracy is within specifications, it is not permitted to be used.

Question 6: What accuracy is required for a torque wrench to be considered acceptable?

Answer: Accuracy of torque wrenches must be within 2 percent of the actual torque value, with a minimum of 4 verification readings evenly spaced over a range of 20 to 100 percent of full scale. If there are any questions about the accuracy of the Contractor's torque wrench, a copy of the latest calibration check after any adjustments were made should be required.

Question 7: What do the terms *break torque* and *moving torque* mean?

Answer: Break torque: The torque value required to initially start a nut in motion from a stationary position.
Moving torque: Torque measured while the nut is in motion.

Question 8: Does Caltrans provide torque wrenches?

Answer: Yes, but only for Caltrans quality assurance testing or checking contractor's values, not for work that is required to be done by the Contractor.

Question 9: When using the calibrated wrench installation method, why is it necessary to determine an installation torque value for each lot of fasteners every day?

Answer: Thread conditions (roughness, coating type and thickness, and pitch diameter), the type and amount of lubricant, and storage and weather conditions may be different for each lot of bolts. These variables can have a huge effect on the relationship between torque and tension, especially when using the calibrated wrench method to install HS fasteners. Therefore, the RCSC Specification requires that certain installation procedures must be performed, and appropriate installation torque values must be determined on a daily basis, using fastener samples from each lot of bolts to be installed in the structure.

3-3 Calibrated Wrenches

Question 1: How often must a calibrated wrench be adjusted and checked to produce proper bolt tension?

Answer: At a minimum, the tension value produced by a calibrated wrench must be checked daily at each job shift for each bolt diameter and length to ensure the cutoff setting is correct. If a different lot of fasteners is used, or operators, length of air lines, tool being operated, or thread conditions on the fasteners change, the calibration of the wrench must be checked and perhaps recalibrated.

Question 2: Which types of calibrated wrenches are acceptable?

Answer: Besides a dial or digital torque wrench, a pneumatic, hydraulic, or electric wrench with an adjustable control unit which can be set to positively shut off at the desired torque, is acceptable, as illustrated in Figure 4. A standard impact wrench without a positive cutoff is not acceptable.

Figure 4. Acceptable Types of Calibrated Wrenches

Question 3: What are some equipment variables with a pneumatic impact wrench that effect the final product?

Answer: Compressor size and condition, the length, number, and size of air lines, air volume demand of other equipment being operated at the same time, condition and size of pneumatic impact wrench, and adjustment settings all can affect torque output of an impact wrench.

Question 4: Why does an impact wrench need to be adjusted and checked so frequently?

Answer: Experience has indicated that operator “feel”, condition and size of compressors, air lines, air tools, air pressure variations, and the number of tools run simultaneously on a single manifold are all variables that account for differences of bolt tension at the snug tight condition, as well as the final tension in the HS bolts. The influence of these numerous factors must be checked to insure consistent and accurate bolt tension.

Question 5: Why should it take approximately 10 seconds to fully tension A325 bolts?

Answer: A wide variety of brands of calibrated impact wrenches with varying torque capacities are available and appropriate for various sizes of HS bolts. When using the

correct size of impact wrench with A325 bolts, it takes about 10 seconds (after snugging) to achieve the minimum required bolt tension. Using *too large* of a calibrated wrench for a given size of bolt can result in the threaded shank of the bolt being elongated with the applied stress far exceeding the elastic limit (well into the plastic zone), resulting in very little remaining ductility. Using an impact wrench which is *too small* or *worn* will result in low fastener tension, wasted time and noise during installation, and excessive hammering on nut, causing damage to any protective coating.

3-4 Torque Multipliers

Question 1: What is this tool and when is it used?

Answer: The torque multiplier is a tool that amplifies a small input torque by gear reduction to produce a large output torque; see Figure 5 for illustration. It is commonly used in conjunction with a torque wrench, to reduce the tightening effort needed for testing, installing, and inspecting larger sizes of HS bolts. By using a multiplier, less tightening effort can be applied using smaller input wrenches and tools, and smoother and safer tightening operation results. This prevents accidents caused by dangerous but commonly used installation practices of overexertion on a short handled manual torque wrench, or hanging on the end of a long, heavy cheater handle. Also, by using a multiplier, permanent damage to smaller torque wrenches which can easily be stressed above their minimum torque rating, can be avoided. An anti-wind-up ratchet is a desirable optional feature available on many of the better multipliers.

Figure 5. Acceptable Types of Torque Multipliers

Question 2: Are different sizes available?

Answer: Yes. Multipliers are available with various multiplication factors and input and output drive sizes (e.g., 1:4, 1:5, 1:10, 1:15, 1:25, 1:75, 1:100, etc.).

Question 3: Who manufactures and sells multipliers?

Answer: Check the catalogues from the following companies: Mountz, Norbar, Proto, Snap-On, and Advanced Witness Series, Inc. Contact information for these companies can be found page 16 of this document. For further information contact the Mechanical Testing Committee Chair at METS.

Question 4: How often does a multiplier need to be recalibrated?

Answer: At least once a year. When a torque wrench is used in conjunction with a torque multiplier, the two should always be used together with a bolt tension calibrator to determine an accurate input torque/bolt tension relationship for installing and inspecting fasteners.

3-5 Electric Installation Tools with Combo Spline/Nut Socket for Installing (TC) Bolts

Question 1: Do all manufacturers of electric installation tools offer the same size of tool?

Answer: No, not all electric tools (called Shear Wrench Tools) for installing TC fasteners have the same capacity (see Figure 6 for a sample tool). Normal electric installation tools require from 11 to 15 inches of working space. Some tools are designed with a right-angled drive for working in tight quarters and have a working clearance of about 7-1/2 inches. In addition, different manufacturers of electric installation tools and sockets for TC fasteners may produce spline sockets with slightly different internal dimensions. Variations in spline dimensions of TC bolts made by different fastener manufacturers and the actual thickness of zinc coating on the spline section may vary slightly. These conditions can prevent a tool socket from fitting onto the fastener spline. A tight socket clearance or heavy zinc coating on the spline may also prevent easy ejection of the broken spline from the inner socket.

Figure 6. Electric Tool for Installing TC Bolts

Question 2: What variables can affect the satisfactory installation of a TC bolt assembly?

Answer: This system is dependent on close manufacturing tolerances (bolt and nut thread dimensions, groove dimensions at tip), steel chemistry, amount and type of nut lubricant, and consistent heat treating all of which can affect the final bolt tension. Typical steps required with all other HS bolt operations, including proper joint fit, snug tightening, tensioning all fasteners evenly in an alternating pattern, are also required when installing TC bolts.

Question 3: Do you need to check the final TC bolt tension with a calibrated torque wrench when fastener installation has been completed?

Answer: Yes. Like any normal HS bolted connection, joints can be improperly fit and TC bolts can be improperly installed. Plates in joints must be flat, should have full bearing after snugging, and all fasteners in a joint must first be evenly snug tightened, and then fully tensioned in stages and in a patterned sequence, or else like any other fastener, some of the TC bolts initially tightened will be loose after the joint has been completed. As required with other tensioning methods, a “job inspecting torque” must be established and 10 percent of bolts in each connection (or a minimum of two bolts) should be checked for adequate tension immediately after tightening of a joint has been completed.

Question 4: How does one know if TC bolts have been tightened to at least the minimum required tension?

Answer: By performing pre-installation tests on each lot, diameter, and length of fasteners, observing that proper installation procedures are followed, and inspecting 10 percent (or a minimum of two) bolts in each joint using the appropriate job inspecting torque value.

Question 5: Should all TC bolts in a joint be taken to a snug condition?

Answer: Yes. First, all TC fasteners should be snugged in a connection without snapping off the splined tails before any final tightening is done. Use of a standard impact wrench, torque wrench, or spud wrench is recommended for the snugging operation. If the snugging operation is skipped, and instead, all TC fasteners are fully tensioned without first drawing all plies together, fasteners initially tightened may be loose. If the splined end of a TC bolt has been sheared off, it merely signifies that at some time during the tightening operation, the fastener has been subjected to sufficient torque to cause shearing of the spline. It does not necessarily mean that the final tension is adequate. An uninformed inspector who looks at a completed job may not be aware that just because the tails of all TC fasteners are broken, it does not necessarily mean that all TC fasteners have adequate tension.

3-6 Tapered Feeler Gages Required for Measuring Gaps between Bumps on Direct Tension Indicators (DTIs)

Question 1: Why do feeler gages need to be tapered in order to inspect for proper gap in an installed DTI?

Answer: Feeler gages used for inspecting DTIs (illustrated in Figure 7), must be tapered and have narrow tips so that they can fit into each gap between closely spaced DTI bumps.

Figure 7. Typical Tapered Feeler Gages for Inspecting an Installed DTI

Question 2: Which thicknesses of tapered feeler gages are used for inspecting DTIs installed on bridge or sign structures: 0.015 inch or 0.005 inch?

Answer: Two thicknesses of these special tapered feeler gages, 0.005 inch and 0.015 inch, are commonly used for inspection. The Contractor should have them available and use them during pre-installation testing, installation, testing of short bolts, and determination of job inspecting torques. Caltrans inspectors should also have them handy. The 0.015 inch feeler gage can be used to inspect DTI gaps after snugging. The 0.005 inch tapered feeler gage is used to verify adequate DTI crushing during final tensioning for bridge and sign structures. After installation of a DTI is complete, the 0.005 inch feeler gage tip must be refused in at least 1/2 of the gaps, but all the bumps must not be fully compressed to a 0.000 inch gap. A whole set of 26 tapered feeler gages is also necessary when determining a “calibrated gap” for performing pre-installation tests and a “job inspecting torque” for short bolts (see the *Structural Bolting Handbook*). Consult with the BCE to obtain a copy of this reference.

Question 3: Where can I obtain tapered feeler gages?

Answer: The 0.005 inch and 0.015 inch tapered feeler gages are available from either DTI manufacturer (see Question 5). Sets of tapered feeler gages (26 leaves) are available from Starrett (model 66T) [phone: 617-249-3551]; Mitutoyo (model 950-242); or McMaster-Carr [phone: 310-692-5911]. The widths of the tapered leaves may have to be trimmed down to match the taper and tip width of the DTI manufacture’s gages, so that they will fit between the DTI bumps.

Question 4: How many gaps must refuse the tapered feeler gage for the DTI to be acceptable?

Answer: Table 3 shows the number of gap refusals required for each size of A325 bolt to ensure that the minimum tensile strength has been attained:

Table 3. Number of Gap Refusals Required for A325 Bolts to Ensure Minimum Tensile Strength

Bolt Diameter, inch	Total Number of Gaps on DTI	1.05 x Minimum Bolt Tension, kips	Minimum Gap Refusals for Minimum Bolt Tensile Strength	Minimum Bolt Tensile Strength, kips
1/2	4	13	2	17
5/8	4	20	2	27
3/4	5	29	3	40
7/8	5	41	3	55
1	6	54	3	73
1 1/8	6	67	3	80
1 1/4	7	85	4	102
1 3/8	7	102	4	121
1 1/2	8	124	4	148

Question 5: What companies manufacture DTIs?

Answer: In the United States, only the two following companies currently make DTIs:

1. Applied Bolting Technology Products, Inc.
   1413 Rockingham Road
   Bellows Falls, Vermont, USA 05101
   Telephone (800) 552-1999
   www.appliedbolting.com

2. TurnaSure LLC
   340 E. Maple Avenue, Suite 303
   Langhorne, PA 19047
   Telephone (215) 750-1300, (800) 525-7193
   turnasure.com

Note: Both DTI manufacturers furnish free installation instructions and tapered feeler gages.