About the Author/WAYNE WALLACE

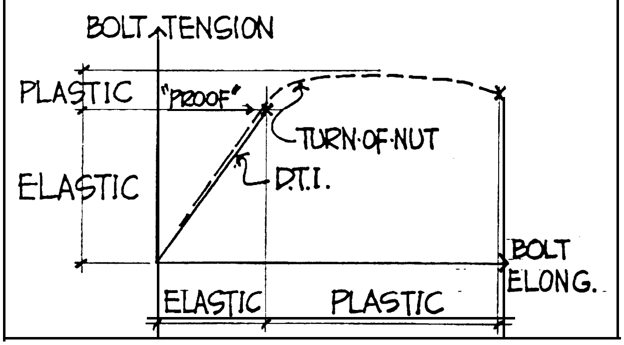
Wayne Wallace is the president of Applied Bolting Technology Products. The company provides bolting consulting sen/ices and manufactures direct tension indicating washers from its base in Ludlow, Vermont. Wallace is a member of the Research Council on Structural Connections, a director of the Bolting Technology Council, and author of numerous papers on the practical aspects of quality assurance in structural bolting.

DTI's Mean Less Bolt Relaxation, Creep

Bolts get longer when they are installed.. .at least they should.

For example, a 4" long ASTM A325 bolt becomes about 4.010" long when tightened with a direct tension indicator (DTI), or it becomes about 4.020" long when tightened by the "turn-of-nut" method. Although the bolt's length change during tightening is not normally measured, it can be, either mechanically, or better, ultrasonically. The change in length of the bolt (see Fig. 1) is at first elastic (the straight line), where the increase in bolt tension is linearly proportional to the increase in bolt elongation. At elongations above the elastic limit, or at loads above the proof load, the bolt becomes inelastic, or plastic (the curved part), and the length changes rapidly with little extra bolt tension.

FIG. 1 **TYPICAL BOLT RESPONSE**



"Part turn" installation methods such as the classic 'turn-of-the-nut" method are known to stretch bolts well past the bolt's elastic limit. DTI's, on the other hand, as we know from ultrasonic field measurements, tend to allow the installer to leave the bolt in or close to the limit of its elastic response. DTI's show how much bolt tension is achieved by the amount of compression of the DTI bumps, and tend to be left by bolt installers just shy of flat. For example, "just shy of flat" for a 7/8" A325 DTI is about 48,000 lb. of bolt tension.

After installation, the stretched bolt wants to return to its original "at rest" length, but cannot, of course, due to the resistance of the connected material. But in the process of trying to return to its "at rest" length, the bolt tension "relaxes," or "creeps" a bit, as its threads seat in and as the nut and bolt head dig into the connected material a little. Coatings on the connected material, such as paint or zinc, are compressible and do exactly that. They compress, and allow the bolt to lose a bit of its length.

Ideally, bolts should retain as much of their initial tension as possible after they have "settled in," so they will be best able to withstand external loads. Too much "creep" is definitely to be avoided if at all possible.

Measurement of bolt length change during initial installation, and then over time as "relaxation" or "creep" takes effect, can help to determine what part of the bolt's initial tension remains after the creep stops. Creep is at first fast, and then slows down quickly.

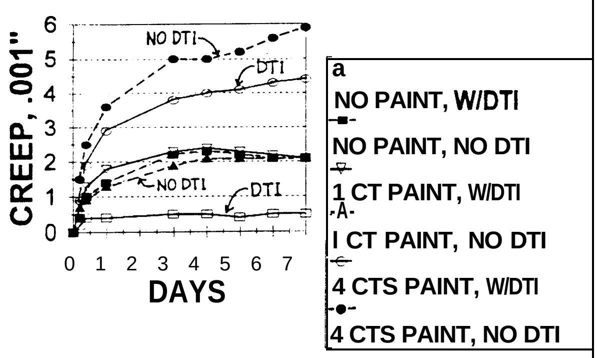
It's a classic error to equate loss in length with loss of tension, because bolts are tensioned according to an "elasto-plastic" response, *but they untension themselves according to their elastic response only.*

The research department of a state bridge engineering department recently made just such a classic error in interpretation of bolt length creep data. They had designed an experiment to discover how bolt tensions creep when installed in connections having various thickness of coatings. This information was needed to help them decide how many coatings to allow on the steelwork in the fabricating shop, and how many coatings to put on in the field after the bolts had been tightened.

Their creep measurements are shown in Fig. 2. Note as the number of coatings increased, the creep length change increased, to very substantial values in the case of multiple coatings.

In their experiment, they installed bolts using two methods of controlling the installation process - DTI's, or direct tension indicators, and conventional turn-of-nut.

FIG. 2 CREEP MEASURED OVER ONE WEEK



To simplify what they found:

- By DTI, the initial length of 4.000" became 4.010".
- By turn-of-nut, the initial length of 4.000" became 4.020".

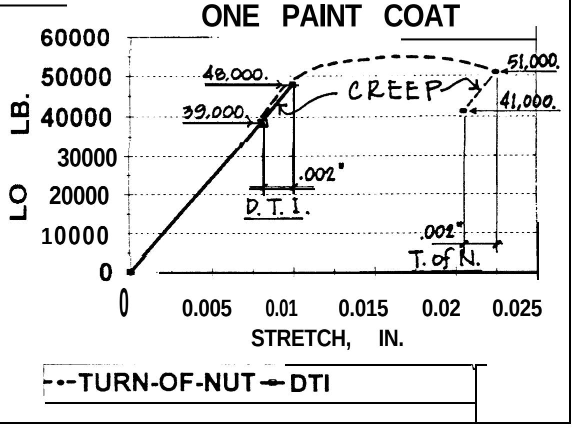
Then, after one week (see Fig. 2) they found that:

- With no paint, the loss of length was .0005" when a DTI was used, and .0020" when turn-of-nut was used (four times as much).
- With one coat of paint, the loss of length was about .002" for all the bolts.
- With four coats of paint, the loss of length was .0044" with a DTI, and .0060" with the turn-of-nut bolt (about 36% more).

Comparing the loss of length with the initial length change before creep, the state research lab concluded from this data, that, for example, with one coat of paint, 20% of the DTI-tightened bolt tension was lost, but only 10% of the turn-of-nut tightened bolt tension was lost. Furthermore, they concluded that, with four coats of paint, 44% of the initial tension was lost for the DTI-tightened bolt, vs. only 30% for the turn-of-nut tightened bolt. These conclusions did not favor the continued use of DTI's by that state on their bridges.

Upon further analysis, they rethought their conclusions, as can be seen by Fig. 3 and Fig. 4, entitled "Bolt Load vs. Stretch" for one and four coats of paint. Fig. 3

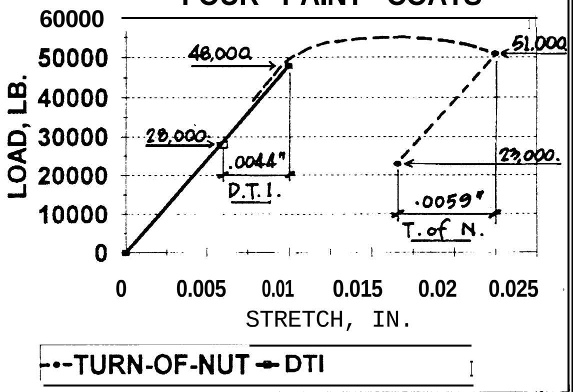
FIG. 3 BOLT LOAD VS STRETCH ONE PAINT COAT



shows that the DTI-tightened bolt remains essentially elastic, to 48,000 lb. tension, and unloads to 39,000 lb. upon losing .002" of length. In comparison, Fig. 3 shows that the turn-of-nut tightened bolt stretches well into the plastic range to an initial tension of 51,000 lb. and then relaxes to 41,000 lb. upon losing .002" of length. Their length-change-only analysis had them believing that the DTI bolt would have lost twice as much tension, but really the bolt tension relaxed to about the same value after the coating compressed.

In the case of the four coats of paint, the length-change-analysis had them believing the DTI-tightened bolt would have lost 50% more tension than the turn-of-nut bolt. But on examining the true relaxation response shown in Fig. 4, they concluded correctly that the DTI-tightened bolt retained a tension of 28,000 lb. vs. the turn-of-nut tightened bolt relaxing to 23,000 lb.!

FIG. 4 BOLT LOAD VS STRETCH FOUR PAINT COATS



In the latter case, both of these final relaxed bolt tensions, after all of the coating-induced creep occurred, were unsatisfactorily low of course. However, the state concluded that they could go ahead and allow DTI's to be used for connections with one shop coat of paint, which lowered the cost of the bridge and made for better corrosion protection in the coastal environment.

Conclusions

DTI's allow tightening of bolts to a more controlled degree of stretch compared to the rather crude turn-of-nut method which typically takes the bolt well into the plastic region. As the state's creep measurements (Fig. 2) show, even when there isn't any compressible coating present, the creep measured in the DTI-tightened bolt was only l/4 of that measured in the turn-of-nut tightened bolt.

When compressible coatings are applied ahead of bolt installation, the use of DTI's never aggravates the bolt tension loss due to creep, and it appears that the presence of DTI's on the bolts lessens the tension loss even when extremely thick coatings are used such as in these tests.