

# MATES

## MICHIGAN DEPARTMENT OF TRANSPORTATION

Issue No. 36

October 1989

### THE TURN OF THE NUT

The typical motorist probably never notices, some highway engineers might notice, and all bridge engineers know that rivet heads obvious in older bridge connections are no longer seen in newer bridges. The rounded heads of large numbers of rivets served to reassure us that the bridge was sturdily built and safe. A close inspection of newer bridges would show that the rounded heads of rivets are now hexagonal in shape, as the old reliable rivets have been replaced in bridge construction by high-strength bolts.

The possibility of high-strength bolting to replace rivets in steel structures was proposed in 1934 by a research team in Great Britain. Their work concluded that high-strength bolts could be tightened enough to prevent slippage in steel plate connections used to assemble buildings and bridges. Further research indicated that fatigue strengths for bolts were comparable to those of driven rivets when the bolts were tightened to yield a high tension in the bolt. In spite of these results, it would be another decade before a move was made to seriously develop high-strength bolting techniques.

The Research Council on Riveted and Bolted Structural Joints, formed in 1947, issued its first specification in 1951. American railway engineers were among the first designers to realize that bolting could be very beneficial in bridge maintenance. The use of high-strength bolts as the primary means of joining steel structures in fabrication shops and in the field, increased significantly after more studies reported findings such as increased design economics, materials savings, and significantly better precision in assembly.

Riveted bridges in Michigan were still common in the construction programs of the 1950's, and in 1960 a design standard plan showed bolted connections for the first time. As the use of ASTM A141 rivets began to decline, two basic types of high-strength bolts were being developed, ASTM A325 and A490. Each is a heavy hex-head structural fastener paired with a heavy hex nut. Most common to Michigan bridges and sign structures is the A325 Type I bolt which is produced from medium carbon steel. All such high-strength bolts are heat treated by quenching and tempering.

In 1983, a significant change in our bolting standards for bridges came about as a result of initiating the total shop coating program (see MATES No. 25). At that time, our reliable, old style black bolts posed a significant problem. How could they be cleaned and coated in the field without destroying the adjacent painted areas? As a matter of economics and practicality, we were endeavoring to eliminate or limit the amount of field blast cleaning and painting. Black bolts are unpainted, with mill scale giving them their black surface appearance. They must be blast-cleaned before painting if the coating is to last. After erecting a shop-coated bridge, there would be hundreds of black bolts requiring blast cleaning in preparation for priming and topcoating. Each area would in effect, become a field repair, creating the exact situation we were trying to avoid. This obstacle to our shop-coating program was overcome by switching to hot-dip galvanized bolts.

#### Installation

There are two methods available for tightening black bolts, the 'turn-of-nut' and the 'calibrated wrench' methods.

The turn-of-nut method was seldom used on Michigan bridges. The calibrated wrench was the primary means of bolt installation, and a torque wrench was used to inspect and assure bolt tightness (a certain torque value related to an approximate bolt tension). For many years, our inspectors would arm themselves with a torque wrench that, for some bolts, required two men and a boy to operate. Bolts in some locations were impossible to check because the area was too confined, in other instances it was hazardous causing safety to become a real concern. There was no assurance that the minimum specified bolt tension had been achieved in all bolts.

Switching to galvanized bolts meant some installation changes would be necessary. High-strength bolts must be tightened to a tension equal to, or greater than, 70 percent of the specified minimum tensile strength. This bolt tension produces a high clamping force that enables tightly mated surfaces to carry loads entirely by friction. For quality assurance reasons, galvanized bolts must be tightened by the turn-of-nut method. Our own studies showed and verified that galvanized bolts, when torqued to the recommended value, do not achieve proper bolt tension primarily due to galling (a seizing together of the galvanized threads of the bolt and nut) in the galvanized threads. There is not a dependable relationship between torque and bolt tension when galvanized bolts are involved. The turn-of-nut method is a strain control as contrasted to a torque control. It is a reliable method, and is the recommended method for tightening galvanized bolts on our structures.

Galvanized bolts are merely black bolts that have been cleaned and coated by hot-dipping in molten zinc, according to ASTM A153. The mechanical properties, yield and tensile strengths, are not affected significantly by the galvanizing process. On occasion these bolts experienced twist-off failure or thread stripping while being tightened, primarily caused by the zinc galling in the threads. Once the nut has seized on the bolt, it is difficult to reach the desired bolt tension without initiating premature torsional failure of the bolt or stripping the threads. To help eliminate or minimize these problems, galvanized nuts are tapped oversize, and are required to be lubricated or coated with wax to reduce friction on the threads.

After all bolts initially have been placed in a connection, the turn-of-nut tightening process commences. The effectiveness of this method is dependent upon the uniformity of the starting point or the 'snug tight' position. All bolts must be brought to the snug position before final tightening. Snug tight is defined as the tightness attained by the full effort of a person using an ordinary 18-in. spud wrench or, if using an impact wrench, when 'impacting' begins. When snugging bolts in a large pattern, the operation must begin near the center of the pattern and alternately work out toward each edge. Before final tightening, the bolts in the center area must be rechecked for snug tight in case the joined plates were not flat and true to begin with and had to be drawn together. The bolted connection is now ready for final turn-of-nut tightening. For bolts less than four diameters in length, the nut must be turned 1/3 turn, or two hex faces; longer bolts require a 1/2 turn (three hex faces). Our spec allows a tolerance of minus 0° to plus 30°. Tightening must progress systematically from the most rigid part of the joint to its free edges. During this operation there must be no rotation of the bolt head while the wrench turns the nut.

## Inspection

Inspection of high-strength bolts begins at the fabrication shop. Our shop inspector randomly samples six nuts, bolts, and washers from each length and diameter scheduled for use on a project. This must be done for each heat/lot number. The sample is sent to the Testing Laboratory for evaluation.

A bolt tension calibrator is used to evaluate the bolt/nut combination. It measures the actual bolt tension produced by tightening the nut (snug, plus 1/3 or 1/2 turn). After this initial bolt tension is recorded, the nut is rotated another 300° (for 1/3 turn combinations) to 360° (for 1/2 turn combinations) to proof load. Bolt tensioning in this device is the first check of lubrication on the nut. Other evaluations include checking the galvanized coating for proper thickness and adhesion, and random checks of tensile strength and hardness.

Samples that fail to be recommended after laboratory evaluation do so for various reasons, the most common being improper lubrication of the threads in the nut. If the nut has little or no lubricant, the turn-of-nut rotation cannot be achieved and the bolt fails to reach the specified minimum tension. A couple of things can cause a sample to fail in the proof load test. Galling may prohibit rotation causing the nut to lock-up prematurely. This results from poor lubrication. Improper galvanizing or excess zinc in the bolt threads, or the nut not being properly tapped over-size also may cause problems. Bolts in some samples have broken or yielded enough to lose significant tension at or before attaining proof load. Under certain circumstances, the heavy hex nuts are cut in half to allow the threads to be inspected optically and to check for the presence of lubricant. The lubricant, which is usually a wax, must conform to the supplementary specification which requires it to be dry to the touch. Oil lubricants, grease, and the like are not permitted.

The inspector in the field must understand the turn-of-nut method and must carefully observe the installation of the bolts. The inspector should witness the snugging operation to ensure the starting point is consistent and adequate before final tightening commences. After a bolted joint has been snugged, a felt-tip marker should be used to mark the start and stop points for each nut to be rotated by either 1/3 or 1/2 of a turn. The final inspection for determining that the minimum bolt tension has been achieved is simply observing that the start mark on the bolt lines-up with the stop mark on the plate (Fig. 1). This visual check

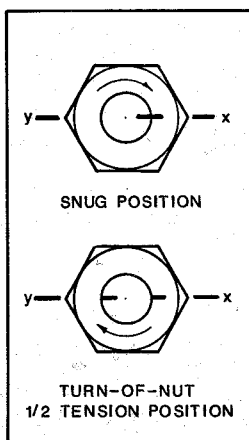


Figure 1. A mark on the wrench socket is aligned with felt marker line x and nut is turned until the socket mark reaches line y. Note felt marker line on nut in snug position extends into the bolt to assure the inspector that the bolt has not turned.

of nut rotation is all that is necessary. Bolt tension and the desired clamping force have been achieved. The torque wrench no longer has validity in this system and should not be used under any circumstances to check turn-of-nut tightened bolts. As was stated earlier, torsion cannot be

used as a dependable measure of strain (tensioning) on galvanized bolts; they are separate and distinct. It should be noted that the turn-of-nut method can be accurately applied to black bolts as well as galvanized ones.

Under no circumstances should a fully tensioned bolt/nut combination be reused if loosened or removed for any reason.

## Painting Field Bolted Connections

Once field bolting has been completed and accepted, the next operation is to prepare the bolted areas for top-coating. The zinc coating on the bolt provides excellent protection against corrosion and acts as a primer for the topcoats. Galvanized bolts are installed on 'primed-only' surfaces. Before they can be topcoated they must be solvent-washed and the coating manufacturer's recommended tie coat applied to the zinc coated surfaces. The tie coat prepares the zinc by etching it to create an adhesive profile for bonding with epoxy intermediate coat. All exposed galvanized surfaces must be tie coated or premature coating failure could occur. The subsequent epoxy and urethane intermediate and topcoats are then applied according to specification requirements.

## Summary

Tightening high-strength bolts may not seem to be an exact science, but by using current test procedures and inspection methods, satisfactory results can be obtained.

Laboratory sampling and testing is the first step in assuring that a quality product reaches the field. It assures proper lubrication of the heavy hex nuts. It is our experience in tightening galvanized ASTM A325 bolts that the turn-of-nut method is best for lubricated galvanized fasteners. The method's 1/3 or 1/2 turn (depending on bolt length) from the snug-tight condition will produce the desired minimum bolt tension. It affords easy inspection for acceptance of the connection and ensures that adequate clamping force is present.

The turn-of-nut method is the most economical and efficient procedure for tightening structural connections where bolt tension is critical. It applies and should be used on steel sign structures (cantilevers and trusses) as well as on bridges. The turn-of-nut method is not applicable in the slip-base portions of breakaway sign supports, as the connections would be too tight and wouldn't fail, as they are designed to do, upon impact.

-Jon Reincke

## PERSONNEL NOTES

Jim Ritchie has been appointed as Section Head for the new Geotechnical and Geoenvironmental Section of M&T. Leo DeFrain has been appointed as Unit Head for the Instrumentation and Data Systems Unit of the Research Laboratory Section. Gail Grove is now the Unit Head for the Materials Research Unit of the Research Laboratory. Glenn Bukoski has been named as Unit Head for the Structural Research Unit of the Research Laboratory. Steven Cook is our new Investigations and Mix Design Engineer in the Bituminous Technical Services Unit of the Testing Laboratory. Fred Carian has been appointed Technician Supervisor in the Investigations Sub-Unit of the Bituminous Technical Services Unit in the Testing Laboratory, and Don Andrews is now the Technician Supervisor in the Mix Design Sub-Unit of the Bituminous Technical Services Unit. Congratulations are in order for these members of our staff, and a sincere welcome for Glenn and Steve as they join our Division as new members.

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