Approved Methods of Tensioning High-Strength Bolted Connections

Introduction

The Caltrans approved methods for tensioning of common high-strength bolt systems consists 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 standard methods alternative methods are known as the Twist Off-Type Tension Control (TC) 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 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 condition only. All fasteners in a joint must first be tightened to a snug 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 insure that bolts are evenly tensioned. The final tensioning of A325 fasteners in slip-critical bolted connection must have the following minimum tensions:

Nominal Bolt Diameter (Inch)	Minimum Tension Values for A325 Fasteners (kips)	
	Actual Minimum*	1.05 x Minimum**
1/2	12	13
5/8	19	20
3/4	28	29
7/8	39	41
1	51	54
1 - 1/8	56	59
1 - 1/4	71	75
1 - 3/8	85	89
1 - 1/2	103	108

* Tension values equal to 70 percent of specified minimum tensile strength, rounded to the nearest kip as specified in Table 4, titled *Minimum Fastener Tension for Slip-Critical Connections and Connections Subject to Direct Tension, T_m*, of the Research Council on Structural Connections (RCSC) Specification for installing A325 fasteners in slip-critical connections.
** Values are used for calibration and pre-installation testing of all A325 high-strength fastener systems.

Once all fasteners in a joint have been fully tensioned, the joint is inspected. This requires 1) a visual check to insure that plies are in full contact, and thread stickout is in the proper range and is uniform for all fasteners, and 2) the job inspecting torque is applied to 10 % of all fasteners in each joint. Joints should always be inspected immediately after being completed. These same basic procedures are common for all of the approved fastener systems.

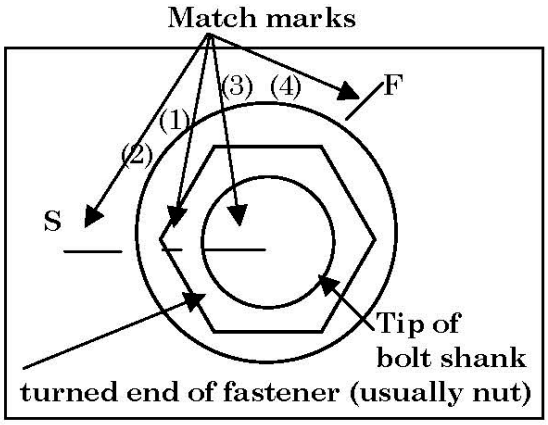
Standard Methods for Installing High-Strength Bolts

The following discussion gives specific information about the two standard methods, Turn-of-Nut and Calibrated Wrench, allowed by Caltrans for installing and checking high-strength bolts:

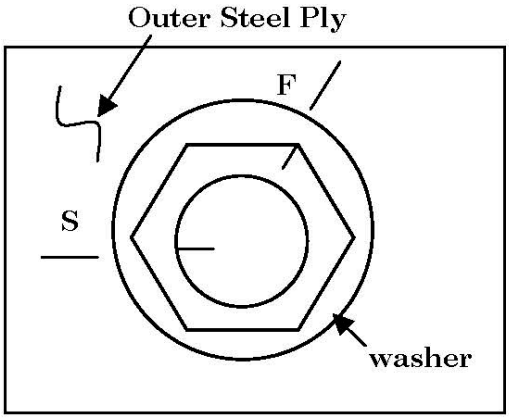
Turn-of-Nut Method

1. 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.

2. **Match mark all bolts:**
When the turn-of-nut tightening method is used to install high-strength 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 below so that the installer and inspector can see that the nuts have been turned a sufficient amount to adequately tension the fastener. The pictures below show the four initial marks made, and the final position of the marks after tightening has been completed.



Initial position of match marks



Final position of match marks

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:

a) ***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.
b) ***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.
c) ***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).
d) ***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.

3. 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 (S) mark 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 5 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 high-strength bolt. The following are acceptable tolerances:

Bolt Length	Specified Turn	Tolerances Allowed
≤ 4*D*	1/3 turn (120°)	□±30 °
over 4D but ≤ 8D	1/2 turn (180°)	□±30 °
over 8 D but ≤12D	2/3 turn (240°)	□±45 °

4. 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 insure 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.

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 shall 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 shall be set to provide a bolt tension not less than five percent in excess of the minimum tension.

All bolts shall be installed with hardened washers under the turned element, and shall be brought to a snug condition prior to applying the final pretension. Snug tightening shall 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 stickout 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 wrenches are used, it should take the operator about 10 seconds (after snugging) to achieve the required minimum bolt tension. This condition may result 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 all 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 which results when attempting to tighten a bolt with an inadequate impact tool, (or too little air pressure or air volume) can distort nuts and damage any protective coating, and will still not provide sufficient bolt tension.

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

1. 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 shall be performed in an appropriate model bolt tension calibrator, according to requirements in the RCSC Specification, Section 8 (d)(2). 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 stickout is flush with the face of the nut when the nut is finger-tight. Final stickout permitted is between flush and 1/4" 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) shall 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 shall 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 high-strength bolts shall then be tensioned in a simulated joint to produce the same calibrated gap verified with DTIs from the same lot (Reference *Direct Tension Indicator Method*) and a torque value read at that gap. The average of the three torque values shall be the installation torque for that lot of short bolts and for that day.

2. 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 high-strength bolts in the actual structure shall be used during installation testing.

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

a. 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 high-strength bolt assembly shall be tested to ensure that the minimum tension is attainable by the installation crew and the tools being used, without exceeding the prescribed rotation.

b. 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.

Alternative Methods for Installing High-Strength 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 high-strength bolts:

Twist Off-Type Tension Control (TC) Fastener Assemblies

All twist-off type tension control (TC) fastener assembly consists 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 a 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% 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 to assure that 1) the installer knows the proper procedure to install the fasteners and follows the manufacturer's instructions, 2) the actual equipment he is using to

install the fasteners works properly, and 3) the fasteners provide the minimum tension as specified in Section 8 (d)(3) of the RCSC Specification.

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

1. A representative sample of not less than three bolts of each diameter, length, grade, and lot shall be installed and tensioned by the Contractor at the job site in a bolt tension calibrator. The Contractor's installer shall demonstrate that each assembly develops a tension not less than five percent greater than the tension required by Table 4 of the RCSC Specification.

2. When testing a TC bolt having a domed head in a bolt tension meter, a flat bushing specifically made for testing the domed tension control 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.

3. The TC fastener assembly shall 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 shall 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 shall be removed and the bolt tension at snug tight checked. If the tension at snug tight exceeds 50% of the minimum required tension load, the effort used to snug tighten the fastener should be reduced and new pre-installation tests run.

4. If when running the pre-installation tests, the TC bolts are too short to fit into a bolt tension-measuring device, direct tension indicators (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 shall 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.

   Rotational capacity testing is also presently 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 tension control fastener assemblies are installed in a structure, the following procedure must be followed:

1. 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.

2. 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.

3. The bolts shall 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 full 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.

4. 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 should be done:

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

   - The contractor should determine a job inspecting torque value.

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

Direct Tension Indicators (DTIs)

A direct tension indicator (DTI) is a special device used in conjunction with each high-strength bolt to insure 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 height (0.005" for bridge and sign structures), the high-strength bolt has been sufficiently tensioned.

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

1. 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”.

2. 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).

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

4. 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.

5. 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". Use a 0.015" feeler gage to check for gaps less than 0.015" at snug.

6. 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.

7. Continue tightening the fastener until the number of gaps which a 0.005" feeler gage won’t enter equals or is greater than that shown in Column 4 of the table on Sheet 10 of 11 in Attachment 2 of BCM 170-2.0. 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 shall 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 shall be tested in a calibrated bolt tension-measuring device. The test assembly shall include a flat, hardened washer under the turned element. By doing the pre- installation test (also called field test in ASTM F959) the installation crew shall 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", it will achieve a tension no less than 1.05 times the specified minimum bolt tension. This requirement is in Section 8 (d)(4) of the RCSC Specification.

When high-strength bolts are installed in the structure in conjunction with DTIs, the fasteners shall 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 such that any gap less than 0.015" shall be removed and replaced with a new indicator.

Once all fasteners in a joint have been snugged, the fasteners shall 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 in order to bring bumps in all DTIs to a uniform gap. When inspected after installation, the minimum number of gaps refusing a 0.005″ tapered feeler gage shall be as follows: If all gaps have been reduced to 0 after installation has been completed, the DTI shall 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 high-strength fastener specialist at the Caltrans Division of 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.

Attachment No. 1 contains answers to frequently asked questions regarding associated tools and equipment used in high-strength bolting.

COMMON QUESTIONS AND ANSWERS CONCERNING TOOLS USED IN HIGH-STRENGTH BOLTING

Bolt Tension Calibrators:

1. Q. What type of equipment should be used to perform torque and tension checks on high-strength fasteners?
   A. Skidmore-Wilhelm (models MS, M, or ML) or Norbar bolt tension calibrators are assigned to some ACM's to do quality assurance testing.

Typical bolt tension calibrator and steel case

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

Minimum Bolt Length (inches) which can be tested in Various Models of Skidmore-Wilhelm Bolt Tension Calibrators

Nominal Bolt Size	Model of Bolt Tension Calibrator				
	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 1/4 – 7		5.000	3.375	5.500	5.500
1 3/8 – 6				5.500	5.500
1 1/2 – 6				5.750	5.750
Max. Tension Capacity	80K max.	110K max.	90K max.	170K max.	225K max.
Weight	65 lbs. +				180 lbs.

There are also 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.

2. Q. Are all of the necessary parts available with the basic bolt tension calibrators?
   A. 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 below.

Special Flat Bushings Required to Test TC Bolts and DTIs

Nominal Bolt Size, inch	Model of Bolt Tension Calibrator					
	M and ML Bushing #/ Approximate Cost		MS Bushing # / Approximate Cost		H Bushing # / Approximate Cost	
1/2	MT-608	$15.00 ea	MS-608	$30.00 ea.	HT-708	$20.00 ea.
5/8	MT-610	$15.00 ea.	MS-610	$30.00 ea	HT-710	$20.00 ea.
3/4	MT-612	$15.00 ea.	MS-612	$30.00 ea.	HT-712	$20.00 ea.
7/8	MT-614	$15.00 ea	MS-614	$30.00 ea	HT-714	$20.00 ea.
1	MT-616	$15.00 ea.	MS-616	$30.00 ea.	HT-716	$20.00 ea.
1 1/8	MT-618	$20.00 ea.	MS-618	$35.00 ea	HT-718	$20.00 ea.
1 1/4	MT-620	$20.00 ea.	MS-620	$35.00 ea.	HT-720	$20.00 ea.
1 3/8					HT-722	$20.00 ea.
1 1/2					HT-724	$20.00 ea

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 tension control fasteners are not meeting minimum tension requirements by 5 to 10%. 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 stickout to between 0" (flush) and 1/4".

3. Q. Should Caltrans provide the bolt tension calibrator for use on construction projects?
   A. No. The Contractor is to perform all pre-installation testing, rotational capacity testing, and inspection of completed joints at the job site, and shall 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.

4. Q. How often should the bolt tension calibrator be recalibrated and adjusted and who is qualified to do this?
   A. 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% of the actual load. The following is a list of acceptable laboratories that are qualified to recalibrate and repair bolt tension calibrators:

Manufacturers* and Laboratory Test Facilities for Bolt Tension Calibrators			
1)	Almay Labs 1415 Newton St. Los Angeles, CA 90021 Phone: (213) 746-1555	4)	Advanced Witness Series, Inc.** 910 Bern Ct. #100 San Jose, CA 95112-1237 Phone: (408) 453-5070
2)	Technical Services Group P.O. Box 250 Alameda, CA 94501 Phone: (510) 522-8326	5)	Mountz, Inc. 1080 North 11th Street San Jose, CA 95112 Phone: (408) 292-2214
3)	Skidmore-Wilhelm * Manufacturing Co. 442 South Green Rd. Cleveland, OH 44121 Phone: (216) 481-4774	6)	Norbar Torque Tools Ltd. * Beaumont Road, Banbury Oxon, OX167XJ United Kingdom Phone: 44(0) 1295 270333

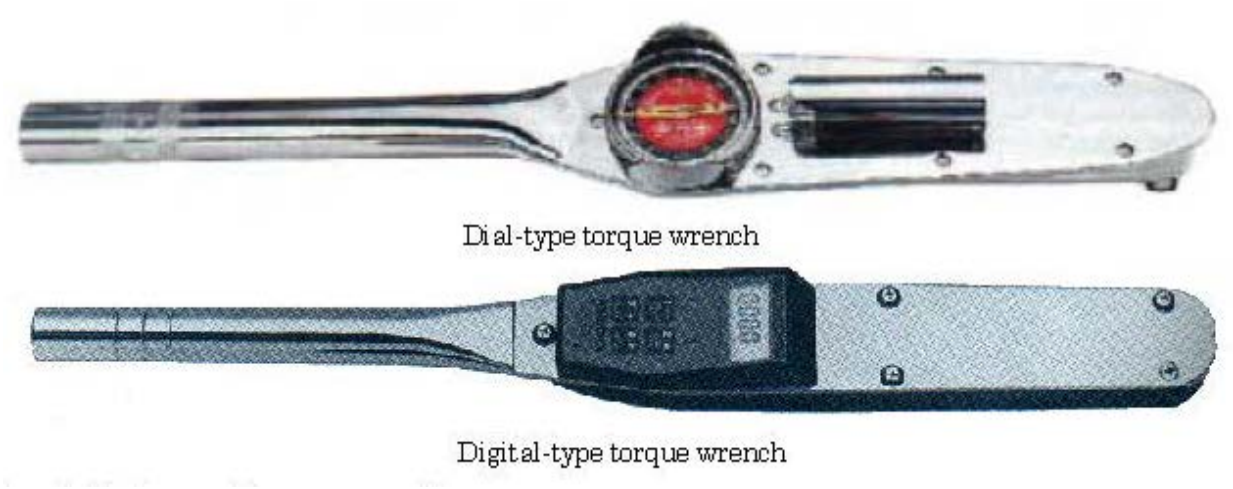
** Local representative and calibration/repair center for Norbar equipment

5. Q. Where can a field Engineer get more information about bolt tension calibrators?
   A. Information and literature can be attained directly from the manufacturers or their representatives (see the listing in Question 4 above).

Torque Wrenches:

1. Q. May the Contractor perform testing or installation of high-strength bolts with a "click-type" torque wrench?
   A. No. Either a dial or digital gauge torque wrench 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.



Acceptable types of torque wrenches

2. Q. What is the "best practice" when using torque wrenches?
   A. A torque wrench is properly used when the following concepts are followed:

   - 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).

   - 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.

   - 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 insure a smooth turning motion (A "jerky" motion generally results when the lever arm is too short). Difficulty attaining adequate tensile loads on large high-strength bolts (i.e., 1-1/8" to 1-1/2") generally indicates the need to use a torque multiplier in conjunction with a torque wrench.

   - 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 (counter-clockwise) direction. It is much better to use an impact wrench or breaker bar for loosening or unloading tensioned fasteners.

   - 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.

3. Q. Where can I obtain information about or purchase a satisfactory torque wrench?
   A. From one of the companies from the following chart:

Torque Wrench Manufacturers* and Calibrator Companies			
1)	Proto* 14117 Industrial Park Blvd., N.E. Covington, GA 30209 Phone: (770) 787-3800	4)	Armstrong Tools* 5200 W. Armstrong Ave. Chicago, Illinois 60646 Phone: (312) 763-3333
2)	Snap-On* 6632 Fig St., Unit B Arvada, CO 80004 Phone: (888) 762-7972	5)	Advanced Witness Series, Inc. 910 Bern Ct. #100 San Jose, CA 95112-1237 Phone: (408) 453-5070
3)	Mitutoyo* 16925 Gale Ave. City of Industry, CA 91745 Phone: (818) 961-9661	6)	Mountz, Inc. 1080 North 11th Street San Jose, CA 95112 Phone: (408) 292-2214

4. Q. How often should a torque wrench be recalibrated and adjusted?
   A. At least once a year. It must be recalibrated and adjusted more often if dropped/mishandled.

5. Q. Who is qualified to perform the recalibration and adjustments, and what information/certificates are required?
   A. 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.

6. Q. What accuracy is required for a torque wrench to be considered acceptable?
   A. Accuracy of torque wrenches shall 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% 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.

7. Q. What do the terms *break torque* and *moving torque* mean?
   A. 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.

8. Q. Does Caltrans provide torque wrenches?
   A. 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.

9. Q. When using the calibrated wrench installation method, why is it necessary to determine an installation torque value for each lot of fasteners every day?
   A. 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 high-strength 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.

Calibrated Wrenches:

1. Q. How often must a calibrated wrench be adjusted and checked to produce proper bolt tension?
   A. 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 insure 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.

2. Q. Which types of calibrated wrenches are acceptable?
   A. 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. A standard impact wrench without a positive cutoff is not acceptable.

Acceptable types of calibrated wrenches

3. Q. What are some equipment variables that effect the final product?
   A. Compressor size and condition, the length, number, and size of air lines, air volume demand of other equipment being operated at same time, condition and size of pneumatic impact wrench, and adjustment settings all can affect torque output of an impact wrench.

4. Q. Why does an impact wrench need to be adjusted and checked so frequently?
   A. 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 high-strength bolts. The influence of these numerous factors must be checked to insure consistent and accurate bolt tension.

5. Q. Why should it take approximately 10 seconds to fully tension A325 bolts?
   A. A wide variety of brands of calibrated impact wrenches with varying torque capacities are available and appropriate for various sizes of high-strength 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.

Torque Multipliers:

1. Q. What is this tool and when is it used?
   A. The torque multiplier is a tool that amplifies a small input torque by gear reduction to produce a large output torque. It is commonly used in conjunction with a torque wrench, to reduce the tightening effort needed for testing, installing, and inspecting larger sizes of high-strength 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.

Acceptable types of torque multipliers

2. Q. Are different sizes available?
   A. 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.)

3. Q. Who manufactures and sells multipliers?
   A. Check the catalogues from following companies: Mountz, Norbar, Proto, Snap-On, and Advanced Witness Series, Inc. Phone numbers for these companies are included in the charts shown in Question 4 on Sheet 3 of 11, Attachment No. 2 of BCM 170-

2.0, and in Question 3 on Sheet 5 of 11, Attachment No. 2 of BCM 170-2.0. For further information contact Dan Thomas in the Division of Structure Construction Headquarters or the fastener specialist at the Division of Materials Engineering and Testing Services.

4. Q. How often does a multiplier need to be recalibrated?
   A. 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.

Electric Installation Tools with combo Spline/Nut Socket for Installing (TC) Bolts:

1. Q. Do all manufacturers of electric installation tools offer the same size of tool?
   A. No, not all electric tools (called Shear Wrench Tools) for installing TC fasteners have the same capacity. 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.

Electric tool for installing TC bolts

2. Q. What variables can affect the satisfactory installation of a TC bolt assembly?
   A. 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 can affect the final bolt tension. Typical steps required with all other high-strength bolt operations, including proper joint fit, snug tightening, tensioning all fasteners evenly in an alternating pattern, are also required when installing TC bolts.

3. Q. Do you need to check the final TC bolt tension with a calibrated torque wrench when fastener installation has been completed?
   A. Yes. Like any normal high-strength bolted connection, joints can be improperly fit and TC bolts can be improperly installed. Plates in joints must 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% of bolts in each connection (or a minimum of 2 bolts) should be checked for adequate tension immediately after tightening of a joint has been completed.

4. Q. How does one know if TC bolts have been tightened to at least the minimum required tension?
   A. By performing pre-installation tests on each lot, diameter, and length of fasteners, observing that proper installation procedures are followed, and inspecting 10% (or a minimum of 2) bolts in each joint using the appropriate job inspecting torque value.

5. Q. Should all TC bolts in a joint be taken to a snug condition?
   A. Yes. First, all TC fasteners should be first 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.

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

1. Q. Why do feeler gages need to be tapered in order to inspect for proper gap in an installed DTI?
   A. Feeler gages used for inspecting DTIs must be tapered and have narrow tips so that they can fit into each gap between closely spaced DTI bumps.

Gage from TurnaSure LLC Gage from Applied Bolting Technology

Typical tapered feeler gages for inspecting an installed DTI

2. Q. Which thicknesses of tapered feeler gages are used for inspecting DTIs installed on bridge or sign structures: 0.015" or 0.005"?
   A. Two thicknesses of these special tapered feeler gages, 0.005" and 0.015", 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" feeler gage can be used to inspect DTI gaps after snugging. The 0.005" 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" 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" 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 pp 17 & 18 of the *Structural Bolting Handbook*).

3. Q. Where can I obtain tapered feeler gages?
   A. The 0.005" and 0.015" 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.

4. Q. How many gaps must refuse the tapered feeler gage for the DTI to be acceptable?
   A. The following chart shows the number of gap refusals required for each size of A325 bolt to insure that the minimum tensile strength has been attained:

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	59	3	80
1 1/4	7	75	4	102
1 3/8	7	89	4	121
1 1/2	8	108	4	148

5. Q. What companies manufacture DTIs?
   A. In the United States, only the two following companies currently make DTIs:

1. Applied Bolting Technology Products, Inc.
   P.O. Box 255
   Ludlow, Vermont 05149-0255

   Telephone:..... 802-228-7390
   800-552-1999
   Facsimile:..... 802-228-7204

2. TurnaSure LLC
   340 E. Maple Avenue, Suite 303
   Langhorne, PA 19047

   Telephone:..... 215-750-1300
   800-525-7193
   Facsimile:..... 215-750-6300

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