

INTRODUCTION

High-strength bolts are well established as economical and efficient devices for connecting structural steel. When North American design and construction practices are followed, the *Specification for Structural Joints Using ASTM A325 or A490 Bolts*, Approved by the Research Council on Structural Connections, sets the basic rules for their use. Designers and inspectors should be thoroughly familiar with this specification.

Direct Tension Indicators (DTIs) are recognized by many engineers as the most reliable method for ensuring correct installation of high-strength bolts according to that specification for both shear/bearing connections and connections requiring fully pretensioned bolts.

This manual is written for engineers, construction superintendents, inspectors and iron workers to assist them in the proper installation of high-strength bolts using DTIs. This will ensure that bolts have been tensioned to the values required whether used in slip-critical connections, connections subjected to direct tension, or shear/bearing connections requiring fully pretensioned bolts. These instructions are also valid when DTIs are specified for use with high strength bolts in other connections as a device to ensure that all bolts have actually been tensioned.

The handbook discusses the theory of slip-critical connections or connections subjected to direct tension, proper installation of DTIs, general rules for bolt installation, problems typically encountered when installing high-strength bolts and many other subjects relative to high-strength bolting.

TurnaSure LLC has years of high-strength bolting experience and provides a range of consultation activity including seminars, site visits, tool recommendations, specification commentary and training programs. In addition TurnaSure LLC prepares instructional DVDs, published technical reports and articles for publication in trade journals. Should you wish to receive any of this information or be placed on our mailing list, please contact us at the address shown on the inside cover.

An inch series edition of this manual is available upon request, or you can print the PDF version available on our web site.

THEORY OF HIGH STRENGTH BOLTING

The principle of slip-critical connections relies upon tensioning each bolt in the connection to a specified minimum tension so that the desired clamping force will be induced in the connection interface. Shear loads are then transferred by frictional resistance in the joint interface rather than by bearing on the bolt shanks and hole faces. In this type of connection there will be no movement of the connected materials when the connection is subjected to these loads. Movement in many types of joints is highly undesirable, hence the development of the slip-critical connection. (Figure 1)

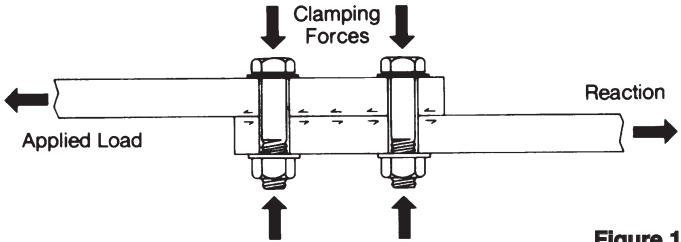


Figure 1

When tension loads are applied in the direction of the bolt axis, tensioning to a specified minimum tension is also important, particularly if the loads are cyclical and could induce loosening or fatigue failure of the bolts. The clamping force at the specified minimum tension should be greater than the applied loads. This will prevent the plies from separating or the bolts from developing any significant increase in tension stress over the installed pretension stress. (Figure 2)

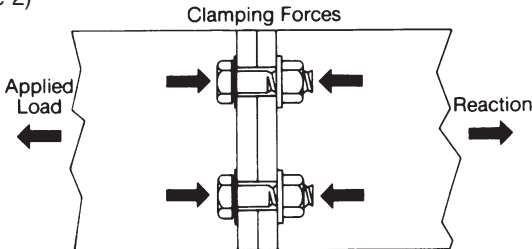


Figure 2

DIRECT TENSION INDICATORS (DTIs)

Direct Tension Indicators (DTIs) are simple and extremely accurate devices for ensuring that bolts have been installed above the specified minimum tension value. Used properly they positively **ensure the correct amount of clamping force. Readers who have installed high-strength bolts using “torque/tension” values will notice that this manual does not relate torque to tension. Torque, or twisting force, is not a reliable measure of bolt tension. DTIs measure tension regardless of applied torque.**

A DTI is a hardened, washer-shaped device with protrusions, “bumps,” pressed out on one face, manufactured according to the provisions of ASTM F959M. The fact that it resembles a washer is incidental. It is, in fact, a precision made mechanical load cell, a device for tensioning which is covered by an ASTM Standard.

When a DTI is installed on a bolt with the “bumps” placed against the underside of the bolt head there are noticeable gaps between the “bumps.” As the nut is turned and the bolt tensioned, the “bumps” flatten. When the “bumps” are flattened so that the gaps have been reduced to the required dimension, the bolt has been properly tensioned and required clamping force is present. A DTI does not make it more difficult to tension a bolt, it merely shows that the bolt has been properly tensioned. (Figure 3)

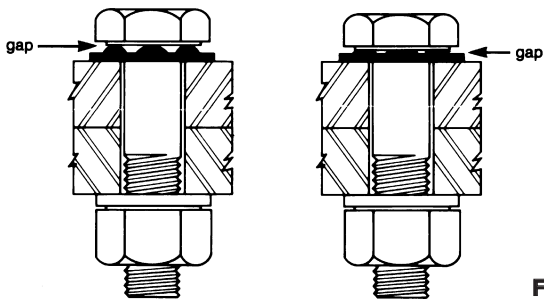


Figure 3

Direct Tension Indicators are supplied either “plain finish,” that is without a coating, mechanically galvanized to ASTM B695 Class 50, or produced from “weathering steel” for use with Type 3 high-strength bolts. Other coatings may be available upon inquiry.

Unless otherwise specified, uncoated DTIs are installed under the bolt head and the nut turned. When the bolt is properly tensioned the gap will be less than 0.400mm in more than half of the spaces. Coated DTIs are installed using a 0.125mm criteria. To assure that the DTI is properly installed, feeler gages, 0.400mm and 0.125mm thick, are provided with DTI shipments. To ensure that the DTI is properly compressed, and the bolt tensioned, the appropriate feeler gage must be refused in a given number of gaps between the “bumps.” (Table I lists the number of “bumps” for each size and grade of DTI and the required number of gage refusals in the gaps.)

Table 1

Bolt Size	TYPE 8.8		TYPE 10.9	
	Bumps	Refusals	Bumps	Refusals
M12*	4	3	4	3
M16	4	3	4	3
M20	5	3	6	4
M22	5	3	6	4
M24	6	4	7	4
M27	6	4	7	4
M30	7	4	8	5
M36	8	5	9	5

*Not currently in ASTM for bolts or DTIs

Should the specifications or conditions of installation call for an average gap of less than 0.125mm the feeler gage must be refused in all spaces.

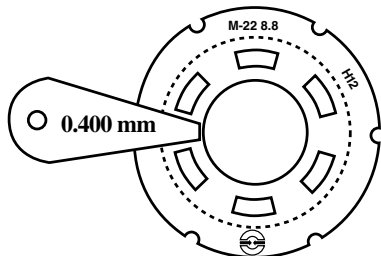


Figure 4

When inserted the feeler gage must be pointed at the center of the bolt and be at the center of the space. “Notches” in the O.D. of the DTI assist in feeler gage inspection. (Figure 4).

Usually, installation crews develop a “feel” for installation and can install DTIs to the correct gap by eye. Inspectors will want to verify that the correct gap has been achieved using a feeler gage on a limited number of DTIs and then compare other gaps by eye.

Fully compressed DTIs should not be rejected. Some inspectors judge that a bolt which has fully compressed a DTI is “overtensioned.” No specific definition of “overtensioned” exists in bolt literature. Many experts believe that unless a tensioned bolt has broken it is acceptable. Further support for this recommendation can be found in a report published in Volume 36, No. 1 of the *Engineering Journal*, The Effects of Over-Compressing ASTM F959 Direct Tension indicators on A325 Bolts Used in Shear Connections.

REUSE OF DIRECT TENSION INDICATORS ON HIGH STRENGTH STRUCTURAL BOLTS

The question has been raised as to whether it is permissible to reuse Direct Tension Indicators (DTIs). This notice is intended to clarify that the reuse of DTIs is not recognized by this manufacturer as a viable and accurate means to assure that required clampforce has been generated in slip-critical or tension connections. DTIs, like other fasteners, plastically deform during use. Thus, reuse of such fasteners cannot be assumed to be sound engineering practice. Admittedly, the RCSC Specification is currently silent on the issue of reuse of DTIs, or for that matter, Twist-Off bolts.

BOLT TENSIONING USING PLAIN FINISH DTIs

METHOD #1

DTI Under the Bolt Head—Turn the Nut to Tension

Preferred method for multiple plies and long bolts (typically large A490M bolts) in order to detect trapped bolts.

ASSEMBLY

Put the DTI under the bolt head with the bumps facing the underside of the bolt head. Put a hardened washer under the nut. (Figure 5a)

With a short-slotted or oversized hole under the bolt head add a hardened flat washer between the DTI and the hole, and if the bolt is also an A490M larger than M24 the hardened washers must be at least 8.0mm thick. (For a long-slotted hole, an external cover plate of sufficient size to completely cover the slot should be provided at a minimum of 8mm thick). (Figure 5b)

Check that the washer hole diameter conforms to ASTM F436M for sizes up to M24. Above M24, because ASTM F436M allows a washer I.D. considerably greater than the nominal diameter of the bolt, the engineer may wish to consider “special” hardened washers with normal sized holes. TurnaS sure can assist in procurement of such washers. Normal sized holes either in a washer or in the structured steel also help prevent DTIs from dishing.

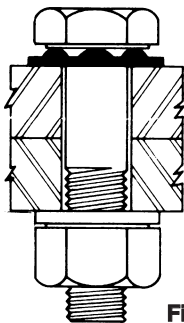


Figure 5a

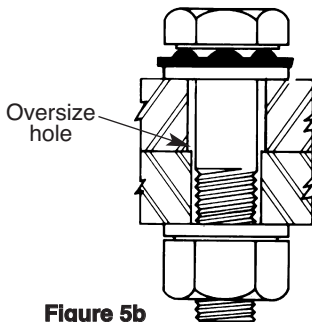


Figure 5b

TENSIONING

Turn the nut until the gap between the bolt head and the DTI face is reduced to less than 0.400mm in more than half of the entry spaces. When turning the nut, prevent the bolt head from spinning with a hand wrench.

BOLT TENSIONING USING PLAIN FINISH DTIs (Continued)

METHOD #2

DTI Under the Nut—Turn the Nut to Tension

Use of this method saves the need for a hardened washer on standard connection not involving multiple plies or large A490M bolts.

ASSEMBLY

Place the DTI under the nut with the bumps facing the nut. (Figure 6a)

With a short-slotted or oversized hole under the bolt head or nut, add a hardened flat washer, and, if the bolt is an A490M and larger than M24 the hardened washers must be at least 8.0mm thick. (For a long-slotted hole, an external cover plate of sufficient size to completely cover the slot should be provided at a minimum of 8mm thick). (Figures 6b and 6c).

Note B: The new TurnaSure DTIs do not need hardened washers between the nut and DTI. This assembly was for DTIs with the older design “straight-sided” protrusions (as depicted in Figures 12 and 13 on page 20). With the old design DTIs a hardened washer has to be used between the nut and DTI to achieve consistent assembly loads.

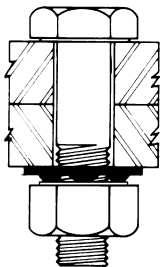


Figure 6a

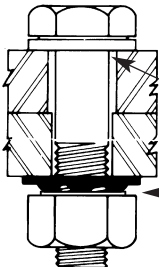


Figure 6b

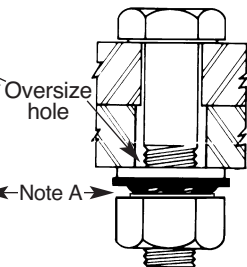


Figure 6c

TENSIONING

Turn the nut until the gap between the nut and the DTI face is reduced to less than 0.125mm in more than half of the entry spaces. When turning the nut, prevent the bolt head from spinning with a hand wrench.

BOLT TENSIONING USING PLAIN FINISH DTIs (End)

METHOD #3

DTI Under the Bolt Head—Turn the Bolt Head to Tension

Use this method if method #1 or #2 can not be used.

ASSEMBLY

Place the DTI under the bolt head with the bumps facing the bolt head. (Figure 7a)

With a short-slotted or oversized hole under the bolt head or nut, add a hardened flat washer, and, if the bolt is an A490M and larger than M24 the hardened washers must be at least 8.0mm thick. (For a long-slotted hole, an external cover plate of sufficient size to completely cover the slot should be provided at a minimum of 8mm thick). (Figures 7b and 7c)

Note B: The new TurnaSure DTIs do not need hardened washers between the nut and DTI. This assembly was for DTIs with older design “straight-sided” protrusions (as depicted in Figures 12 and 13 on page 20). With the old design DTIs a hardened washer has to be used between the nut and DTI to achieve consistent assembly loads.

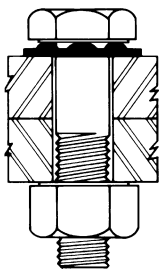


Figure 7a

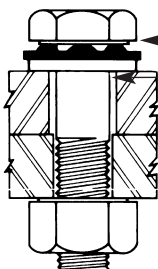


Figure 7b

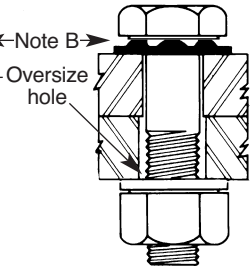


Figure 7c

TENSIONING

Turn the bolt head until the gap between the bolt head and the DTI is reduced to less than 0.125mm in more than half of the spaces. When turning the bolt head, prevent the nut from spinning with a hand wrench.

BOLT TENSIONING USING COATED DTIs OR TYPE-3 WEATHERING STEEL DTIs

METHOD #1

DTI Under the Bolt Head—Turn the Nut to Tension

Coated DTIs should be assembled under the bolt head wherever possible. Assembly and tensioning should proceed as with “plain.” For galvanized and epoxy coated or weathering steel DTIs the gap between the bolt head and the DTI face should be reduced to less than 0.125mm in more than half of the entry spaces. (Figure 8a)

*The use of flat hardened washers per the provisions of the *RCSC Specification* varies with the bolt strength, hole size and yield strength of connected steel and tightening method. For example, with a short-slotted or oversized hole under the bolt head add a hardened flat washer between the DTI and the hole, and, if the bolt is an A490M and larger than M24 the hardened washers must be at least 8.0mm thick. (For a long-slotted hole, an external cover plate of sufficient size to completely cover the slot should be provided at a minimum of 8mm thick). (Figure 8b)

For bridge applications see **INSTALLATION INSTRUCTIONS FOR BRIDGE APPLICATIONS PER AASHTO**, found on the inside back cover.

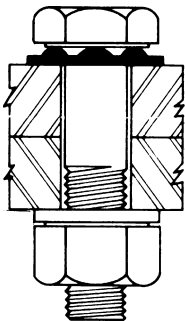


Figure 8a

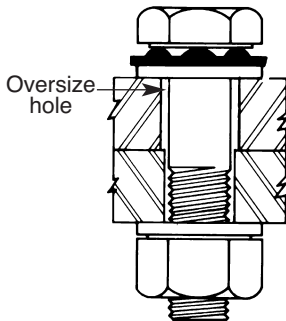


Figure 8b

BOLT TENSIONING USING COATED DTIs (End)

Note C: The new TurnaSure DTIs do not need hardened washers between the nut and DTI. This assembly was for DTIs with the older design “straight-sided” protrusions (as depicted in Figures 12 and 13 on page 20). With the old design DTIs a hardened washer has to be used between the nut and DTI to achieve consistent assembly loads.

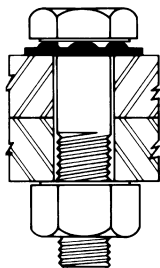


Figure 10a

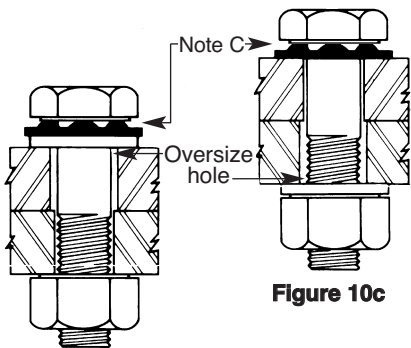


Figure 10b

Figure 10c

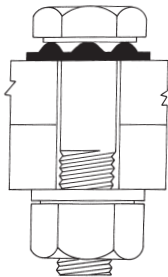
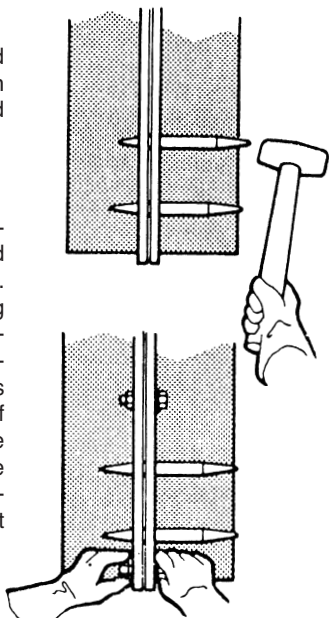
RECOMMENDED BOLT INSTALLATION PROCEDURE

Step 1

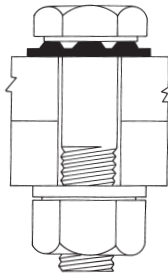
Bring the members to be joined together and align the holes with drift pins. (Bolts should not be used as drift pins to achieve alignment.)

Step 2

Fill the remaining holes with high-strength bolts, nuts, washers, and DTIs of the correct size and grade. Partially tension the bolts to snug the connection. Partial tension is evidenced by slight, but visible, flattening of the DTI protrusions. At this point there will be as much as 50% of the minimum specified tension in the bolt. This amount of tension should be sufficient to produce a snug connection. Work from the most rigid part of the connection to the free edges.



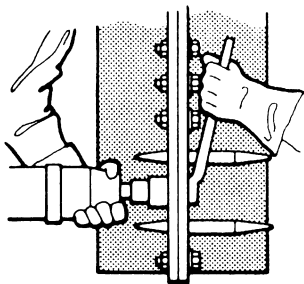
No Tension



**Partial Tension
"Snug"**

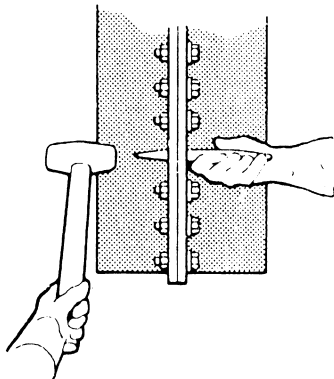
Step 3

Tension the bolts until the average gap on each DTI is as specified. Again, work from the most rigid part of the connection toward the edges. Leave the drift pins in during this operation. Premature removal of the drift pins may cause trapping of the bolts by joint slippage.



Step 4

Knock out the remaining drift pins, replacing them with bolts. Tighten these bolts.



Notes

On A490M bolts, try not close all the gaps to nil. There is no need to tension these bolts (which have less ductility than A325M bolts) that much. However a nil gap should not be cause for rejection. If there is a concern about "overtensioning," remove a sample number of bolts from the work and inspect them for deformation by running the nut down to the thread runout. If the nut runs down there is no excessive elongation. Note however if the removed bolt is A490M or galvanized A325M it cannot be reused.

When using impact wrenches, final tightening should be accomplished in 10 seconds or less. Large A490M bolts may take as long as 20 seconds. If these limits are exceeded check to see that the correct tools are being used or that one of the problems listed on pages 14 and 15 is not being encountered.

PROBLEMS COMMONLY ENCOUNTERED WHEN TENSIONING BOLTS

Dry or Rusty Threads or Nut Faces—Usually caused by poor storage conditions, dry or rusty bolts, nuts or washers should not be permitted. Ideally nuts, bolts, washers and DTIs should be kept in dry storage and their containers not opened until immediately before use. Rust significantly increases the amount of torque required to tension a bolt. Ideally nuts should be wax dipped before use, particularly on large A490M bolts. Lubricant on the face of the nut is very desirable. If it is necessary to lubricate bolts at the site at the time of installation Castrol Industrial STICK WAX Lubricant is recommended. It is available from many sources including TurnaSure LLC. **The necessity of adequate lubricant to achieve the desired level of bolt pretension cannot be over-emphasized.**

Galvanized Nuts and Bolts—Hot dipped galvanized nuts should have threads tapped oversize after galvanizing. Mechanically galvanized nuts are tapped before galvanizing. The nuts should be dipped in a wax lubricant, preferably with dye so the lubricant can be seen. A turn test, which is mandatory and described in A325M, should be performed on samples from every lot combination shipped to assure that the bolts can be tensioned without either seizure or stripping the nut threads.

Damaged Threads—Usually caused by forcing the bolt through misaligned holes, this will cause the nut to “freeze.”

Trapped Bolts—Usually caused by slippage in the joint as a result of removal of drift pins before enough bolts have been tensioned to prevent slippage. Trapped bolts cannot develop tension along their entire length.

Bolts Too Long—The nut runs up against the thread runout before the bolt is properly tensioned.

Recommended Nuts—Nuts with less than 1245MPa proof stress may gall, are prone to stripping and generally require more torque to tension bolts. Nuts manufactured to ASTM A563M 10S are recommended when bolts are to be tensioned.

PROBLEMS COMMONLY ENCOUNTERED WHEN TIGHTENING BOLTS (Continued)

Omission of Hardened Washers under the Turned Element—Hardened washers are not required by the *RCSC Specification* for all high-strength bolt installations where tensioning is required. However, the use of hardened washers under the turned element significantly reduces the torque required to tension a bolt and is recommended by TurnaSure LLC whether DTIs are used or not.

Oversized Hardened Washer ID—Above M24, because ASTM F436M allows a washer I.D. significantly greater than the diameter of the bolt, engineers may wish to consider “special” ASTM F436M hardened washers with a smaller inside diameter consistent with a “normal size” hole.

Hot Forged Bolts—Hot forged bolts must be free of die fins, burrs and excessive swelling under the bolt heads which might prevent DTIs from properly contacting the washer face of the bolt. If necessary, to avoid this condition consider installing the DTI under the nut.

Oversized Holes—Hardened washers are required to cover oversized and slotted holes. Requirements are spelled out in the *RCSC Specification*. A490M bolts larger than M24 require 8.0mm thick washers, which are necessary to prevent the dishing of DTIs as well as the washer.

AIR-TOOL SELECTION AND PERFORMANCE

Air driven impact wrenches are the prevalent tool for installing high-strength bolts. These wrenches require between 25 and 120 cu. ft./min. of air at a pressure of 100psi, at the tool, while running, to deliver a particular torque. The torque required to install a high-strength bolt to the correct tension varies with the size and grade of the bolt, and with the bolt and nut thread condition. **There are no specific relationships between torque and tension.**

Assuming the wrench is of adequate size, if problems are encountered in compressing DTIs within the time span noted, check the equipment for:

- Insufficient air pressure at the compressor.
- Too many tools running at one time.
- Too long an air line, or leaks in the air line.
- Blockage of the inlet or outlet filter on the tool.
- Broken tool.

If the tool is merely sluggish, blow it out with solvent to clean it and relubricate it with a light oil, SAE 5 or 10.

The chart below gives a rough guide to the suitable tool, based on our field experience.

Bolt Size	Chicago A325M A490M	Pneumatic	Ingersoll Rand	Norbar	CLECO
M16	—	610/6041	2934/2906	PT500	WS2110
M20	M16	610/6500	2934/2920	PT1000	WS2110
M22	M20	611/6060	2940/2920	PT1000	WS2110
M24	M22	6120/6110	2950/2934	PT1500	WS2120
M27	M24	6120/6110	2950/2940	PT2000	WS2120
M30	M27	6210*/614	5980/2940	PT6/PT2000	—
—	M30	614*	5980/2940	PT7/PT4500	—
M36	M36	614*	5980/2940	PT7/PT4500	—

*Only if the bolt and nut are well lubricated.

When tensioning large A490M bolts, hydraulic torque wrenches should be considered as an alternative to air driven impact wrenches.

CHECKING FOR CONFORMANCE TO SPECIFICATIONS

Identification and Certification

Inspectors should check that all fastener components conform to applicable ASTM standards before use. Manufacturers' marks should be clearly identifiable on all fasteners. Where required, test certificates should accompany product to the job site. Bolt certificates should state tensile strength and hardness. Nut certificates should state hardness and proof-load. Hardened washer certificates should identify that they are in a hardness range of 38 to 45 Rockwell C. DTIs should be marked to identify the lot number, manufacturer and Type (8.8 or 10.9).

TurnaSure LLC DTIs are carefully tested throughout the manufacturing process utilizing statistical process control procedures. The finished product is tested by an independent accredited laboratory in A Digital Compression Load Analyzer with a dial gage.

Certification of testing, according to ASTM F959M requires 29 pieces per lot, without failure, in the as-shipped condition, coated or uncoated, be tested, following ASTM F1470 Guide for Fastener Sampling.

Laboratory duplication of the ASTM product performance test by the user should not be required. There should be no attempt to reproduce the product performance test in the field. Instead, the following test of the DTI and bolt/nut/washer assembly in a bolt tension calibrator is suggested. This will assist the user in qualifying all of the components, and verifying their compatibility.

Field Verification Test for Bolt Assembly Performance

Assemble the bolt, nut, washer and DTI in a bolt tension calibrator as shown in Figure 5.

Verify that the tension calibrator has been certified and calibrated within the last year. The certification document provides a traceable comparison of the calibrator's readings with those established by the U.S. National Institute of Standards and Technology or the standards agency having jurisdiction in the construction location. Apply any noted variations to the load readings during testing on the calibrator.

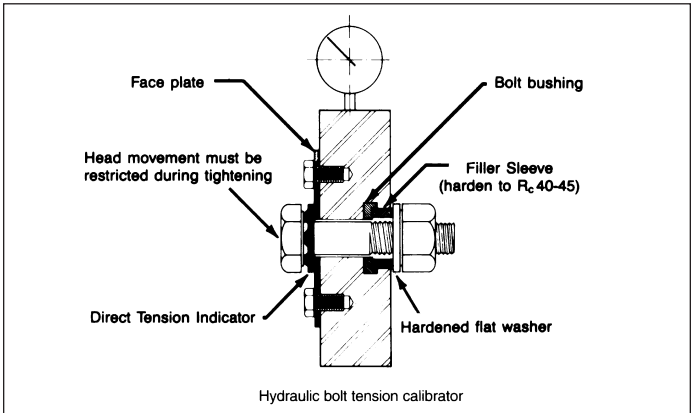


Figure 5

Tension the bolt to the minimum required bolt tension and check that the applicable feeler gage enters as least the proper number of spaces (tension and spaces given in Table II). A 0.400mm feeler gage is used when an uncoated DTI is installed under the bolt head and the nut is turned, Method #1. A 0.125mm feeler gage is used with Methods #2 and #3 and with coated DTIs in any arrangement. The load should be increased on the calibrator as smoothly as possible so as to avoid “fallback” where the load cell “bleeds off” and the calibrator starts to show a lower load than the actual bolt load. At this point the assembly has demonstrated the ability to reach the desired tension prior to compression of the number of bumps which are required to be compressed in the work.

Next tension the bolt until the point where the feeler gage refuses to enter the number spaces in Table II. The tension in the bolt as measured by the calibrator must be less than the minimum tensile strength of the bolt. At this point the assembly has demonstrated the ability to compress the bumps to the gap required in the work without exceeding the minimum tensile strength of the bolt.

If an impact wrench is used to tension the bolts in the calibrator, the wrench should not be used to exceed 2/3 of the required tension. A manual wrench should be used to bring the load up to the value specified.

Table II

TYPE 325M

Nominal Bolt Diameter (in.)	Minimum Bolt Tension (kN)	Minimum Bolt Tensile Strength (kN)	DTI Spaces	Feeler-Gage Entries	Feeler-Gage Refusals
M16	91	130	4	2	3
M20	142	203	5	3	3
M22	176	251	5	3	3
M24	205	293	6	3	4
M27	267	381	6	3	4
M30	326	466	7	4	4
M36	475	678	8	4	5

TYPE 490M

Nominal Bolt Diameter (in.)	Minimum Bolt Tension (kN)	Minimum Bolt Tensile Strength (kN)	DTI Spaces	Feeler-Gage Entries	Feeler-Gage Refusals
M16	114	163	4	2	3
M20	179	255	5	3	3
M22	221	315	6	3	4
M24	257	367	7	4	4
M27	334	477	7	4	4
M30	408	583	8	4	5
M36	595	850	9	5	5

For bridge applications see **INSTALLATION INSTRUCTIONS FOR BRIDGE APPLICATIONS PER AASHTO**, found on the inside back cover.

DTI IDENTIFICATION MARKINGS

TRADEMARK

The trademark of TurnaSure LLC is shown on the cover of this booklet. DTIs marked with it have been manufactured by TurnaSure LLC.

GRADE AND SIZE

Each DTI is marked with a series of numbers. “8.8” signifies the DTI is for use with A325M bolts, “10.9 for A490M bolts. DTIs for use with Type 3 weathering steel A325M bolts are marked “8.8-3”. Such DTIs are the newer versions that are produced from a weathering steel and thus do not require epoxy coating to protect them from excessive corrosion.

LOT NUMBER

For purposes of absolute traceability ASTM requires each DTI be marked with a lot number. The lot number will take the form of a letter followed by either one or more numbers.

Figure 11 illustrates the new and improved 8.8 DTI design.

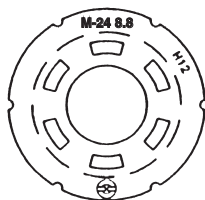


Figure 11

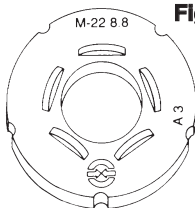


Figure 12

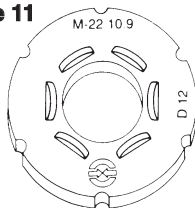


Figure 13

Older designs look like Figures 12 & 13

INSTALLATION INSTRUCTIONS FOR BRIDGE APPLICATIONS PER AASHTO

The AASHTO Standard Specification for Highway Bridges, 16th Edition, Division II - Construction, Article 11.5.6.4.7 Direct Tension Indicator Installation Method has been revised to reflect the recommendations in Appendix A6—Procedure for Verification and Installation of High-Strength Bolts with Direct Tension Indicators (DTIs) (Part of Report No. FHWA-SA-91-031 May 1991, revised April 1992) which presents detailed instructions for the verification procedure and installation of DTIs in federally funded bridges.

The major difference between the instructions given in the AASHTO Specifications and those presented in this manual is the requirement that the gap closure requirement is 0.125mm for installation of plain finish DTIs under the bolt head, not 0.400mm. The 0.400mm gap was selected as convenient for building installation where plain DTIs are usually installed within the enclosed structure. But since bridge steel is exposed and tests have shown that paint systems usually used on bridges will “bridge” a gap of 0.125mm successfully, but may not “bridge” a gap of 0.400mm, and since many states specify galvanized fasteners, AASHTO has set a gap of 0.125mm for “plain” and “coated” DTIs.

Note, Article 11.5.6.4.7 has two parts, *7a Verification*, and *7b Installation* and an accompanying Commentary. Verification assures that before the DTI is compressed to an average gap of 0.125mm the tension in the bolt will be at least 1.05 times the minimum required bolt tension. It also assures that when the DTI is all but completely compressed, the bolt will not have excessive permanent inelastic deformation.

Copies of Article 11.5.6.4.7 are available from TurnaSure LLC.



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