Field Bolting

Torque vs. Tension

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Vice President, Infrastructure
TRC Engineers, Inc.
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Connecting Structural Steel

- The primary connection methods for structural steel are bolting and welding.
- A structure’s strength depends on proper use of these connection methods.
- Bolting and welding may be used for shop connections and field connections.
- Welding is better suited to the controlled environment of a fabrication shop.
- Bolting is more “field friendly”...although not necessarily a better connection.
- Specifically talking about high-strength bolting...not bearing type fasteners.
Parts of the Bolt 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 and bolts: e.g. the thickness of the steel plates
- 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
What is tension?
and
What is torque?
What is tension?

Tension is effectively the stretching of the metal in a fastener that occurs as the bolt, nut, and washer assembly are installed and tightened.

As the metal plates are clamped by the fastener assembly and torque is applied to the turned element (usually the nut), the applied stress results in stretch and elongation of the bolt (strain).

Stress is virtually always applied to the assembly by torque...and that torque creates the scenario where the bolt wants to stretch and tension is the result.

So...that means that torque and tension are related!!!
Then...what is torque?

Torque \((T)\) is the product of force applied to the fastener assembly times the length of the lever arm.

As the iron worker turns the nut with the wrench the force is applied. The length of the lever arm is the length of the wrench...or the distance away from the nut to the iron workers hands.

If we put a “cheater” or pipe on the wrench and increase the lever arm, the result is greater torque.
Then...why am I required to get a tension value when I can just measure torque?

It is more complicated than just measuring the torque.

There are many factors that go into a torque value that is measured...the lubrication that is used, the coating on the bolt and nut, how much rust is present, how much lubricant is used, the temperature of the environment, the pitch of the threads, the thread profile, rate of installation, humidity...
Torque

We do not use or recognize torque directly as an installation measurement for bolts because of the different variables.

We need a means to express the variability across different bolt diameters, pitches, coatings, lubrication, lengths, etc.

So, we need to understand and calculate the “K” value or what is often referred to as the “Nut Factor”
“K” – The Nut Factor

Within the elastic range or before the bolt takes on permanent stretch from tightening, the relationship between torque and tension is linear.

Over 50 variables have an effect on the relationship between torque and tension, some of which we have discussed.

50/40/10 rule – Bearing face, Threads, and Pretension
“K” – The Nut Factor

Typical value ranges for “K”...this can be highly variable

K = 0.10 to 0.17 – bolts and nuts with wax lubricant

K = 0.20 – as-received bolts and nuts with no added or supplemental lubrication

K = 0.28 – bolts and nuts with hot-dipped galvanizing, no lubricant
“K” – The Nut Factor

The friction relationship or K-factor between applied torque and the resulting tension in the fastener assembly needs to be determined. The following formula can be used to get the K-factor if the torque, tension, and fastener size are known

\[ K = \frac{T}{N} \times \frac{12}{D} \]

Where
- \( K \) = Nut factor
- \( T \) = Torque
- \( N \) = Clamp force (Tension)
- \( D \) = Bolt nominal diameter

Example: \( \frac{3}{4}'' \times 2'' \) TC Bolt, 300 ft.-lbs. torque, and 35,000 lbs. clamp load
- \( K = \frac{300}{35,000} \times \frac{12}{0.75} \)
- \( K = 0.0086 \times 16 = 0.1371 \)
- \( K = 0.137 \)

If \( K \) is known, we can solve the formula for Torque. The equation becomes: \( T = K \times D \times N \)
“K” – The Nut Factor

\[ T = K \times D \times N \]

Where:
- \( T \) = Torque in ft.-lbs.
- \( K \) = Friction factor: a dimensionless number
- \( N \) = Clamp force (Tension) in Lbs. of forces (Lbf)
- \( D \) = Bolt nominal diameter in feet

Example: ¾” A325 plain bolt, tightened to 28,000 Lbf, \( K = 0.20 \) (as received/lubricated)

\[
T = (0.20) \times (0.75/12) \times 28,000
\]
\[
T = 350 \text{ ft.-lbs.}
\]

So, in this case we would need to measure a torque value of 350 ft.-lbs. to get 28,000 Lbf. of tension

Figure 3: The rust increases the turning force (torque) needed by causing more friction or resistance between the threads.
Lubrication or Coating “K” factor
Lubrication

<table>
<thead>
<tr>
<th>Bolt Dia. 0.75</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
<th>K - Factor</th>
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<td></td>
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Torque, ft./lbs.
Lubrication
Isn’t that a problem?
So…Torque is valuable, but complicated

- Torque is wildly variable and cumbersome the way our industry uses it
- So…we don’t use torque as a measure unless:
  - We use a calibrated wrench
  - We calibrate daily between tension and torque
- We can use twist-off bolts where the bolt producer controls the “torque” needed to install the assembly
- Performing rotational capacity testing (Skidmore)
- Performing post-installation connection inspection
- Performing arbitration inspection (10%)
- We define the vague terms used in codes and specification “full effort of an iron worker” or “a few impacts of a wrench”
So...Torque is valuable, but complicated

- Torque is a great means of fitting-up and snugging
- Torque can provide a uniform measure of initial loading, unlike angle or “turn-of-the-nut”
- Torque can be precise and accurate when all factors are controlled
- There are no provisions for torque control, so please don’t ask “What is the installation torque?”
- For the same fastener assembly the measured torque is different if we are turning the nut or turning the bolt.
- Therefore it is critical to perform the pre-installation tests the same way that we are going to install the fastener assembly
# The Torque – Tension Relationship

<table>
<thead>
<tr>
<th>Fastener Diameter</th>
<th>Tensile Stress Area</th>
<th>Fastener Coating</th>
<th>Torque (Ft-Lb)</th>
<th>Clamp Load (lb)</th>
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<tr>
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</table>

**SAE J429**

- Grade 2: 3,196
- Grade 5: 4,040
- Grade 8: 6,074

**ASTM A574**

- Socket Head Cap Screw: 8,136
- Plain - Dry: 51

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**Fig. 14** Torque-Tension Relationship

**Fig. 15** Recommended Setting Torque (Ft-Lbs) for Application in Various Materials

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**Table 1**

<table>
<thead>
<tr>
<th>Material</th>
<th>Grade 2</th>
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**Table 2**

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<th>Diameter</th>
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</tr>
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<tr>
<td>UNC 1/2</td>
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<td></td>
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</tr>
</tbody>
</table>

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**NOTES:**

1. Torque based on a 30,000 psi tensile stress under head of screw.
2. Torque based on 40,000 psi tensile stress under head of screw.
3. Torque based on 60,000 psi tensile stress under head of screw.

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**Fig. 16** Torque-Tension Relationship

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**Fig. 17** Torque-Tension Relationship

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**Fig. 18** Torque-Tension Relationship

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**Fig. 19** Torque-Tension Relationship
Let’s get to the “Meat and Potatoes”...again
Transportation and storage of fasteners

460-4.1.3 Fastener Assemblies (Bolts, Nuts and Washers): Transport and store fastener assemblies in sealed, watertight containers. Label the side of each container with the supplier’s name and LOT identification number, and marked to identify the contents and size of the fastener components. Ensure that all surfaces of the nuts are lubricated prior to their placement in watertight containers. Provide containers for components that are capable of protecting them from moisture and other harmful materials. Maintain containers in their sealed conditions until they are opened for use at their assembly locations.

Do not remove more fastener assemblies from the protected area than can be installed and tightened during a work shift. Leave the containers unopened until needed for assembly. At the end of the work shift, return unused fastener assemblies to the protected storage area for future use. Protect opened storage containers from contamination.
Storage of Components

Per the RCSC Specification:

- Fastener components must be protected from dirt and moisture in closed containers on the jobsite.
- Only fasteners anticipated to be installed during the work shift are to be taken from protected storage.
- Protected storage is defined as the continuous protection of fastener components in closed containers in a protected shelter.
- Any unused fasteners must be promptly returned to protected storage.
The lubrication on fasteners is vital to their proper installation.

A water-soluble oil is used on most black bolts.

This oil is easily washed off when exposed to moisture.

Fasteners that accumulate rust or dirt must be cleaned and re-lubricated before they may be installed.

TC or “twist-off” bolts (shown above) shall not be re-lubricated, except by the manufacturer (RCSC 2009, SSTC 2010)
Storage of Components (cont.)

- Production lot *traceability* is required by RCSC
- It is necessary to keep lots separate for proper pre-installation verification testing which is required for pretensioned and slip-critical joints
- Mixing bolts and nuts from different production lots is not permitted (SSTC 2010)
- Tension Control (TC) Bolts are not permitted for FDOT projects
Storage of Components (cont.)

- Galvanized bolts and nuts (above) are provided by the supplier in a set and special storage requirements
- Each bolt/nut set is pretested by the supplier and shipped together and must be kept together as an assembly
- Poor thread fit may result if the bolt and nut are mismatched
- The lubrication on galvanized fasteners is generally more durable than that on black bolts, but protected storage is still recommended
- A490, F1852 and F2280 bolts are not allowed to be hot-dipped galvanized (ASTM F1136 Grade 3 coating is permitted) (SSTC 2010)
Testing

460-5.2 Testing:

460-5.2.1 Rotational Capacity (RC) Tests: At the location of and prior to installation of permanent high-strength fasteners in main or primary load-carrying member connections, perform RC tests in accordance with FM 5-581 (for long bolts) or FM 5-582 (for short bolts) to ensure that the fasteners are capable of developing the specified strength and that the fasteners are properly lubricated. As a minimum, test two assemblies per LOT designation.

The bolt, nut and washer shall come from the same LOT and be packed in the same container (or group of containers assigned the same LOT), except in special cases where nuts and washers have only one production LOT number for each size.

Short bolts may also be tested using FM 5-583 with DTIs calibrated with long bolts installed in a Tension Measuring Device.

Washers are required for RC tests even though they may not be required for jobsite installation. Where washers are not required for jobsite installation, LOT identification is not required. The washer coating shall be the same as that for the bolt and nut.

If any of the required tests fails, the entire LOT will be rejected.
Assembly

460-5.4 Assembly of Bolted Connections:

460-5.4.1 General: Verify that the faying surfaces are in accordance with the Contract Documents, are free of dirt or other foreign materials, and that the geometry of the bolt holes and the connection meets the requirements of 460-4.3.5.

Install fastener assembly components of the same LOT and of the size and quality specified in the Contract Documents. Provide final bolts, cylindrical erection pins or other fit-up bolts as indicated in the Erection Plan. When it is impractical to turn the nut, tighten the fastener by turning the bolt while preventing the nut from rotating. During this tightening operation, do not allow the rotation of the part of the fastener assembly not turned by the wrench.
Snug-tight Installation

Snug-tight is a joint in which the bolts have been installed in accordance with RCSC Section 8.1. Snug tight is the condition that exists when all of the plies in a connection have been pulled into firm contact by the bolts in the joint and all of the bolts in the joint have been tightened sufficiently to prevent the removal of the nuts without the use of a wrench. There is no maximum tension specified for a snug-tight bolt since the process of pulling all plies into firm contact may require the bolt to be fully tensioned.
Equipment

- Common tools used by Ironworkers include: spud wrenches, pins, and corrections bars of various sizes (above left)
- Impact wrenches will be needed for certain installations (above center)
- Electricity or compressed air is required depending on the impact wrench being used. A generator as well as an air compressor may be needed (above right)
Installation

460-5.4.6 Installation of Fastener Assemblies: Unless shown otherwise in the Erection Plan, install the bolts of the connection by progressing systematically from the most rigid part of the connection to the free edges. Install bolts in all holes of the connection and bring them to a “snug tight” condition. Following the sequence indicated in the Erection Plan, further tighten all the bolts in the connection.

For ASTM A325 bolts, obtain the required bolt tension as shown in Table 460-6, Minimum Required Fastener Tension in accordance with the turn-of-nut method specified in 460-5.4.8, or when DTIs are used, the DTI tightening method specified in 460-5.4.9.

For connections (such as large main load-carrying members or truss joints) in which previously tightened high strength bolts become loose and require retightening upon the tensioning of others, install into a minimum of ten percent of the holes fully tensioned bolts prior to final tensioning of the permanent bolts. Distribute these first bolts randomly throughout the connection. If directed by the Engineer, remove the initial bolts and install permanent bolts at each location, otherwise retighten in accordance with 460-5.3.
Installation (cont.)

Note that this table will be changing in July 2017 as part of the Specification changes to SS 460.

<table>
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<tr>
<th>Bolt Size, inch</th>
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<td>7/8</td>
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<td>1 3/8</td>
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<tr>
<td>1 1/2</td>
<td>103</td>
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</table>
Installation (cont.)

460-5.4.7 Bolt Tension: Provide a Skidmore-Wilhelm Calibrator, or other equivalent bolt tension measuring device, wherever final connections are being made. Confirm the accuracy of the tension measuring device by having it calibrated by an approved testing agency once a year.

Bolt Tension Calibrator (Skidmore)

- What does a Skidmore do?
  - Simulates bolted joint
  - Measures Force in Lbs
- How does a Skidmore work?
  - Hydraulic Load cell
- Why is it used?
  - Test Bolts
  - Verify bolt tensioning
Turn of Nut Installation

- Installation beyond snug-tight is called pretensioning.
- Turn-of-nut pretensioning involves several steps:
  1. The bolt is snug-tightened.
  2. Match marks are placed on each nut, bolt, and steel surface in a straight line.
  3. The part not turned by the wrench is prevented from turning.
  4. The bolt is tightened with a prescribed rotation past the snug-tight condition.
- The specified rotation varies by diameter and length (between 1/3 and 1 turn).

(RCSC 2009)
**Turn of Nut Installation (cont.)**

**460-5.4.8 Turn-of-Nut Tightening:** For each work shift, perform tests utilizing a representative sample of five fastener assemblies, from each LOT to be installed that shift. Perform the tests using the tension measuring device, following the same procedure to be used for actual installation of the fastener assemblies, to a snug-tight tension and corresponding torque, which, when the additional turns required in Table 460-7, Nut Rotation from the Snug-Tight Condition are added, will result in at least 1.05 times the minimum required fastener installation tension as shown in Table 460-6. Place a washer under the part turned in the tightening of the bolt. Consider the job inspection snug-tight torque as the average of three test values determined after rejecting the high and low-test values.

For fastener assemblies too short to fit in the tension measuring device, modify the determination of the job inspection snug-tight torque in accordance with FM 5-582.

**460-5.4.8.1 Snug-Tight Condition:** In the turn-of-nut method, first bring all the fastener assemblies of the connection to a “snug-tight” condition to ensure that all parts of the connection are in firm contact with each other. For the purposes of this specification, “firm contact” shall mean the condition that exists on a faying surface when the plies are solidly seated against each other, but not necessarily in continuous contact. Regard snug-tight as the tightness required to produce the bolt tension, which following the final applied rotation, produces at least 1.05 times the minimum required bolt tension in accordance with Table 460-6, Minimum Required Fastener Tension. In the presence of the Engineer, and on a daily basis, determine the job inspection snug-tight torque as specified herein.

**460-5.4.8.2 Final Tightening:** After verification of the snug-tight condition in accordance with 460-5.4.11 by the Engineer, tighten all fastener assemblies in the joint by applying the applicable amount of nut rotation specified in Table 460-7, Nut Rotation from the Snug-Tight Condition. Once snug-tight, bring all fasteners to the required tension within the same work shift.
Nut rotation from the snug-tight condition will result in a minimum of at least 1.05 times the tension shown in Table 460-6 (Slide 31)
Inspections

- In addition to the erector’s quality control program, tests and inspection are specified/required by the Department and/or Engineer of Record
- Snug-tightened joints require visual inspection for firm contact and proper use of washers
- Pretensioned joints require pre-installation verification and routine observation of proper application
- Slip-critical joints require inspection of the faying surfaces in addition to the above listed inspections
Inspections

Inspect the turn-of-nut match marks to ensure the bolts have been pretensioned

If F1852 or F2280 bolts are used, make sure the ends have been snapped off all bolts (above)

In some cases, due to insufficient clearance for the installation wrench, F1852 and F2280 bolts will be tightened by alternative methods so the ends will not be snapped off
Whoa...is there more?

We have just scratched the surface...but I’m out of time
So...what does this mean for you?

- **Contractors** read and understand the Specification, Special Provisions, and Technical Special Provisions. If you have questions about fasteners, storage, installation, etc. then talk to your fastener supplier. They will help you.

- **Fabricators and erectors** have to follow the Specification, Special Provisions, and Technical Special Provisions too. Depending on the type of fasteners that are being installed, you may need a Skidmore or special installation devices. Don’t forget about calibrations and especially don’t forget about appropriate training for your personnel.

- **CEI’s** need to make sure that bolting is a topic that is discussed at the Preconstruction Conference and weekly progress meetings. Make sure that your personnel are also trained and that appropriate testing and inspections are being performed.
There is so much to...
QUESTIONs

- John Westphal, P.E., FDOT State Construction Structures Engineer
  850.414.4141, John.Westphal@dot.state.fl.us
- Steven Duke, FDOT Field Operations Specialist IV – Steel & Timber
  352.955.6682, Steve.Duke@dot.state.fl.us
- George Tedder, P.E., TRC Engineers, Inc. Vice President Infrastructure
  352.378.0332 (o), 352.494.9931 (c), GTedder@TRCSolutions.com
Thank you!