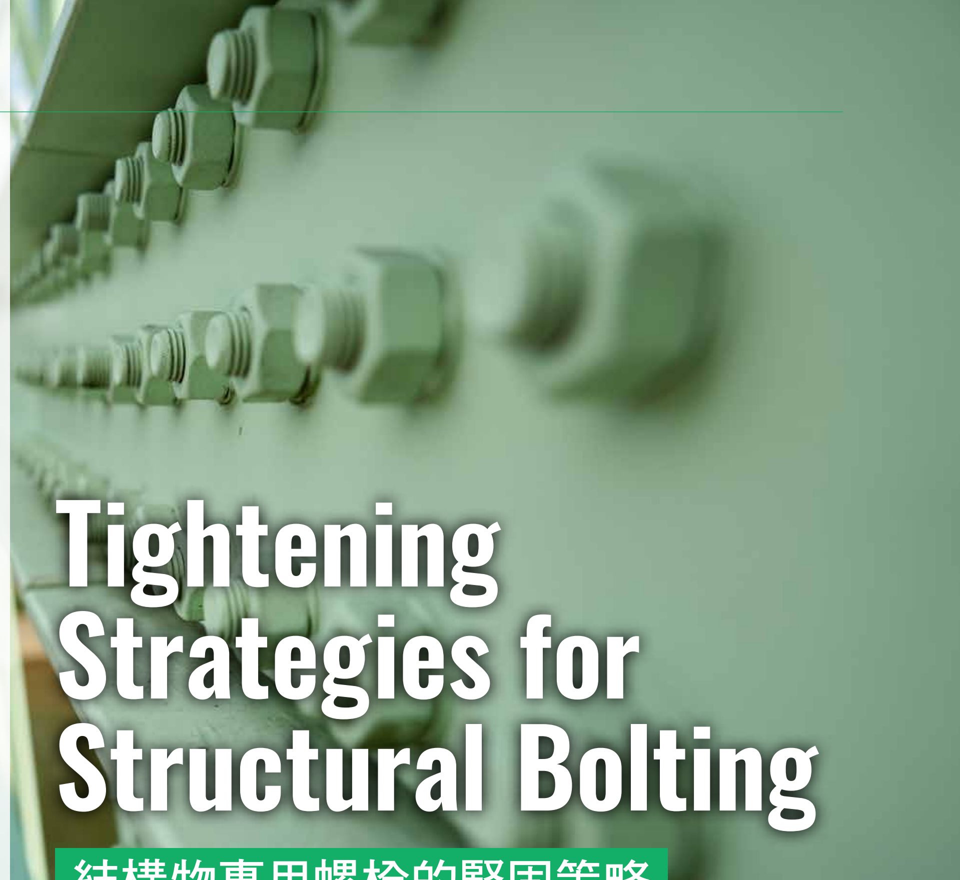


Tightening Strategies for Structural Bolting

結構物專用螺栓的緊固策略

Structures do not have to be only buildings and bridges; they are anything larger than a PC board that is assembled outside of a mass assembly line. This would include cranes, lift trucks, wind turbines, storage tanks, amusement rides, etc. Each structure has special assembly needs to assure safety and performance of the finished product.

The only accurate method of producing a predictable amount of clamp load is by measuring the actual stretch of the fastener. This may be achieved by several different means and products that produce a low amount of error. Those methods include load cells, load washers, load indicating cap screws, ultrasonic transducers and even the turn-of-the-nut method.

Load cells are used on site to 'qualify' the projected performance of job-site bolts and nuts. This, of course, is used in conjunction with a digital or click-type torque wrench. This method, like others, does not guarantee installation performance due to some external variables. However, the per-cent of errors are low.

Load indicating washers, or Direct Tension Indicators (DTI) are quite simple to use, are a bit expensive but very useful on critical assemblies. Their accuracy is only as consistent as the operator.

Ultrasonic transducers are also an extremely accurate means of measuring the stretch of the fastener. This method is very expensive and is not a permanent fixture as is a load washer. The transducer head can be moved from one fastener to the next, but the only drawback is that the head and point end of the cap screw must be smooth and flat to accept the transducer head. This would mean grinding off the grade markings and manufacturer's identification marks: removing all traceability of the fastener.

Torque multipliers are very useful and accurate for large diameter bolts requiring high torque values. As torque values increase, so does the lever requirement of the wrench. Torque is measured in the amount of force (pounds for example) times the distance of the lever (foot for example). Therefore, we have a pound-foot. Some torque wrenches are up to three feet long to provide the leverage needed to tighten the nut or bolt. Beyond this, a torque multiplier is used.

Torque multipliers are extremely useful when mounting wind generator platforms or rotating crane structures. Some units are manually operated while others are either electric or pneumatically actuated.

Another great tool used in structures is by not using torque at all, but by turning the nut a certain degree of rotation. This method works with coarse threaded fasteners only and on solid metal-to-metal joints whose joint compression has been removed by pre-tightening with a short handled wrench. This will not directly translate to metric bolts, as the same thread pitch is used on other metric bolt diameters. Actual experimentation is needed for a particular size, thread pitch and joint thickness.

How this works so well is because the threads of any standard bolt is a perfect helix. Therefore, when the mating helix threads of the nut are rotated along the threads of the bolt, the nut travels in a consistent linear direction. As the nut rotates against a solid joint surface, the bolt is being tensioned proportionately with respect to the rotation of the nut.

This reasoning is derived from Hooke's Law. Work is now being done on a 'linear' scale: if the nut is moved the same distance each time, or all of the nuts in the connection move the same distance, the stretch of the fastener is reproduced the same amount on each fastener. This gauged amount of stretch will produce a clamping force that is greater, more consistent and is more predictable with any fastener grade, surface condition or length of fastener using common assembly methods.

So, what happens to torque? Torque is still present; we just do not measure it as such. Torque is always present in the form of friction as it is the energy we must overcome in order to move the nut a certain distance. Torque will not be measured here because we are more concerned with the distance the nut moves, not how we get there.

For example: consider using four 1/2-13 Grade 8 fasteners; three are plated, the fourth is not. Of the plated bolts, one is dry to the touch, one is lubricated and the last one has a thread nick. If all four bolts are installed together in a connection and torqued to the same 105 lb-ft, none of the clamp loads will be remotely close to each other due to all of the friction variables present.

Fig 1

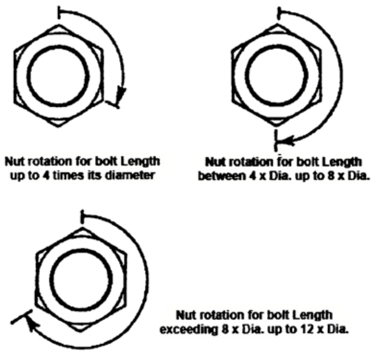


Fig 2

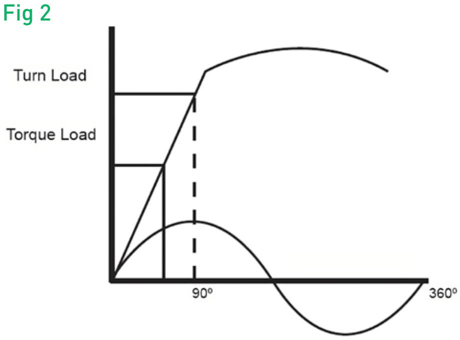


Fig 3

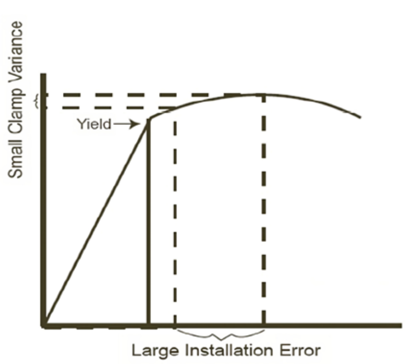
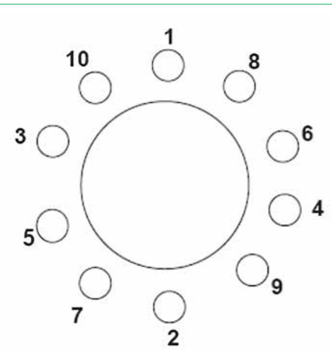


Fig 4



The lubricated bolt will be the tightest because there was a tremendous reduction in friction. This bolt will probably produce over 18,000 pounds of clamp load and is just into yield. The dry plated bolt will be the closest to producing 12,800 pounds of clamp load, while the one with the thread nick will be around 10,000 lbs. The non-plated bolt will only produce approximately 8,000 pounds due to its rough surface finish. This is conservatively a 10,000 pound scatter.

If after making sure the joint was soundly compressed and the bolt head was restrained from turning and all four UNC bolts were tightened by rotating the nut using the same angular degrees of rotation, then all of the fasteners would be stretched an equivalent amount. This would produce clamping forces that would only be a few hundred pounds apart, not thousands.

The difference to the operator is how much energy he must expend to cause the nut to rotate the prescribed amount. The non-plated fastener and the one with the nicked thread will require more 'torque' energy to turn the nut the same distance X as the others. Of course, the lubricated fastener will require the least amount of effort.

The key element here is that all of the nuts have been rotated to X, not X-1 or X+2. This is the principle of the Turn-Of-the-Nut (TON) method.

Structural joints use the ASTM A325 and A490 fasteners. Since Hooke's Law states that stress is directly proportional to strain, and using the modulus of elasticity for steel, we find that if a bolt is stretched 0.001", per loaded inch, it will produce a load of approximately 30,000 psi.

Therefore, **according to the AISC Manual, the TON method uses the amount of rotation applied to the nut as a function of the diameter of the bolt based on the overall bolt length. This method, as shown in Fig. 1, provides the following three general rotations with respect to the diameter of the fastener and the joint thickness.**

First, if the fastener length is no larger than four times the diameter of the fastener, the nut is turned 1/3 of a turn or 120□ after the nut has been snug tightened. Longer fastener lengths and their rotations are noted in **Fig 1**.

By looking at **Figure 2**, we can see the relationship of the helix thread to the stretch of a bolt using standard torque methods and the turn method. A torque value may stretch the bolt to less than 90º whereas using the turn method to rotate the nut 90º will have produced a much higher clamp load.

Tightening the bolt to the TON method of 120º, as in Fig. 1 for example, will stretch the bolt into yield as shown in **Fig. 3**. By doing so, the bolts will produce a maximum amount of clamp load with a minimal amount of clamp load scatter while input error does not matter.

Since the fasteners are into yield, they can never be reused again. This is also the principle of Torque-Turn-to-Yield (TTY) used by engine builders and others to maximize the load of the joint and minimize load scatter.

First, the joint must be set rigid so all of the initial compression is removed. After this, the fastener is assured to be placed into immediate stretch while turning the nut. The TTY method uses a pre-torque to set the joint, the TON method uses a short handled hand wrench to 'snug' the nut until it is felt the joint has come together and any joint compression is removed.

Again, these assembly methods place all the fasteners into yield. This same method used for ASTM structural fastener grades (ASTM A325 and A490) can be used for their strength equivalents of the SAE J429 Grades 5 and 8. The A325 or Grade 5 has a longer elastic curve than the 150 ksi A490, so both grades can use the same turn.

The only caveat I have when using any of these methods in a multiple bolt pattern is to tighten the bolts incrementally and in a cross pattern. (Fig 4) ◘

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