Michigan Department of Transportation

# Field Manual for Structural Bolting

MDOT Michigan Department of Transportation

BUREAU of BRIDGES and STRUCTURES
SPANNING CONNECTING SAFELY EFFICIENTLY

2nd Edition – January 2024

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# Glossary

**coated faying surface** – A faying surface that has been primed, primed and painted, or protected against corrosion, except by hot-dip galvanizing (HDG).

**connection** – An assembly of one or more joints that is used to transmit forces between two or more members.

**direct tension indicators** – Special washers with raised protrusions on one face that compress when the bolt is tightened. They are used for verifying proper tensioning without relying on turn-of-nut (TON) markings.

**faying surface** – The plane of contact between two plies of a joint.

**firm contact** – The condition that exists on a faying surface when the plies are solidly seated against each other, but not necessarily in continuous contact.

**galvanized faying surface** – A faying surface that has been hot-dip galvanized (HDG).

**grip** – The total thickness of the plies of a joint through which the bolt passes, exclusive of washers or direct-tension indicators.

**high-strength bolt** – An ASTM F3125 Grades A325 or A490, A449, ASTM F1852, or F2280 or an alternative-design fastener approved by the engineer of record.

**joint** – The area of a connection in which one group of bolting assemblies joins two or more members or connection elements.

**pre-installation bolt tension verification (PIV)** – Prior to fastener installation, a representative sample of bolt assemblies must be checked in a tension measurement device. These tests should demonstrate that controlling the required turns from a snug-tight condition develops a tension no less than the minimum pre-installation bolt tension verification values shown in Table 707-5 of the MDOT SSC.

**pre-tensioned joint** – A joint that transmits shear and/or tensile loads in which the bolts have been installed to provide a minimum specified pretension in the installed bolt.

**rotational-capacity test** – Rotational-capacity tests are intended to document the relationship between torque and pretension and ensure that the high strength bolts can develop the necessary pretension without undergoing failure. They are performed by the bolt manufacturer and MDOT Metals Laboratory prior to incorporation and are carried out in accordance with ASTM F3125. These tests are conducted in a bolt tension measurement device to evaluate the effectiveness of a lubricant, the efficiency of the lubricant, and compatibility of rotational capacity lot (bolt, washer, and nut).

**shear/bearing joint** – A snug-tightened joint or pre-tensioned joint with bolts that transmit shear loads and for which the design criteria are based upon the shear strength of the bolts and the bearing strength of the connected materials.

**slip-critical joint** – A joint that transmits shear loads or shear loads in combination with tensile loads in which the bolts have been installed to provide a pretension in the installed bolt (clamping force on the faying surfaces), and with faying surfaces that have been prepared to provide a calculable resistance against slip.

**snug-tight (high strength bolts)** – Unless otherwise defined, the tightness that is attainted with a few impacts of an impact wrench or the full effort of a person using an ordinary spud wrench to bring the connected plies into firm contact. More than once cycle through the bolt pattern is required to achieve the snug-tight joint. A bolt in snug-tight condition will be sufficiently pretensioned to meet the minimum pre-installation bolt tension verification after turn-of-nut (TON) is performed.

**standoff distance** – Standoff distance of anchor bolts in structural supports for highway signs, luminaires, and traffic signals refers to the clearance between the bottom of the leveling nuts and the top of the concrete foundation. The maximum allowable standoff distance is one inch.

**tension measurement device** – A calibrated tension-indicating device (e.g., Skidmore-Wilhelm, Calibore) that is used to perform the PIV and rotational-capacity test to verify the acceptability of the pre-tensioning method when a pre-tensioned or slip-critical joint is specified. The device should be calibrated annually by a certified laboratory.

**turn-of-nut (TON)** – A technique for ensuring that the minimum pre-tensioning has been achieved. TON pre-tensioning involves holding one end of the bolt assembly (head or nut) and rotating the other end to achieve a specified rotation, which varies by bolt diameter and length.

**uncoated faying surface** – A faying surface that has neither been primed, painted, nor HDG and is free of loose scale, dirt, and other foreign material.

# Equivalent ASTM and AASHTO Standard Specifications

The following are some common American Society for Testing Materials (ASTM) standard specifications and their American Association of State Highway and Transportation Officials (AASHTO) equivalents.

| ASTM | Title | AASHTO Equivalent |
|---|---|---|
| A123 | Standard Specification for Zinc (Hot-Dip Galvanized) Coatings on Iron and Steel Products | M111 |
| A153 | Standard Specification for Zinc Coating (Hot-Dip Galvanized) on Iron and Steel Hardware | M232 |
| A194 | Standard Specification for Carbon and Alloy Steel Nuts for Bolts for High Pressure or High Temperature Service, or Both | M292 |
| A449 | Standard Specification for Hex Cap Screws, Bolts and Studs, Steel, Heat Treated, 120/105/90 ksi Minimum Tensile Strength, General Use | NA |
| F3125 Grade A325 | Standard Specification for Structural Bolts, Steel, Heat Treated, 120 ksi Minimum Tensile Strength | M164 (discontinued) |
| F3125 Grade A490 | Standard Specification for Structural Bolts, Alloy Steel, Heat Treated, 150 ksi Minimum Tensile Strength | M253 (discontinued) |
| A563 | Standard Specification for Carbon and Alloy Steel Nuts | M291 (discontinued) |
| F436 | Standard Specification for Hardened Steel Washers | M293 (discontinued) |
| F1554 | Standard Specification for Anchor Bolts, Steel, 36, 55, and 105-ksi Yield Strength | M314 |
| F2329 | Standard Specification for Zinc Coating, Hot-Dip, Requirements for Application to Carbon and Alloy Steel Bolts, Screws, Washers, Nuts, and Special Threaded Fasteners | NA |

# Acknowledgement

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Content was taken from several sources, including:

- CAASHTO LRFD Bridge Design Specifications, 9th Edition, 2020 (AASHTO Design).
- AASHTO LRFD Bridge Construction Specifications, 4th Edition, 2017 (AASHTO Construction).
- AASHTO LRFD Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals, 2015 (AASHTO Signs).
- Research Council on Structural Connections Specification for Structural Joints Using High-Strength Bolts, 2020 (RCSC).
- MDOT Bridge Design Manual, current (MDOT BDM).
- MDOT Standard Specifications for Construction, 2020 (MDOT SSC).
- Additional content was adapted from the Transportation Curriculum Coordination Council (TCCC) Bolted Connections course offered by the National Highway Institute (Course Number FHWA-NHI-134074) and American Institute of Steel Construction's (AISC) Bolting and Welding Course (https://www.aisc.org/WorkArea/showcontent.aspx?id=37216).

# Introduction and Purpose

The purpose of this Field Manual for Structural Bolting is to summarize basic definitions, concepts, and procedures for bolted connections used to connect structural members. It addresses general considerations for bolting, installation preparation, installation techniques, and inspection procedures. The intent is to assist engineers, inspectors, and construction workers in designing, installing, and inspecting bolted connections to meet current specifications.

The primary function of bolted connections is to join or anchor structural members and safely transmit loads from one member to the other or to a foundation. As such, bolted connections are critical components of any structure. For many types of structural systems, failure of a bolted connection could lead to collapse or extensive system-wide damage. Therefore, current design specifications and construction procedures impose rigorous design, installation, and inspection practices to ensure that such connections can perform their function safely.

Structural connections may be subjected to multiple types of forces, including flexure, shear, axial, torsional, or a combination of these forces. Bolts can transmit shear, axial or combined shear/axial loads. Therefore, bolted connections, regardless of how they are loaded, are configured and designed such that bolts are loaded to resist shear and axial loads.

## Governing Specifications

The design of highway bridges in Michigan is based on AASHTO Design. The construction and fabrication of highway bridges is based on the published MDOT SSC. The design of ancillary structures is governed by AASHTO Signs that references AASHTO Design as applicable. In some cases, the AASHTO specifications are vague or leave a decision to the judgment of the engineer. Guidelines in the MDOT BDM are provided as clarification and thus supplement the

AASHTO provisions. Some minimum requirements in the AASHTO specifications have been found through experience to be insufficient. In these instances, the MDOT BDM supersedes AASHTO with more rigorous controls.

The RCSC prepares specifications and documents related to structural connections. RCSC is a widely used specification that discusses joints, fasteners, limit states, installation, and inspections. AASHTO adopts (with modifications) some of the RCSC recommendations.

The MDOT SSC is the standard for basic requirements governing materials, equipment, and methods used in construction contracts administered by MDOT. MDOT BDM will primarily reference AASHTO specifications. MDOT SSC is for construction and does not reference the MDOT BDM. Any references within MDOT SSC usually pertain to ASTM or AASHTO material specs, AASHTO Construction, RCSC, and other subsections within itself. Figure 1 shows the various standards mentioned.


Figure 1: Standards used for preparation of this Field Manual for Structural Bolting.

# Part I - High-Strength Bolt (HSB) Connections

## General Considerations for HSB Connections

### Bolt Assembly

Figure 2 shows the main parts of the HSB assembly. Grip is the distance from behind the bolt head to the back of the nut or washer. It is the sum of the thicknesses of all the parts being joined exclusive of washers. Thread length is the threaded portion of the bolt. Bolt length is the distance from behind the bolt head to the end of the bolt.

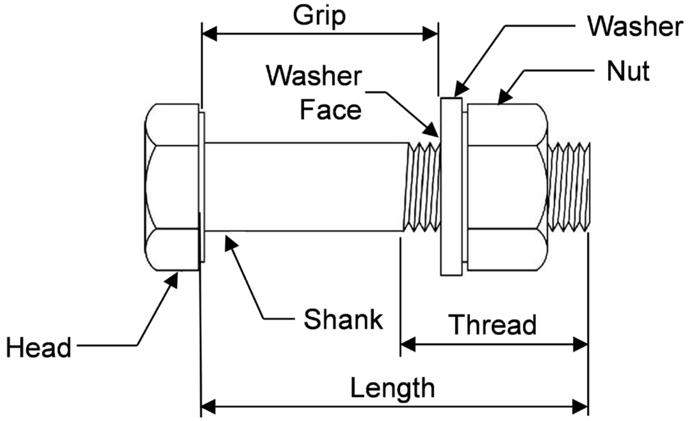



Figure 2: HSB assembly components.

## Types of HSB Joints

There are two basic load transfer mechanisms in bolted joints: bearing and slip critical. Note that MDOT does not permit bolted connections with threads included unless explicitly called out in the contract plans.

**Bearing Joints:** Load is transferred between components by bearing on the bolts. This can be seen in Figure 3, where the two bolted plates bear against the shank (and threads) of the bolt, which then transmits load between them.

**Slip-Critical Joints:** Load is transferred between components by friction between the bolted components (Figure 4). The bolts are fully pre-tensioned to cause a clamping force between the connected components, which allows frictional resistance to develop between them. The frictional resistance prevents the connected components from slipping into bearing against the body of the bolt. However, the bolts must still be designed for bearing for strength loads since slip-critical joints are only designed for service conditions. To ensure successful performance, the faying surfaces in slip-critical joints require special preparation. The vast majority of MDOT's bolted bridge connections are designed to be slip-critical. Because of this, the installation processes for all HSB connections are treated as slip-critical joints by the MDOT SSC.

Note that MDOT does not permit bolted connections with threads included unless explicitly called out in the contract plans.

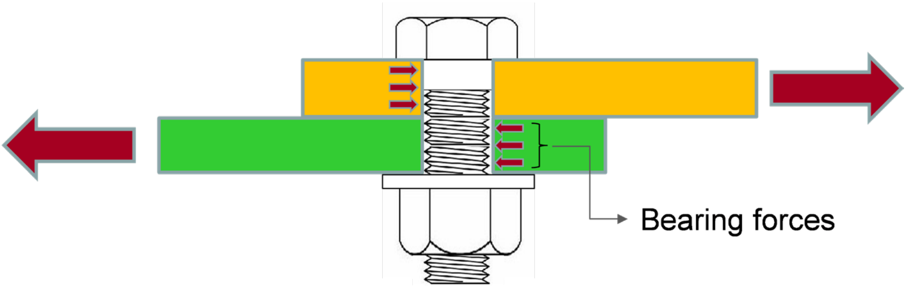



Figure 3: Load transmission in a bearing-type connection.

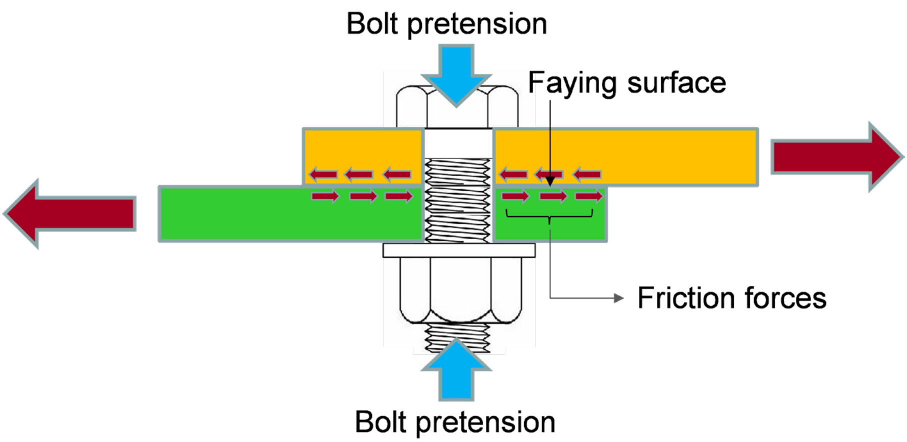



Figure 4: Load transmission in a slip critical-type connection (bolt pretension prevents slip into bearing for service loads).

## Bolts

There are two grades of ASTM F3125 bolts defined as follows.

**Grade A325:** These bolts have a minimum tensile strength of 120 ksi. They are made of heat treated, medium carbon steel and are the most common bolts used by MDOT.

**Grade A490:** These bolts are made of high-strength, heat treated steel with a minimum tensile strength of 150 ksi. A490 bolts cannot be HDG due to hydrogen embrittlement; therefore, they are not used for bridges or highway structures and are not permitted by MDOT.

ASTM grade designation is indicated on the head of the bolts as shown in Figure 5. Bolts must be HDG in accordance with AASHTO M232 or ASTM F2329.

ASTM F3125 Grade A325 bolts are available in diameters ranging from 1/2 inch to 1-1/2 inches. However, all structural bolts must be at least 0.625 inches in diameter per AASHTO. The most common sizes are 3/4 inch, 7/8 inch, and 1 inch. HSBs are commonly available in incremental lengths up to 8 inches.


Figure 5: ASTM grade designation on bolt heads.

## Washers

Hardened flat circular washers (Figure 6) are used to spread pressure from the bolt tightening process over a larger area. They may also be used to cover an oversized or short-slotted hole. ASTM F436 flat washers are most commonly used. Beveled washers (Figure 7) are used when the surface being bolted has a sloped surface, such as the flange of a channel, S shape, or out-of-plumb anchor bolt.

Figure 6: Flat circular washers.

Figure 7: Beveled washers.

For pre-tensioned joints, ASTM F3125 Grade A325 bolts require a washer under the element (head or nut) being turned to tighten the bolt. For pre-tensioned joints with specified base metal yield strength less than 40ksi, ASTM F3125 Grade A490 and F2280 bolts require a washer under both the head and nut to prevent base metal yielding.

Hardened flat washers for structural joints must meet the requirements of AASHTO M 293 Type 1 for circular, beveled, clipped circular, and clipped beveled washers. Washers must be HDG in accordance with AASHTO M232 or ASTM F2329.

Hardened flat washers must be installed over oversize and short-slotted holes in an outer ply. Plate washers are required to completely cover long-slotted holes (see Figure 8). Because plate washers are not hardened, a hardened flat washer is placed over the plate washer.

Washer use is encouraged by MDOT even if not required by specifications.

## Nuts

High-strength nuts for structural joints must meet the requirements of ASTM A563 Grade DH or ASTM A194 Grade 2H.

Nuts must be HDG in accordance with AASHTO M232 or ASTM F2329. HDG nuts must be tapped oversize in accordance with ASTM A563 and must be coated with a lubricant containing a dry visible dye.

## Bolt Holes

There are four types of holes shown in Figure 8: standard (STD), oversize (OVS), short slot (SSL), and long slot (LSL). Unless otherwise specified in the contract or approved by the engineer, only standard holes are permitted to be used in bridge construction.

Allowed tolerances for hole diameter are 1/32 inch. Burrs that prevent solid seating of connected parts in the snug-tight condition must be removed by reaming or light grinding. Note that recoating is required after reaming or grinding. Connections with holes exceeding the specified tolerances must be replaced unless approved by the engineer.

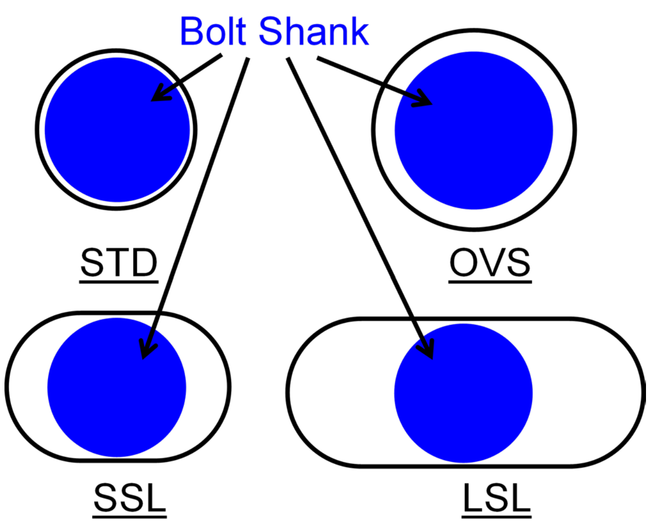



Figure 8: Bolt hole types.

## Faying Surface for Slip-Critical Connections

Faying surfaces are surfaces placed in contact during bolting operations (see Figure 4) and include the surfaces beneath the bolt head, nut, and washer. All joint surfaces (including surfaces adjacent to the bolt head and nut) must be non-compressible material, free of loose mill scale (tight mill scale is acceptable), and free of dirt and foreign material. Joint surfaces should be inspected prior to lifting the steel component into its final location. As shown in Figure 9, there are two classes of faying surfaces depending on preparation.

| Class A | Class B |
|---|---|
| Least amount of friction resistance<br>Unpainted clean mill scale<br>Blast cleaned surface with Class A coating<br>HDG surface<br>Slip coefficient = 0.30<br>**Not permitted by MDOT** | Highest amount of friction resistance<br>Unpainted blast cleaned surfaces<br>Blast cleaned surface with Class B coating<br>Slip coefficient = 0.50<br>**Required by MDOT** |

Figure 9: Classes of faying surfaces and their characteristics.

# Installation Considerations and Techniques

## Snug-Tight Joints

See subsection 707.03.E.6.c of the MDOT SSC on snug-tightening requirements for high-strength bolts.

Figure 10: Spud wrenches.

## Turn-of-Nut (TON) Pre-tensioning

Installation beyond snug-tight is called pre-tensioning as described in subsection 707.03.E.6.d of the MDOT SSC for TON pre-tensioning requirements for high-strength bolts.

## Calibrated Wrench Method

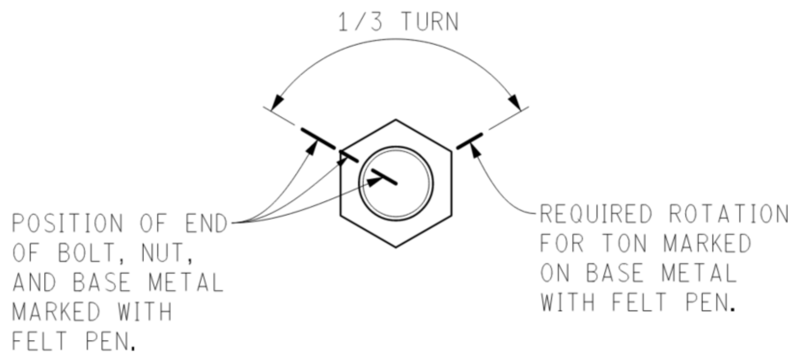
This technique is not permitted by MDOT.

## Direct Tension Indicators

Direct tension indicators (DTIs) are special washers with raised protrusions on one face that compress when the bolt is tightened. They are a method for verifying proper tensioning without relying on TON markings and are identified by material specification and manufacturer.

This technique is not permitted by MDOT.

1. AFTER SNUG-TIGHT




2. AFTER TURN-OF-NUT (TON)

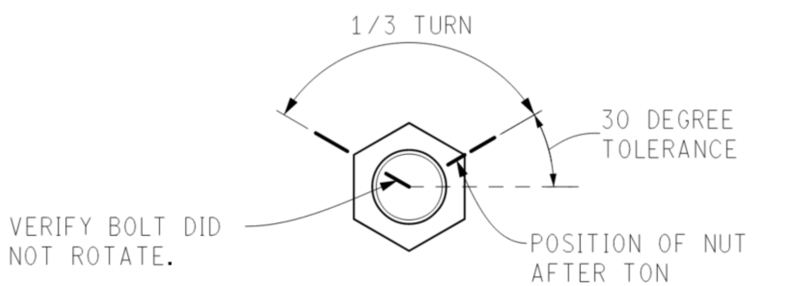



Figure 11: Example TON pre-tensioning match marking procedures.

# Installation Procedures

## Shipping of Fasteners

Bolts, loose nuts, and washers of each length, diameter, or size should be packed separately. Storage and shipping should be done in moisture-proof boxes, crates, kegs, or barrels. The gross weight of each package is limited to 300 pounds. Contents should be labeled on the outside of the shipping container. The contractor must supply 5 percent more HSBs of each size and length than required for the job.

Nuts of HDG fasteners must be lubricated with a clean and dry material to the touch (wax) that contains a visible dye.

## Storage of Fasteners

Fastener components must be protected from dirt and moisture in closed containers (Figure 12). Only the number of fasteners required to be installed and tightened during a working shift should be removed from storage. Unused fasteners should be returned to protected storage at the end of a shift. Lubricant should not be removed. Visible corrosion is a cause for rejection.

Figure 12: Storage of fasteners.

## Fastener Paperwork

Documents with each bolt shipment become part of the construction record. These include:

- Packing list with each shipment of bolts
- Other documents and test reports [mill test report (MTR)
- Manufacturer certified test report (MCTR)
- Distributor certified test report (DCTR)]

Paperwork for any lot of bolts, nuts, and washers should be maintained. Container information should be checked to ensure it matches the provided paperwork (see Figure 13). The packing list should contain the following information:

- Verification of Buy America provisions
- Detailed list of all fastener assemblies
- Manufacturer and supplier name
- Bolt, nut, and washer lot number
- Quantity
- Coating data
- Shipment item
- Bolt size and grade

**Important:** Mixing bolts and nuts from different production lots is not permitted.

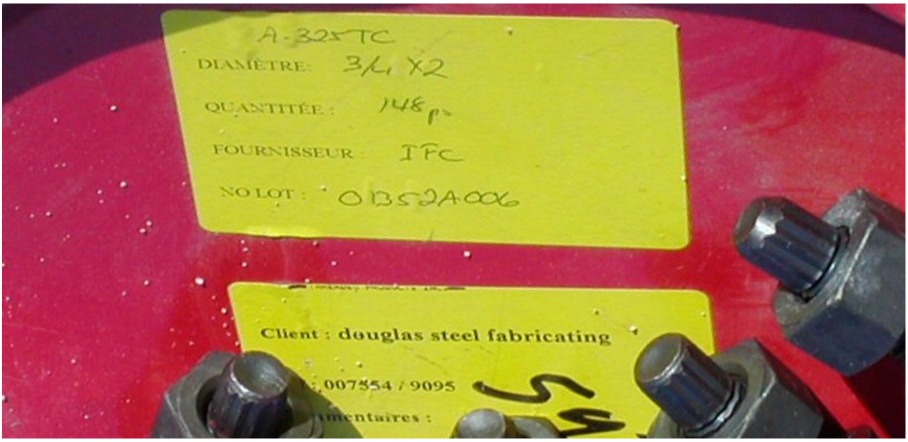



Figure 13: Type of information found on container.

## MDOT Specific Certification Documentation

General certification documents must include all the following:

- List of all applicable specifications (ASTM, AASHTO, MDOT, etc.) that the material is certified to meet.
- Any specification modifiers (class, grade, type, style, etc.).
- Signed statement by representative of the manufacturer or supplier that material meets all MDOT listed specification requirements.
- Manufacturer's name on certification if certified by supplier.
- Contract number (control section – job number).
- Date of shipment.
- Name of contractor.
- Name of material (MDOT designation Spec No. – High-Strength Bolts 906.07).
- Identification markings on shipment.
- Quantity of material represented by the certification.

Test data certification documents must include:

- Laboratory test reports for samples obtained from the lot(s) of material represented by the certification and tested according to applicable specifications (ASTM, AASHTO, MDOT, etc.).
- General certification documents listed above.

## Tagging and Marking Material

Methods for informing the status of sampling and/or testing of bolts in storage are specified in subsection 1.07.02 of the MDOT Materials Quality Assurance Procedures Manual. Bolt samples are often tagged using a numbered plastic sample tag and the containers of sampled bolts are often tagged using adhesive or wire sampled tags.

## Pre-Test Documentation

MDOT Materials Source List (Form 0501)

- Required project documentation.
- Not a substitute for other required quality control and quality assurance documentation.
- Responsibility of the prime contractor to submit at or prior to the preconstruction meeting.

## MDOT Material Acceptance Requirements

Testing is required as follows: one per diameter per length per lot per project. The sample size is three bolts, nuts, and washers. See the Materials Acceptance Requirements table in the MQAP manual for more information.

Bolt, nut, and washer test data certification must identify the manufacturer and must be attached to the MDOT Sample Identification (Form 1923).

## Pre-Bolting Inspection

Pre-bolting inspection ensures minimum requirements for quality control and quality assurance.

Observation is the primary method used to confirm that the materials, procedures, and workmanship are in conformance with the construction documents and specifications. Table 3 shows typical tasks considered.

| Inspection Tasks Prior to Bolting<br>Table N5.6-1 | | |
|---|---|---|
| Inspection Tasks Prior to Bolting | QC | QA |
| Manufacturer's certifications available for fastener materials | O | P |
| Fasteners marked in accordance with ASTM requirements | O | O |
| Proper fasteners selected for the joint detail (grade, type, bolt length if threads are to be excluded from shear plane) | O | O |
| Proper bolting procedure selected for joint detail | O | O |
| Connecting elements, including the appropriate faying surface condition and hole preparation, if specified, meet applicable requirements | O | O |
| Pre-installation verification testing by installation personnel observed and documented for fastener assemblies and methods used | P | O |
| Proper storage provided for bolts, nuts, washers and other fastener components | O | O |

Note: O – Observe these items on a random basis
P – Perform these tasks for each bolted connection

Table 1: Inspection tasks prior to bolting.

## Rotational-Capacity Test

Rotational-capacity tests are intended to document the relationship between torque and pretension and ensure that the bolts can develop the necessary pretension without undergoing failure. They are performed by the bolt manufacturer and the MDOT Metals Laboratory prior to incorporation and are carried out in accordance with ASTM F3125.

Washers are required even though they may not be required for installation (coating must be the same as on the bolt and nut). A minimum of two assemblies must be tested per rotational-capacity lot. A bolt tension measurement device is usually used in this type of test. The Skidmore-Wilhelm bolt tension measurement device (Figure 14), the Skidmore, as it is commonly known, is the standard for developing torque-tension relationships and should be on any jobsite. It should be calibrated annually by a certified laboratory.

## Rotational-Capacity Test Procedure

A rotational-capacity test is conducted as follows:

- Select two bolt, nut, and washer assemblies for each rotational-capacity lot.
- Install bolt, nut, and washer with additional face plates and shims to achieve 3 - 5 threads in grip or 0 - 3 thread stick out (Figure 15).
- First, tighten the nut to 10 percent of the minimum required tension.
- After initial tightening, the nut position shall be marked relative to the bolt, and the rotation shown in Figure 16 shall be applied. The nut can be tightened with a hand, pneumatic, or electric wrench. During rotation, the bolt head shall be restrained from turning.
- Rotation values will be 2 times the values used during TON pre-tensioning (Figure 16). Minimum tension in the bolt at the specified rotation shall be equal to or greater than 1.15 times the minimum required installation tension.
- Record one reading of tension and torque after exceeding the minimum required installation tension. Torque shall not exceed:

$$T \leq 0.25\, PD$$

T: Max Allowable Torque (ft.-lbs)

D: Bolt Diameter (ft.)

P: Measured Bolt Tension (lbs.)

- Continue rotating the nut to the final rotation and record the tension, which must be equal to or greater than 1.15 times the minimum required installation tension.
- Remove and examine the bolt and nut (Figures 17 and 18) for:
  - Thread stripping
  - Shearing of threads
  - Torsional failure
- Check to see if the nut still turns freely onto the bolt up to the location of the nut at the start of the test.
- Elongation of the bolt in the threads is not classified as failure.

Figure 14: Skidmore-Wilhelm bolt tension measurement device with plates for various bolt sizes.

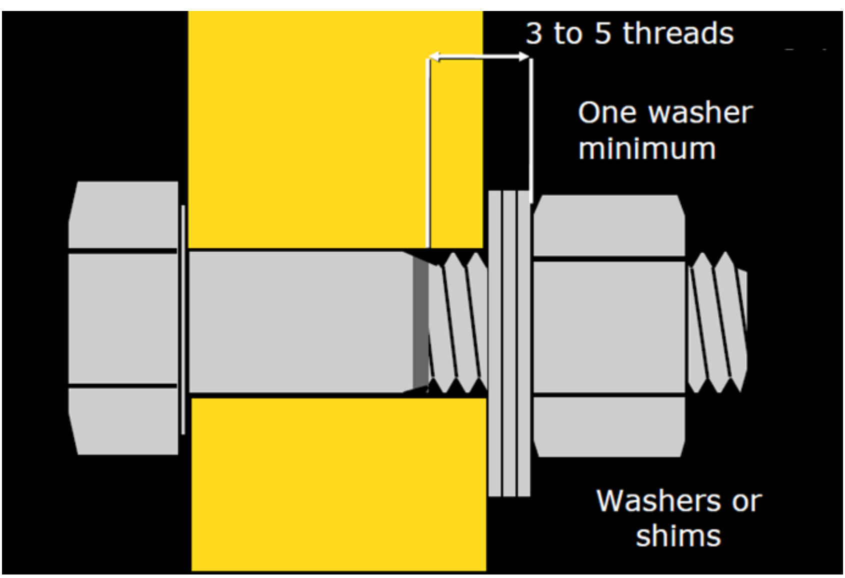
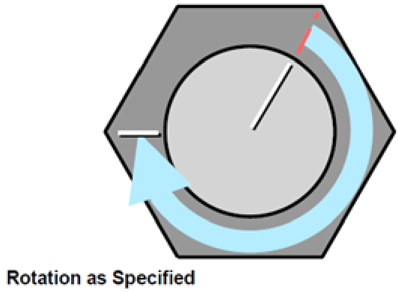



Figure 15: Bolt configuration for rotational capacity test.




| Bolt Length | Rotation |
|---|---|
| L ≤ 4D | 2/3 turn (240°) |
| 4D < L ≤ 8D | 1 turn (360°) |
| 8D < L ≤ 12D | 1-1/3 turn (480°) |
| hold bolt head from turning | |

Figure 16: Rotation for rotational capacity test
(D = bolt diameter, L = bolt length).

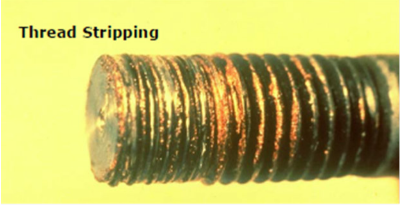




Figure 17: Failure modes to look for after rotational capacity test.

(a) Torsional Failure

(b) Tension Failure

Figure 18: Bolt failure in torsion versus tension.

## Pre-Installation Bolt Tension Verification

Pre-installation bolt tension verification (PIV) is required for high-strength bolt assemblies to verify the TON pre-tensioning method results in the required minimum bolt tension. The contractor is required to perform this test using their bolt tension measurement device.

PIV testing is essential for:

- Evaluating the suitability of the bolting assembly, including the lubrication that is applied by the bolt manufacturer, to develop the specified minimum pretension;
- Verifying the adequacy and proper use of the TON pretensioning method; and
- Demonstrating the suitability of the bolt tightening equipment to be used during installation.

PIV testing provides a practical means for ensuring that nonconforming bolting assemblies are not incorporated into the work. Experience on many projects has shown that bolts, nuts, and/or bolting assemblies not meeting the requirements of the applicable ASTM/AASHTO standards would have been identified prior to installation if they had been tested as an assembly in a bolt tension measurement device. The expense of replacing bolts installed in the structure when nonconforming bolts were discovered at a later date could have been avoided.

In addition, PIV testing clarifies for the bolting crew and the on-site inspector the proper implementation of the TON pretensioning method and the adequacy of the installation equipment. It will also identify potential sources of problems, such as lack of lubrication, under-strength assemblies resulting from excessive overtapping of hot-dip galvanized nuts, incorrect nut grade, etc.

## Required Testing

PIV testing must be performed in compliance with all of the following steps:

1) Performed at the site of installation;

2) Prior to the placement of bolting assemblies in the work;

3) On a sample not fewer than three complete bolting assemblies of each combination of diameter, length, grade, and lot to be used in the work;

4) Using bolting assemblies that are representative of the condition of those that will be pretensioned in the work;

5) Using hardened flat washers meeting ASTM F436 positioned in accordance with the contract; and

6) PIV testing in accordance with the following test procedure.

## Test Procedure

The bolting assembly must be tested in a bolt tension measurement device to verify that the TON pretensioning method develops a pretension that is equal to or greater than that specified in Table 707-5 of the MDOT SSC. The accuracy of the bolt tension measurement device must be confirmed through calibration at least annually.

Impact wrenches, if used, must be of adequate capacity and, if pneumatic, supplied with sufficient air to perform the required pretensioning of each bolt within approximately 10 seconds for bolts up to and including 1 1/4-inch diameter, and within approximately 15 seconds for larger bolts.

### *Step 1: Snug-Tightening*

The bolting assembly must be installed to the snug-tight condition in the bolt tension measurement device using the tools, bolting components, assembly configuration, and installation methods to be used in the work.

### *Step 2: Matchmarking*

The bolting assembly must be matchmarked.

### *Step 3: Pretensioning*

The rotation specified in Table 707-6 of the MDOT SSC must be applied to the bolting assembly.

### *Step 4: Final Verification*

If the actual pretension developed in the bolting assembly is less than that specified in Table 707-5, the cause(s) must be determined and resolved before the bolting assemblies are incorporated into the work.

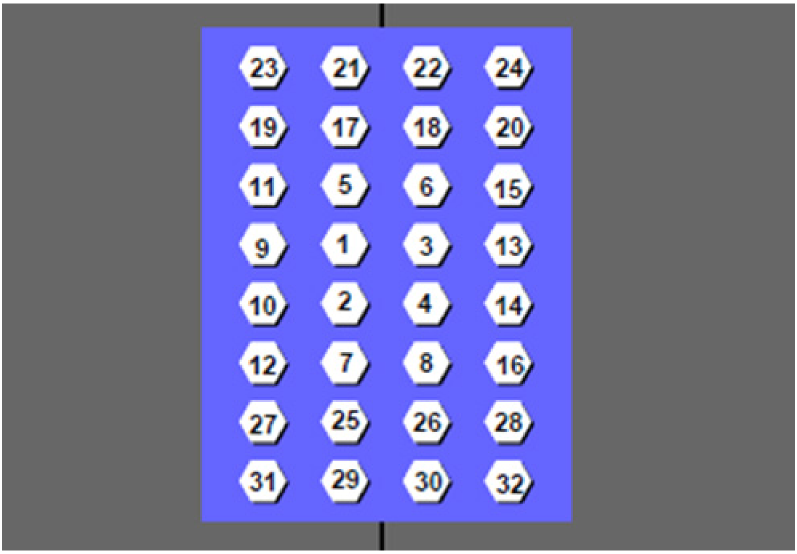



Figure 19: Typical installation pattern for high strength bolts.

## Inspection Tasks During and After Bolting

Snug-tightened joints require visual inspection for firm contact and proper use of washers. Pre-tensioned joints require pre-installation bolt tension verification and routine observation by the inspector to verify the contractor has not changed their tightening process (equipment, effort, installation pattern, snug-tight, or TON process). Slip-critical joints require inspection of the faying surfaces in addition to the above inspections. There are several HSB tightening inspections that can be performed:

- Look at the bolt stick-out (Figure 20).
    - √ Stick-out is the amount the bolt extends beyond the outside surface of the nut
    - √ Positive or zero stick-out is acceptable
    - √ Negative stick-out, where the end of the bolt is inside the nut, is not acceptable
    - √ Stick-out on bottom flange field splices must be on top of the bottom flange (bolt head on bottom side of bottom flange)
- Inspect the TON match marks to ensure the bolts have been pre-tensioned (Figure 21).
- Note that corrosion is cause for rejection.


Figure 20: Acceptable bolt stick-out.

Figure 21: Inspect the TON match marks to ensure the bolts have been properly pre-tensioned.

# Part 2 – Anchor Bolt (AB) Connections for Highway Structures

## Types of AB Connections

AB connections are designed to transmit tension, bearing, and shear forces associated with highway structures into a concrete support or foundation. These types of connections use cast-in-place anchor bolts in new construction. Although the anchor bolts may be headed, hooked, or deformed reinforcing bars, headed are generally preferred. There are two types of AB connections: single-nut and double-nut connections.

Figure 22 shows a single nut AB connection. These types of joints are also known as threaded-shear-uplift joints. In such connections, the base plate rests directly on a concrete or grout pad. The anchor bolts transmit shear and tension, while the concrete carries all compression forces. Therefore, the grout support must achieve full strength prior to pre-tensioning. The connection does not require leveling nuts or shim plates. This type of connection has some structural disadvantages and is not permitted by MDOT.

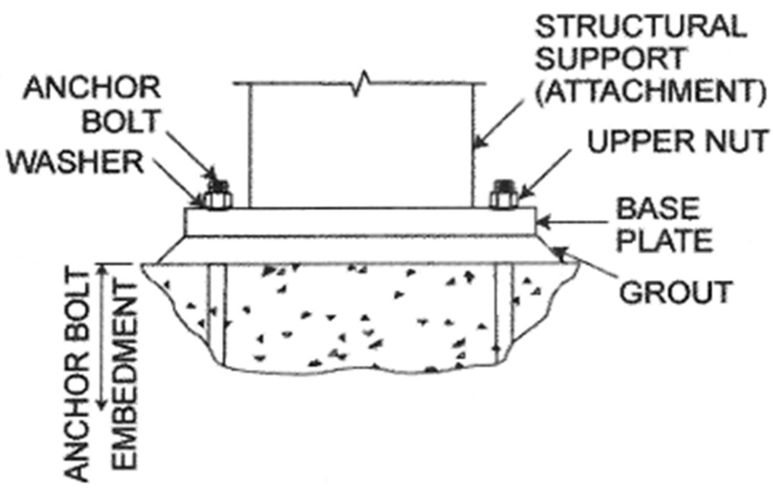



Figure 22: Typical single-nut AB connection (not permitted by MDOT).

Figure 23 shows a double-nut AB connection. In these connections, pretension exists between the upper and lower (leveling) nuts. MDOT does not allow grout to be placed below the base plate of double-nut connections. AASHTO requires a minimum of six anchor bolts for highway structures, except for a minimum of eight anchor bolts required for high mast luminaires.

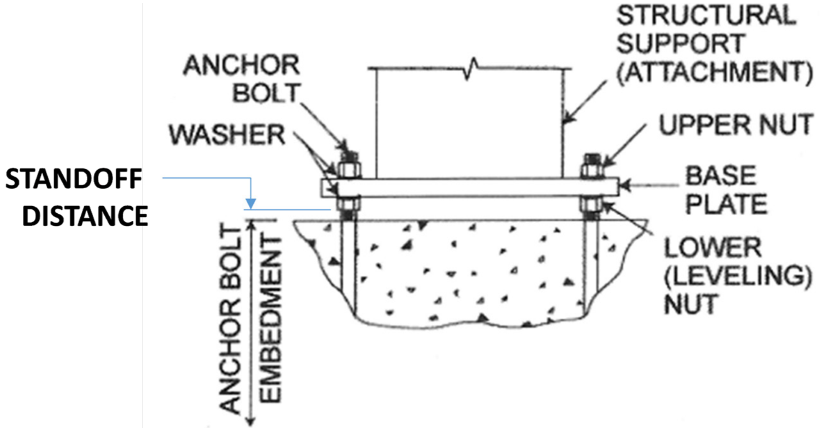



Figure 23: Typical double-nut AB connection.

## AB Materials

Headed and hooked anchor bolts (Figure 24) provide anchorage to concrete. Note that MDOT requires the use of headed anchor bolts as recommended by AASHTO Signs. Unless otherwise stated, anchor bolt material must meet the requirements of ASTM F1554 utilizing grades 36, 55, and 105 ksi as required by the design.

The supplier must provide test data certification for anchor bolts with a reference to heat number of steel. The test results must include yield strength, tensile strength, elongation, reduction of area, and Charpy V-notch toughness.

Materials must meet MDOT Special Provision for Miscellaneous Metal Products Revisions (20SP-908A).

Figure 24: Headed anchor bolts.

## Base Plate and AB Holes

Base plates should be at least as thick as the anchor bolt diameter to evenly distribute load and minimize prying forces. The minimum distance from the center of the anchor bolt hole to the edge of the base plate should be 2 times the nominal anchor bolt diameter. The maximum nominal anchor bolt hole diameter is specified in Table 5.

| Maximum Nominal Anchor Bolt Hole Dimensions | | |
|---|---|---|
| Anchor Bolt Diameter, $d_b$ (inch) | Maximum Nominal Anchor Bolt Hole Dimensions (inch) | |
| | Shear Hole Diameter | Normal Hole Diameter |
| 5/8 | 13/16 | 1 3/16 |
| 3/4 | 15/16 | 1 5/16 |
| 7/8 | 1 1/16 | 1 9/16 |
| 1 | 1 1/4 | 1 13/16 |
| 1 1/4 | 1 9/16 | 2 1/16 |
| 1 1/2 | 1 13/16 | 2 5/16 |
| 1 3/4 | 2 1/16 | 2 3/4 |
| 2 | 5/16 + $d_b$ | 1 1/4 + $d_b$ |

Upper tolerance on the tabulated nominal dimensions shall not exceed 1/16-inch. Slightly conical holes from proper punching are acceptable.

Table 2: Maximum nominal anchor bolt hole diameter.

## General Installation Requirements

To ensure a 50-year design life given an anchor bolt's susceptibility to corrosion and fatigue, the following should be observed:

- A minimum of eight anchor bolts are required to connect tower lighting unit luminaire supports.
- A minimum of six anchor bolts are required for base plates of cantilever structures.
- A minimum of six anchor bolts are needed for foundations of overhead non-cantilevered bridge structures.

In addition, HDG shall conform to AASHTO M232 or ASTM F2329 requirements. Essentially, exposed parts shall be zinc coated and the coating should extend at least 4 inches into the concrete. MDOT specifications require at least 20 inches of the anchor bolt (measured from the end projecting out of the foundation) to be HDG.

## AB Pre-Tensioning

Anchor bolts must be properly tightened so that the connection does not loosen under service loads, which is a fatigue concern. This is achieved using the TON pre-tensioning method. For the double-nut connection, follow MDOT Special Provision for Permanent Traffic Signs and Supports Revisions (20SP-810H).

Torque should not be used to tension the anchor bolts other than to snug-tighten the top nuts prior to TON and to verify that excessive relaxation did not occur after TON during the torque verification test. Torque is used as the best estimation in both of these applications; however, it is not permitted as a method for fully pre-tensioning the anchor bolts due to significant variation in torque-tension relationships affected by many factors. The TON process must be used to properly pre-tension anchor bolts.

If the top nut moves during the torque verification test, the engineer will determine if removal, disassembly, and re-erection of the structure is necessary. The most common occurrences of the nut moving when the test is conducted are due to out-of-specification anchor bolts or nuts, improperly performed snug-tight, out-of-plumb anchor bolts, or warped base plates. If nuts move during the torque verification test, verify these conditions do not exist or contact the MDOT Bureau of Bridges and Structures for assistance. Do not automatically tighten the nuts to the minimum torque and assume full and uniform pre-tensioning of all anchor bolts has been attained. Strict adherence to the entire process is required.

Note that unlike high-strength bolts, anchor bolts for cantilever and truss sign supports, light standards, dynamic message sign structures and CCTV poles, tower lighting units, and traffic signal mast arm poles and mast arms can be loosened and re-tensioned without replacement. This is due to the TON procedure established to pre-tension the anchor bolts to approximately 60 percent of the yield stress of the anchor bolt; whereas, high-strength bolt pre-tensioning is designed to exceed the yield stress of the high-strength bolt.

## Common Deficiencies

The observations shown in the following figures should be rejected by the engineer.

Figure 25: Incorrect washer size.

Figure 26: Damaged anchor bolt threads.

Figure 27: Damaged anchor bolt threads.

Figure 28: Stacked washers and insufficient anchor bolt projection.

Figure 29: Misaligned anchor bolts greater than 1:40 out-of-plumb.

Figure 30: Misaligned anchor bolt that may be acceptable if beveled washers are used.

Figure 31: Anchor bolt hole and washer incompatibility.

Figure 32: Insufficient anchor bolt projection from nut.

Figure 33: Standoff distance greater than 1 inch.

## NOTES:

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