



Inspection Procedure for Checking Tension in High-Strength Bolts

Introduction

Following is a brief summary of information that will aid personnel charged with the responsibility of inspecting high-strength bolted connections.

Phases of Inspection

There are three main phases of inspection necessary when high-strength fasteners are installed. These are: 1) Preliminary inspection and testing, 2) Inspection during high-strength fastener installation, and 3) Inspection after high-strength fasteners have been installed.

Phase 1 - Preliminary Inspection and Testing

1. Sampling components and laboratory quality assurance testing:

Fasteners arriving at the job site should be sampled and tested by Caltrans to insure compliance to American Society for Testing and Materials (ASTM) requirements prior to use.

2. Pre-installation testing:

After the satisfactory quality of fasteners is confirmed, the Contractor is required to perform pre installation testing. A calibrated bolt tension-measuring device (Skidmore-Wilhelm or Norbar) is required for this testing. This testing will demonstrate that the Contractor has proper equipment and knowledgeable personnel to correctly install high-strength fastener systems being used and can obtain the proper fastener pre-tension for all lots of fasteners to be used. This includes insuring that "snug- tight" tension is correct, impact wrenches and torque wrenches produce the adequate minimum tension, the correct size of calibrated wrench is used (it should take about 10 seconds to fully tension a fastener with a pneumatic or hydraulic wrench).

3. Rotational capacity (RoCap) testing:

This test will verify that the quantity and quality of lubricant and numerous other variables affecting nut factors including thread fit and condition and coating type and thickness will allow fasteners to be tensioned without galling or stripping.

When doing RoCap testing for all lots of fastener systems, a calibrated bolt tension measuring device (calibrated within the last year and traceable to the National Institute of Standards and Technology) shall be used. If fasteners are too short to fit in a bolt tension

meter and obtain a full nut, then the short bolt test procedure, as outlined in the current Caltrans Standard Special Provisions shall be used.

Phase 2 - Inspection during High-Strength Fastener Installation

The Inspector shall verify that:

1. The contractor has chosen an acceptable type of high-strength fastener systems as permitted in the contract. Acceptable types may include:
 - a) Black bolt (ASTM A325) [with a suitable nut (ASTM A563) and washer (ASTM F436)].
 - b) Zinc-coated bolt (ASTM A325) [with a suitable nut (ASTM A563) and washer (ASTM F436)].
 - c) Tension control (TC) fastener assembly (ASTM F1852).
 - d) Black or mechanically zinc-coated bolt (ASTM A325) [with a zinc-coated Type 325 DTI (ASTM F959), suitable nut (ASTM A563) and washer (ASTM F436)].
2. The contractor is using an approved method of installing high-strength bolts and maintains proper installation technique throughout the project. Approved installation methods include:
 - a) Turn-of-nut.
 - b) Calibrated wrench [impact wrench (pneumatic, hydraulic, or electric) with positive shut-off system or manual torque wrench - dial or digital only]
 - c) Direct tension indicators (DTI's) with black or mechanically zinc-coated bolts.
 - d) Tension control (TC) fastener assemblies.
3. All high-strength bolts are installed with a flat hardened washer under the nut or bolt head, whichever is the element turned in tightening. A maximum of one additional hardened washer may be installed under the non-turning element of the fastener assembly so as to prevent the nut from "bottoming out" within the thread transition zone on the bolt shank. (Lock washers are not an allowable substitute).
4. A back-up wrench is used on each fastener to prevent the non-turning element (usually the bolt head) from turning while the fastener is being tensioned.
5. Installation tests have already been run for all equipment and workers involved, and for each different lot of fasteners used. If a different lot of fasteners or installation equipment is used, or new or different installation crewmembers begin work, new pre-installation tests must be conducted.
6. All fasteners in a joint are installed and tensioned at one time. (It is not acceptable to partially install some of the bolts in a joint, or to "stuff" bolts in a joint and let them remain loose for long periods untensioned).
7. All fasteners, no matter which type are used, shall first be taken to a "snug-tight" condition in a systematic tightening pattern, and then fully tensioned in stages using a systematic tightening pattern.

8. Faying surfaces of all plies in each joint and are in firm contact with each other after the members have been brought to a “snug-tight” condition (defined as the full effort of a person using a spud wrench or 12” flex-handle and socket).
9. No short cuts are taken in the proper installation procedure.
10. The fasteners are properly stored after each shift is done and are not allowed to be exposed to degrading elements (especially rain, fog, dampness, dirt, wind, or extreme temperatures).

Phase 3 - Inspection after High-Strength Fasteners Have Been Installed

After all fasteners have been installed and fully tensioned, a final inspection check is done to ensure the job was done properly. This includes 1) a visual check to confirm all plies of a joint are in firm contact, especially around bolts, 2) a check of tension in 10% of the fasteners in each connection (but not less than two) using a torque wrench (dial or digital gage) to confirm that minimum required bolt tension has been attained. This torque requires that a “job inspecting torque” be determined by the contractor for each different lot of fasteners used. A bolt tension calibrator should be used to establish the "job inspecting torque". Bolt tensions in a joint should be inspected immediately after a joint has been completed. If nuts on any of the bolts checked during the inspection move prior to reaching the job inspecting torque, the remainder of the fasteners in the connection should be inspected and retensioned. Directions for establishing a job inspecting torque value and adjusting tensions in loose bolts are found in paragraph 9(c) of the RCSC Specification (Reference 4 of Attachment No. 3) and shall be followed. Methods for inspecting short bolts are contained in the Structural Bolting Handbook [SBH] (Reference 10 of Attachment No. 3) and require the use of DTIs. Joint seams shall be caulked if needed after fastener tensions in the connection have been inspected and the joint has been approved.

Besides checking bolt tension, the thread stickout should be checked to verify that it is between 0 (flush) and 1/4" beyond the outer face of the nut and that it is the same for all fasteners of similar length. An equal amount of thread stickout in each bolt is an indication that bolt tensions are consistent. Variations in bolt stickout are an indication that some fasteners may be undertensioned, or that joint plies are not in firm contact. Additionally, variations in the thread stickout could indicate that fasteners from different lots have been improperly utilized within the same joint.

It is the contractor’s responsibility to provide all required testing equipment and to perform the tests in the presence of the Engineer. If needed, the Division of Structure Construction has bolt tension calibrators and torque wrenches that are available for use by Caltrans personnel for quality assurance inspection.

Attachment No. 1 contains answers to frequently asked questions regarding high-strength fasteners. Attachment No. 2 is a list of specifications and references for high-strength bolting.

COMMON QUESTIONS AND ANSWERS CONCERNING HIGH-STRENGTH FASTENERS

1.
 - Q. What is a Pre-Installation Test (also called an Installation Verification (IV) or Calibration Test)?
 - A. The pre-installation tests are performed by the Contractor's personnel using the same installation equipment and witnessed by the Engineer. At least three fasteners from each lot shall be tested in a bolt tension calibration device; if bolts are too short to be installed in such a device, then DTIs and the procedure outlined in the SBH (Reference No. 10 of Attachment No. 3) shall be followed. Rules and required testing frequency are described in Section 8(d) of the RCSC Specification (Reference No. 4 Attachment No. 3). These pre-installation tests will determine the ability of the Contractor's personnel, equipment and procedures used in the actual construction to properly install the same high-strength fasteners used in the structure, according to the approved installation method specified or chosen.
2.
 - Q. What is a Rotational Capacity (RoCap) Test?
 - A. This test must be performed by the manufacturer/supplier according to the procedure in the Caltrans Standard Special Provisions. The Contractor is also required to perform the RoCap test at the job site using the same test procedure. This test will verify that the various lots of fastener assemblies when finally ready to be installed at the job site, are capable of withstanding a prescribed nut rotation without failure of the fastener (insures good ductility of fastener), that nuts have been properly lubricated in order to prevent seizing or galling of the threads, and that bolts and nuts are properly tapped and heat treated to prevent thread stripping.
3.
 - Q. Do RoCap tests need to be done on TC bolts, and on fasteners on which DTIs have been installed?
 - A. Yes.
4.
 - Q. How many bolt assemblies are necessary for each test required?
 - A. Pre-Installation Test: 3 minimum per lot (perhaps checked daily)
Rotational Capacity Test: 2 minimum per lot
Job Inspecting Torque determination: 5 minimum per lot (discard 2 test values)
5.
 - Q. May any fastener components which have been used for any tests (including any Pre Installation, torque/ tension calibration, RoCap, or determination of Job Inspecting Torque) be reused?
 - A. No.
6.
 - Q. Why are torque values from torque-tension tables or formulas not permitted to be used to established proper torque?

A. Each lot of bolts, nuts, and washers is different (amount and type of lubricant, fit and roughness of threads, and thickness, roughness and type of corrosion-protective coating may vary). A standard table or formula relating torque and tension cannot accurately predict the many variables for a particular lot of fasteners; therefore, values chosen from tables or calculated from a theoretical formula are not acceptable. If an emergency situation arises, contact the fastener specialist at Caltrans Division of Materials Engineering and Testing Services (METS).

7.

Q. Who determines the bolt length to be used in a connection?

A. It is the Contractor's responsibility to provide the correct bolt length, unless the Designer has specified the length in the contract documents. Caltrans specifications require that the final thread stickout shall be a maximum of 1/4" and at least flush with the nut face. This insures full bolt thread engagement with the nut, and also provides a maximum number of threads (at least 3 to 5) within the grip length to insure good ductile capacity of the bolt if loaded in extreme conditions.

8.

Q. If a bolt is too long, can additional washers be added?

A. One washer is required to be placed under the nut (or turned end) of the fastener. Caltrans allows only one additional washer to be added (under the unturned fastener end) as a minor adjustment for proper thread stickout.

9.

Q. What should be done when fastener holes in joint plies are misaligned?

A. The Designer should be contacted and address this condition. It may be permissible to ream misaligned bolt holes up to 1/32" over the diameter normally required for a standard hole. Further reaming to permit use of the next size larger fastener may be acceptable if ample spacing, edge distance, and remaining net section are available in the joint and if allowed by the Engineer. Bolt holes shall only be modified by implementing the placement of holes as stated in Section 55-3.14 of the Caltrans Standard Specifications (Reference 1 of Attachment No. 3).

10.

Q. Are warped plates allowed in a bolted joint?

A. Generally, firm contact between plies cannot be attained during the snugging operation, as required, when warped plates or improper fit-up are present in a bolted connection. Gaps around bolt holes and between plies of a friction-type connection are not acceptable. Proper fit-up of a joint prior to bolting is required. Heat straightening and shimming may be possible corrective measures, which can be used to correct warped plates prior to bolting. The Engineer, however, should use prudent judgement as to the acceptability of any material, given the design considerations. The Paragraphs 3.5.1.14 and 3.5.1.15 of the American Welding Society (AWS) Code D1.5 address the general issue of warped plates for mechanically connected joints and splices.

11.

Q. What measures should be taken if Contractor does not handle or store fasteners properly?

A. Section 8(a) of the RCSC Specification requires that fasteners be stored properly. The Inspector at the job site should immediately notify the Contractor if any fastener

components are improperly handled or stored, and should document any instances of improper storage or handling in a diary. Proper handling and storage includes: 1) storing fasteners out of the weather in their original containers, off the ground, preferably in a closed building with a roof. 2) removing only as many fasteners from their original containers as can be installed during a work shift. 3) returning unused fasteners to their original containers in protected storage at the end of the shift, and 4) Not altering the original lubricant in any way from the way it was in the as-delivered condition. These requirements are all covered in Section 8(a) of the RCSC Specification.

12.

- Q. What should be done to fasteners that have become dirty or rusty, or have lost their original lubricant?
- A. Fastener components that have not been properly stored may have been exposed to moisture, dirt, or dust, and as a result, may have had lost their original lubricant, or become dirty or rusty. Any changes in the original lubricant or thread condition on most fastener components, especially ones such as Tension Control (TC) fasteners, will affect their torque-tension relationship and how they function and may prevent adequate minimum tension from being attained. Fasteners which have become dirty, rusty or whose original lubricant has changed or been altered should be rejected by the Engineer. Whether the rejected fasteners can be restored to a satisfactory useable condition will vary depending on the degree of degradation and damage. If they are deemed salvageable, how they are to be restored to a useable condition and who can do the restoration will vary, depending on the type of fastener, the type of restoration work required, and the facilities available to the Contractor to rework the fastener components. Each case may require the Engineer to assess what facilities and capabilities the Contractor has available and whether he can do a satisfactory job.

Black fasteners are generally easier to clean and relubricate than zinc-coated ones, and in some cases, this operation can be done by the contractor. Light dust or dirt on fasteners can often be removed and fasteners may be relubricated. Rust on fasteners generally results from improper storage and exposure to moisture. The degree of rust damage and the effect of pitting is often more difficult assess and correct. The degree of rust and pitting will determine whether fasteners are salvageable. Light rust on the male threads can often be removed successfully, and fasteners may be relubricated and reused. Moderate to heavy rust that causes heavy pitting usually cannot be corrected and fasteners should be rejected. Rust on the internal threads of nuts is much more difficult to assess or remove; rusty nuts that cannot be thoroughly cleaned or restored should be rejected. Any restoration of damaged fasteners to their original condition and retesting is the responsibility of the contractor. If the Engineer deems that fasteners can be saved, the Contractor is responsible for assuring that the fasteners are thoroughly cleaned and uniformly relubricated, and then for performing additional pre-installation and rotational capacity tests at his expense, to prove the modified fasteners are acceptable.

Often the Contractor is not equipped to perform satisfactory cleaning and relubrication at the job site. Reworking fasteners that have been rejected due to excessive dirt, rust,

or lack of proper lubrication requires certain minimum facilities and equipment. These may include a suitable indoor site, equipment and manpower to 1) thoroughly clean the fasteners (i.e., remove all dirt and rust with appropriate cleaning solvent), 2) apply a uniform amount of suitable lubricant similar to what was originally applied to the fasteners, 3) maintain lot integrity of each fastener component requiring cleaning, and repackage each component and remark containers. The Contractor may wish to rework lots of rejected fasteners, but the Engineer needs to judge whether the Contractor is capable of doing a satisfactory job. If the Engineer does not feel that the Contractor is capable of satisfactorily cleaning and relubricating rejected fastener lots, the Engineer should advise him why.

Each component of a black fastener system is originally provided with a water-soluble oil to protect it from rust and to reduce friction when nuts are being snugged and tightened. For zinc-coated fasteners, only the nuts are lubricated with a special dyed, dry lubricant that is clean to the touch.

The type and quantity of lubricant applied by the original manufacturer to nuts on TC fastener systems is very critical and important. Therefore, any lot of TC fasteners that have been rejected for dirt, rust, or improper lubrication should only be reworked, retested, and recertified by the original manufacturer. Any alteration of the original lubricant by anyone other than the original manufacturer voids any certification or warranty made by the manufacturer of a TC fastener system, and should never be allowed. The Engineer should reject TC fastener systems failing to meet any of the required job site tests. The Contractor may return any rejected lot of TC fasteners to the manufacturer for reworking, retesting, and recertification.

The contractor should be aware that some types of lubricant used on fasteners cannot easily be removed from exposed fastener surfaces after installation and prior to painting the bolts. Some lubricants, such as beeswax, are not water-soluble, are extremely difficult to remove, and may require harsh solvents.

Additionally, lubricants should not be sprayed or applied to bolts that have already been installed in a connection, as the lubricant could seep into the faying surfaces of the joint and result in a loss of friction on faying surfaces of a slip-critical joint.

13.

Q. Can a Contractor alter (either add or remove) the original lubricant present on fasteners that he received from the manufacturer?

A. No. The original lubricant on the fasteners must not be altered. The manufacturer or responsible party for each fastener system has applied a certain amount and type of lubricant to each fastener in a lot, has tested each lot, and certified that the fasteners comply with all appropriate specifications and ASTM requirements. The original fasteners must be properly stored and maintained to preserve their original condition for all preliminary testing, installation, and tension verification checks on each completed joint. The contractor is not permitted to alter any original lubricant on high-strength fastener systems in any way, either for preliminary testing, or before or during installation. If a particular lot of fasteners should fail any of the preliminary tests required and done at the job site, the Engineer should reject the lot.

14.

Q. May one type/grade of high-strength fastener be substituted for another?

A. Generally not. Each grade/type has its own specific material composition, strength and dimensions. Because of smaller head dimensions and shank diameter tolerances, Society of Automotive Engineers (SAE) grades of fasteners (Grades 5 and 8) generally should not be interchanged with ASTM high-strength bolt types. Any request for substitution of a type or grade of bolt different from what was originally specified should be submitted to the Engineer for review prior to acceptance. For further information, contact the high-strength fastener specialist at the Division of METS.

15.

Q. If the exterior surface of any steel member is sloped/angled greater than 1:20, can high-strength bolts be used?

A. Yes; however, if the slope of the exterior face of any member exceeds 1:20 (about 2.9 degrees), relative to the washer-faced bearing surface of the bolt or nut face, a hardened beveled washer must be used between the exterior face of the sloped steel part and the bolt head and/or nut to compensate for the excessive slope, and reduce the slope(s) to less than 1:20.

16.

Q. May high-strength bolts that were used/tightened once, be reused?

A. Neither ASTM A490 nor galvanized A325 bolts may be reused. Only plain "black" A325 high-strength bolts should be considered for reuse. Reuse of any black A325 bolts and nuts should only be permitted if the Engineer determines the bolts are in good condition, the bolt threads have not been significantly elongated plastically (this can be checked by spinning the nut by hand over the entire length of bolt threads), and each lot of used fasteners is re-tested and passes the pre-installation and rotational capacity tests. All fastener components used for pre-installation or rotational capacity tests, or for determining job inspecting torques shall be discarded.

17.

Q. May TC bolts and/or DTI's be reused?

A. No. Once installed and fully tensioned or used for any type of testing, they must be discarded.

18.

Q. Where should a DTI be installed, which way do the bumps face, and how do I determine if the bolt has adequate tension?

A. The correct preferred position of a DTI is under the bolt head, with the DTI bumps bearing against the underside of the hardened bolt head. Alternate positions are possible, but only when reviewed and approved by the Engineer. DTI bumps must never bear against any soft steel or any turned component. For bolts to have adequate tension, the gaps on zinc-coated DTIs need to be compressed to 0.005" or less (and also need to be greater than 0). The manufacturer's installation procedure should be followed. For more information, obtain appropriate installation instructions from either DTI manufacturer (see Sheet 10 of 10 of Attachment No. 2), or contact the fastener specialist at the Division of Materials Engineering and Testing Services.

19.

Q. Who establishes the job inspecting torque and how is it determined?

A. The Contractor determines the value for inspection torque by testing 5 fasteners, in the presence of the Engineer, in accordance with Section 9(b)(3) of the RCSC Specification. One high and one low reading are discarded, and the remaining three readings are averaged. The Engineer will record the job torque, determine which bolts in the joint shall be inspected, and witness the Contractor performing the actual checking. The procedure shall be performed in accordance with Section 9(b) (4) of the RCSC Specification.

20.

Q. Can a contractor partially install (“stuff”) some or all fasteners loosely in a joint with the intent of coming back in the near future and completing his tightening operation?

A. No, absolutely not! The RCSC Specification [Section 8(A)] clearly prohibits this practice. Only as many fasteners as can be completely installed and tensioned during a work shift can be removed from the storage area. This rule helps prevent fasteners from losing their lubricant and rusting before the tightening operation and tension verification check has been completed. Occasionally an uneducated or unscrupulous contractor will attempt to do this so that he can speed up his operation. Wise inspectors of course prevent this practice and explain why it is a bad thing to do.

21.

Q. Why must hot-dip galvanized faying surfaces be hand wire brushed?

A. Hand wire brushing is required in order to assure that the galvanized surfaces will have sufficient friction between the plates in contact. Using power driven wire brushes can result in polishing of the surfaces, which would reduce the friction between the surfaces and the capacity of the connection.

22.

Q. Why is the thread stickout limited to ¼ inch beyond the face of the nut?

A. If the thread stickout exceeds ¼ inch, the length of full threads within the grip of the joint is very short, and any elongation that occurs in the bolt during tightening is limited to a very small portion of bolt threads within the grip. Excessive thread stickout reduces the ductile capacity of the fastener during extreme unusual combined tensile and shear loading that might take place during an earthquake. In addition, if thread stickout is extremely large, it is possible that the nut would “bottom out” in the transition zone of the threads during tightening and prior to the full tension of the bolt being achieved. In this case, there may be insufficient tension in the bolt although high torque readings may give a false indication otherwise.

23.

Q. What level of inspection is required in order to assure that the bolts have been installed properly?

A. All stages of bolt installation and tensioning must be witnessed in order to assure compliance with the specifications. It is the responsibility of the inspector witnessing high-strength bolting at the job site to thoroughly understand and enforce Sections 2, 3, and 8 of the RCSC Specification. Verifying that the required final torque has been achieved, without witnessing that the snugging and tensioning operations were

performed properly, does not guarantee that, after the joint has been completed, each of the fasteners have the minimum tension required

LIST OF SPECIFICATIONS AND REFERENCES FOR HIGH-STRENGTH BOLTING:

1. Caltrans Standard Specifications, Section 55-3.14, *Bolted Connections*.
2. Standard Special Provisions for high-strength bolting.
3. Project Special Provisions.
4. **"Specification for Structural Joints Using ASTM A325 or A490 Bolts"(RCSC Specification)**, Research Council on Structural Connections, American Institute of Steel Construction, Inc., (Allowable Stress Design edition [publication No. S329 (20M596)] or Load and Resistance Factor Design edition [publication No. S345L (30M496)] Chicago, IL, June 3, 1994. Phone No. 1-800-644-2400. **Available on the OSC Web Site at:**
<https://ctlibrary.onramp.dot.ca.gov/>

Note: By reference in the Caltrans Standard Specifications, this RCSC Specification is made a part of all Caltrans construction contracts. The use of high-strength bolts in structural steel connections must conform to requirements in this specification, unless otherwise stated in the contract Standard Specifications or Standard Special Provisions.

5. The following Specifications within the Annual Book of ASTM Standards, Volume 01.08, "Fasteners":
 - ASTM A325 or ASTM A325M, *Structural Bolts*.
 - ASTM A563 or ASTM A563M, *Nuts*.
 - ASTM F436 or F436M, *Hardened Washers*.
 - ASTM F959 or F959M, zinc coated *Direct Tension Indicators*.
 - ASTM F1852, *Twist off type TC Bolt Assemblies*.
6. The following National Standard titled *Fasteners for Use in Structural Applications*, ASME B18.2.6-1996, published by the American Society of Mechanical Engineers.
7. *High Strength Bolts for Bridges*, Report No. FHWA-SA-91-031, May 1991, U.S. Department of Transportation, Federal Highway Administration.
8. Division II- Construction, Article 11.5.6, *Connections Using High-Strength Bolts*, Section 11 *Steel Structures*, of the AASHTO Standard Specifications for Highway Bridges, 16th Edition.
9. AISC Steel Construction Manual.
10. ***Structural Bolting Handbook***, Steel Structures Technology Center, Inc., 42400 W. Nine Mile Rd., Novi, MI, 48375-4132, (1999 edition) Phone: (248) 344-2910. **(Contact DSC Headquarters [916-227-8387] to obtain a copy).**

- 11.** *Instruction Manual for Installing High-Strength Bolts with Direct Tension Indicators*, (ASTM F959) Inch Series Edition, Turna Sure LLC, 340 E. Maple Ave, Suite 303, Langhorne, PA 19047 (July 1999, 10th edition) Phone: 1-800-525-7193.