# Better Bolt Tightening Method For Grade 8 Bolts

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If a survey was taken to determine what is the least understood issue regarding the installation of threaded fasteners, what would it be? A few guesses might include susceptibility to vibration loosening, cross-threading or corrosion resistance. Or, perhaps risk of failure from hydrogen embrittlement or stress corrosion? Although it is none of these, it is something that most of us have depended upon at one time or another, only later to be let down. What could it possibly be?

Would you believe that it is "torque." More precisely, the use of torque control as a means of achieving a specified or targeted tension. Regular readers of this magazine know that articles on torque are a perennial favorite. There is even a published compilation of ten such articles.[1] Industry experts like John Bickford, Joe Greenslade and Bengt Blendolf provide insight into the numerous factors that can affect the torque-tension relationship. Clearly, something is odd about torque tensioning or engineers wouldn't be so reluctant to answer the question, "What's the right torque for this Grade 8 bolt?"

## Traditional Torque Tensioning of Grade 8 Bolts

Tightening torques are often calculated using the following formula:

**T = KDP**

where:
T=Tightening **T**orque used (in.-lb. or 2ft.-lb.)
D=Nominal **D**iameter of bolt or screw (in.)
P=Targeted **P**reload or induced clamp load (lb.)
K=Torque Coefficient or Nut Factor

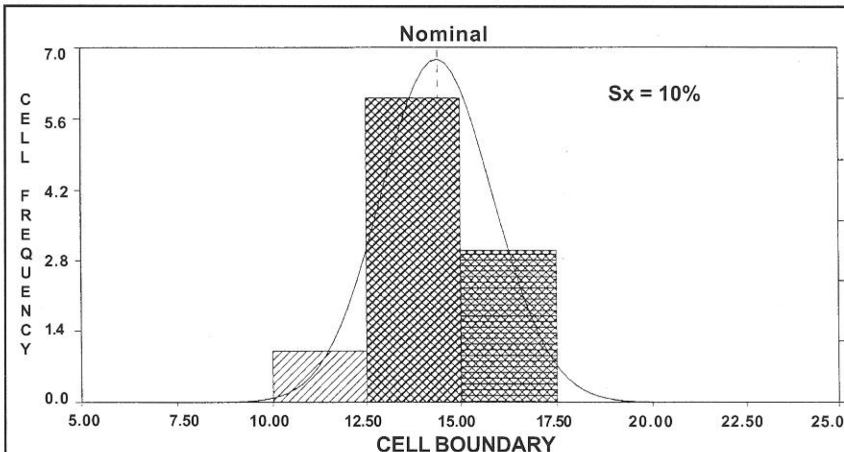
The torque-tensioning formula is most often accompanied by disclaimers like "All material in this article is advisory only, and its use by anyone is entirely voluntary," etc. In fine print somewhere it will say something like "Under controlled conditions the actual preloads achieved for a given torque will vary about ±30%, and changes in lubricity, surface finish, thread geometry or other factors can greatly increase this variaton."

When NASA did research on this torque-tension formula, the resulting statement was, "Bolt preload calculated with aid of the universally used equation is NOT supported by experimental evidence. The equation is based on a 'stretched-out' assumption that friction coefficient for mating parts stays constant during bolt installation. As a result, it generates a straight line of constant slope which departs from the actual torque-load curve by a substantial margin."[2] Those are pretty tough words coming from rocket scientists.

How useful is torque-tensioning in the real world and are there other options? Let's put the formula to work and see. If we took a whole carton of 1/2" Grade 8 bolts with a target tension[3] of 14,400 lb., we would be directed to use 92 ft. lb.[4] torque for targeted tension. Using a calibrated tension measuring device, we could record how much tension was actually achieved in each bolt and make a histogram of the range of tensions actually achieved using 92 ft. lb. Under controlled conditions, the results would look like **Figure 1.**

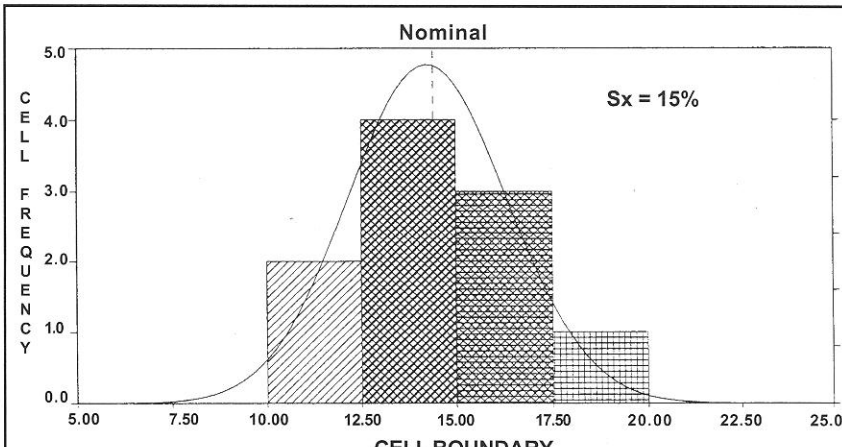
One way to describe the frequency distribution created in **Figure 1** is to say that the range of tensions varies ±30% from the target of 14,400 lb. An easier way to express the diversity of tensions seen in **Figure 1** is to say that the standard deviation "s" of the achieved tensions is 10%. Using "s" is a convenient way to compare results from different tests. The lower the "s," the better. In a perfect world, all of the bolts would achieve exactly 14,400 lb. and "s" would be 0%. As **Figure 1** indicates, a 10% standard deviation results in tensions that range from as little as 10,080 lb. to as much as 18,720 lb., again all from the same torque.

In the real world, where dirt, thread nicks, grease or corrosion are possible, something more like the results in **Figure 2**




Fitted curve is a normal. K-S test: 0.997. Lack of fit is not significant.

**Fig. 1 — Grade 8 Target tension with 10% standard deviation.**




Fitted curve is a normal. K-S test: 0.983. Lack of fit is not significant.

**Fig. 2 — Grade 8 Target tension with 15% standard deviation.**

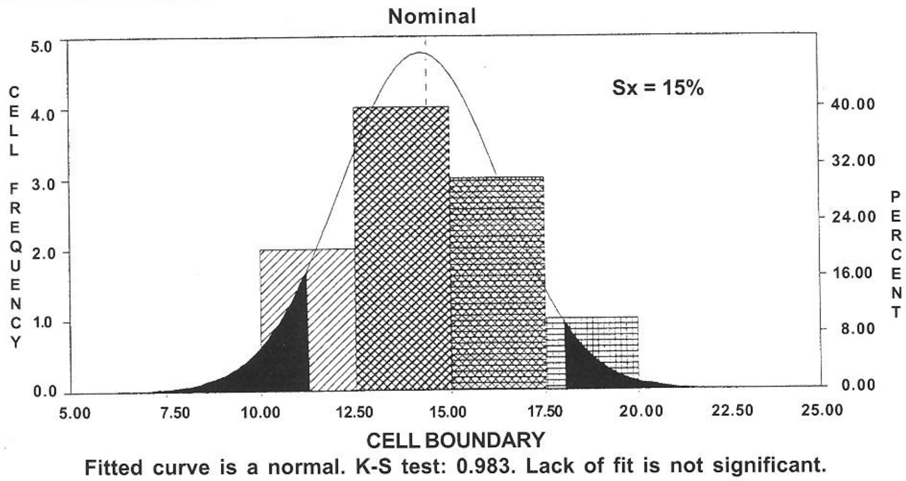



**Fig. 3 — Masked version of *Figure 2* to show failure risk regions.**

take place when 92 ft. lb. torque is applied to each Grade 8 bolt.

Due to the real world factors we've introduced, the tensions in **Figure 2** vary more than those in the previous 10% standard deviation example. The standard deviation shown in **Figure 2** is 15%. This means that some of our 1/2" Grade 8 bolts will have tensions that are sometimes as low as 8640 lb., and at other times, as much as 20,160 lb. and again installed with exactly the same torque. **Figure 2** shows us that some of the bolts are twice as tight as others. Also, there is no way to know which are tensioned to 8640 lb. and which are tensioned to over 20,160 lb. Don't forget that if we checked each one with a torque wrench, they would all indicate the same 92 ft. lb. torque. A mechanic with a $750 calibrated torque wrench could rightfully say "I torqued 'em all up good."

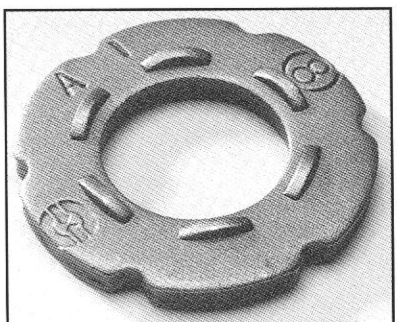


**Fig. 4a — DTI.**

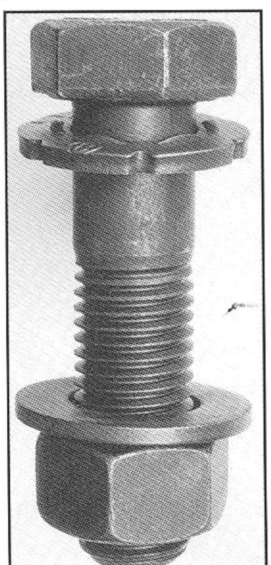


**Fig. 4b – DTI assembly.**

Wide ranging tensions like those resulting from the torque method can lead to two common types of failure. The first is overtightening failure which may occur while the bolts are being installed (for purposes of illustration, we simplify our example by ignoring the fact that it is a combination of torque and tensile stresses that lead to bolt fracture during installation). Overtightening or bolt fracture typically occur when far more tension is induced than was targeted. The bolt's strength is exceeded during installation. This often and incorrectly leads to the assumption that the bolt supplier is somehow responsible.

A second type of failure occurs when bolts loosen,[5] fall out or ultimately break in a fatigue failure. These failures are more likely to occur when the tension of the installed fasteners is below the target. Fatigue failures due to undertightening may take quite a while to occur, depending on where the bolts are installed. The passage of time before failure allows many of us to forget that the cause of the failure is related to the installation method—torque—and that the bolt was insufficiently tightened from the start. Fatigue failures can often be recognized by the classic "beach marks"[6] on them.

With what we know about the risks of failure discussed above, we could revise **Figure 2** to indicate which of our Grade 8 bolts are at greater risk of failure from overtightening (the extreme right side) and those which are at greater risk of fatigue failure (the extreme left side). See **Figure 3.**

Using our simplified example, we could describe the 1/2" Grade 8 bolts which happen to achieve clamp loads very near our target load of 14,400 lb. as least likely to fail. Wouldn't it be nice if there was an inexpensive way to install all of these Grade 8 bolts so that each and every one of them were very near the target tension?

## Solution: Direct Tension Indicators

It just so happens that there now is such a method for Grade 8 bolts.[7] It involves the use of washer-shaped devices known as Direct Tension Indicators or DTIs. Although new to the Grade 8 market, DTIs are not new to users in the construction market. Fabricators and erectors of structural steel projects like bridges, tall buildings and power plants have been using DTIs since the 1960s. Structural type DTIs are manufactured to ASTM F959 and are for use with heavy hex structural bolts like those made to ASTM A325 or ASTM A490. A Grade 8 type DTI is pictured in **Figure 4a**, and a Grade 8 bolt assembly with a DTI is pictured in **Figure 4b.**

When DTIs are installed on bolts, there are noticeable gaps in the spaces between the protrusions (see **Figure 5a**). As the bolt is tightened, the protrusions (or bumps) start to flatten. When the protrusions are sufficiently flattened, the required bolt tension has been accurately achieved (see **Figure 5b**).

DTIs do not share the limitations of the torque-tensioning method. For example, the DTI is not affected by presence of oil or lubricant. It measures tension regardless of surface condi-

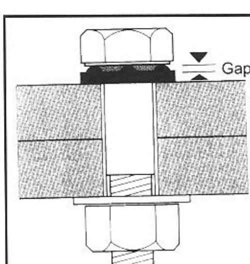



**Fig. 5a — DTI before tensioning.**

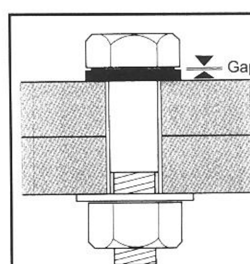
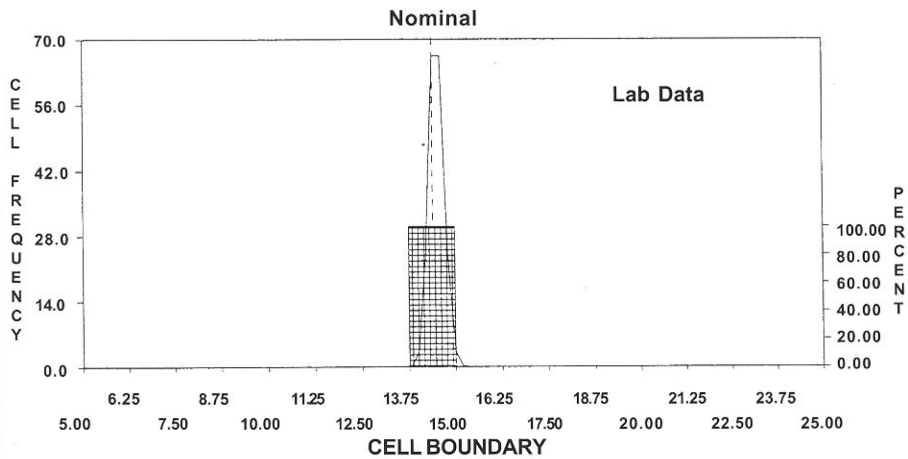



**Fig. 5b — DTI after tensioning.**



Fitted curve is a normal. K-S test: 0.725. Lack of fit is not significant.

**Fig. 6 — DTI compression load analysis 1.5% standard deviation.**

tion. If the bumps don't go down, tension has not been achieved. In this way, DTIs give visual proof that Grade 8 bolts have been properly tensioned. And conversely, inspection with a torque wrench does not ensure tension.

Most experts would agree that most bolting failures arise when there is not enough tension. This is where DTIs really shine. An unflattened DTI acts as a signal to the user that tightening has been insufficient for whatever reason, and that the bolt has not yet been properly tensioned. To bring a bolt up to tension like the others, the installer must further tighten or "tune up" the joint until the DTI is flattened.[8] Some customers continue to use torque control equipment to install Grade 8 bolts, but they also use the DTI to visually indicate which bolts were not tightened sufficiently by the specified torque. DTIs can't fix the torque method, they can only point out where it fell short—in effect which bolts are the loose ones.

Users who use a combination of torque control for installation and DTIs for inspection, initially obtain results that look like **Figure 2** after torque-tensioning. After the DTIs are inspected and the undertightened bolts further tightened until all of the DTIs are flattened, then the histogram will look like the right-hand side only of **Figure 2.**

## DTI Uses

The DTI method is currently being tested by original equipment manufacturers (OEMs) of large trucks, off-highway vehicles, construction, mining and other heavy industrial equipment. They are being used by manufacturers of tunnel boring equipment and post-tensioned masonry fencing. Most often, the DTI is introduced as the problem-solver for a troublesome joint only to become the long-term solution because it provides visual proof that the joint is actually properly tensioned.

Likewise, the DTI is a maintenance-friendly device because it only flattens when tension has been achieved. There are many applications where a torque wrench isn't practical to use, whereas a simple box wrench or socket wrench can be used for accurate tensioning with the DTI method. Use of DTIs alleviates OEM concerns about maintenance or field tightening with the DTI fasteners. Typically, OEMs employ much more sophisticated tensioning systems[9] in production than can be cost justified for use in maintenance. It is unrealistic to ever expect field conditions to be controlled anything like the conditions on the factory floor. OEMs realize that use of torque control in field or maintenance bolting just isn't controllable. All too often, use of torque leads to disputes when the maintenance group is blamed for bolting failures when they in fact used precisely the torque they were directed to. Of course, after a failure, it is nearly impossible to prove that you did use the right torque. However, a flattened DTI is verifiable proof that you did your job and tension was achieved.

## DTI Accuracy

A question that comes to mind is "How accurate are DTIs?" **Figure 6** shows a histogram of 1/2" Grade 8 DTIs tested for compressive force on a calibrated compression loading system. The standard deviation is about 1.5%.

It is not by mistake that variation in DTI performance is so minimal. DTI production processes use SPC on production lots limited to a maximum of 25,000 pieces. Such controls provide 100% assurance that required preloads will be achieved in properly installed fasteners. Also, each DTI is marked with a unique lot number to provide permanent traceability.

Recently, research found that when DTIs were inspected visually on a mixture of "as received" dry, rusting and molybdenum disulfide lubricated 1/2" Grade 8 bolts, the standard deviation was still only 5%. It may be too early to sell your torque wrenches, but with results like this it is only a question of time before DTIs are as popular in the Grade 8 market as they are in the structural steel market.

**References:**

1 ***Torque Tensioning***, *a Ten Part Compilation, available from* ***Fastener Technology International (FTI)***, *Stow, OH.*

2 *NASA Tech Briefs, MSC-21786,* ***Torque, Tension, and Friction in Bolts***, *Johnson Space Center, Houston, TX.*

3 *Taken from* ***FTI Torque Tensioning Guide***, *Part II, Table 3. Target tension is based upon 75% of proof load, as is typical of torque guides.*

4 ***IBID.***

5 *Fasteners which are undertensioned and then subject to vibration can loosen when there is insufficient friction between threads and under the head to resist (un)turning.*

6 *A good illustration of fatigue failure can be seen on page 21 of* ***Guide to Design Criteria for Bolted and Riveted Joints***; *Kulak, Fisher and Struik;* ***John Wiley and Sons, Inc.***

7 *Also available for SAE Grade 5 bolts, proprietary 'Grade 9' bolts and metric Class 8.8 or 10.9 bolts.*

8 *Most inspectors use a visual judgement that the DTI is flattened. Use of a 0.010" (0.254 mm) no-go feeler gage on Grade 8 bolted joints can be sued for absolute certainty.*

9 *Two noteworthy production tensioning systems are the yield control system developed by* ***SPS Technologies*** *and the* ***Huck Fastener*** *system.*

FTI